UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

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Performance Assessment of the Environment21 V2B1 Model 4 for Removing Suspended Sediments from Stormwater

By

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Abstract

Environment 21 requested a series of tests to be conducted on their V2B1 Model 4 hydrodynamic separator. A V2B1 Model 4 was brought into St. Anthony Falls Laboratory (SAFL) and set up for testing. Four series of tests were conducted. The first two series of tests were to meet the New Jersey Corporation for Advanced Technology (NJCAT) requirements for assessing the V2B1 Model 4 efficiency in removing suspended sediments and scour potential. The third test series was to determine the performance function of V2B1 Model 4 and the fourth test series was a repeat of the NJCAT requirements with some modifications to the test procedure and design flow, which were all discussed with the New Jersey Corporation for Advanced Technology (NJCAT) representative. The main change in the fourth test series was to preload the sump and to use load cells to determine the removal efficiency of the device while the materials in the sump were subject to resuspension. The first, second, and third test series are described in a separate report.

The report herein is a summary of the test setup, the test procedure and the results of the fourth test series. The results of the fourth test series showed that V2B1 Model 4 is on average capable of removing 65% of the suspended sediments with the particle size distribution and runoff hydrograph recommended by the NJDEP.

Acknowledgements

The work reported herein was funded by Environment 21, LLC. Mr. Jeff Benty and Mr. Paul Rowe from Environment 21 were the project officers. We would like to thank David Saddoris and Adam Howard for their contribution to the data collection.

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1. Introduction

In 2007, Environment 21, LLC requested a third party performance evaluation of the V2B1 hydrodynamic separator in a laboratory setting. The separator manhole tested was made of fiberglass, ordered, built and transported to the St. Anthony Falls Laboratory (SAFL). The scope of the laboratory testing was to determine the maximum hydraulic rate (MHR), to assess the performance of the device according to the NJDEP requirements, to determine effluent concentrations under high flow conditions, and to determine the general performance of the system.

In 2006, the SAFL personnel conducted a series of controlled tests on a V2B1 model in the field. That testing was funded by the Minnesota Local Road Research Board and the Twin Cities Metropolitan Council and was part of a series of field testing on four different hydrodynamic separators. The V2B1 tested in 2006 had a different design than the one tested in 2008 at SAFL. Also, the scope of the field tests was to determine the sediment removal performance function of the device.

The V2B1 hydrodynamic separator was tested as an in-line storm water treatment system for the removal of solids and floatables. The system is comprised of two in-line manholes, M_1 and M_2, connected by a pipe with a 90-degree elbow at its upstream end (Figure 1.1). The second manhole is divided into two compartments by a baffle wall, with the first compartment for removal of floatables. A bypass pipe has also been provided which connects M_1 to the second compartment of M_2. The bypass pipe allows a portion of inflowing water to travel directly to the outflow pipe as discharge exceeds the design flow[1].

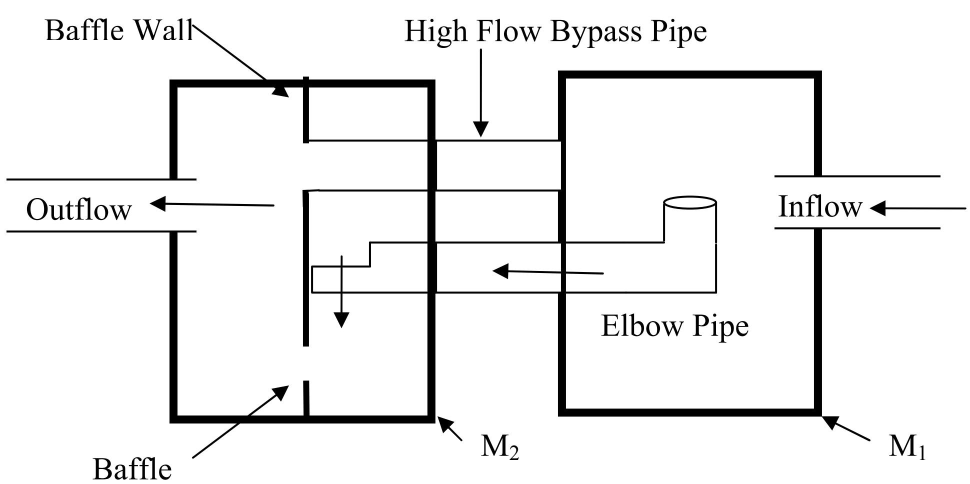

Figure 1.1. Schematic of V2B1 tested at SAFL.

As water enters M_2 through the elbow pipe, it hits the baffle wall. All of the water under the design rate must travel through the two orifices in the baffle wall before it leaves through the

[1] This discharge has been conventionally called the maximum treatment rate (MTR). However, treatment can occur at discharges above this rate, therefore in this report, the term the 'design rate' has been used instead of MTR.

outflow pipe (Figure 1.2). These two orifices are located approximately 12 inches above the floor of the manhole. The baffle wall is intended to trap floatable material in the upstream chamber of M_2 and allow it to be removed during the scheduled cleanout of the device.

The inflow pipe is mounted tangentially in M_1. This creates a swirl flow in M_1 as water enters the manhole. Suspended sediment removal primarily occurs within the M_1 manhole, however, some sediment removal also occurs in M_2.

This report summarizes the tests and analyses done on a V2B1 Model 4 for the New Jersey Corporation for Advanced Technology (NJCAT) verification program. The main body of the report includes the experimental facility used for testing (Section 2), the load cell instrumentation for weighing the system (Section 3), the testing methodology to meet the NJDEP requirements, and the results of fourth test series (Section 4). The first, second, and third test series are described in a separate report.

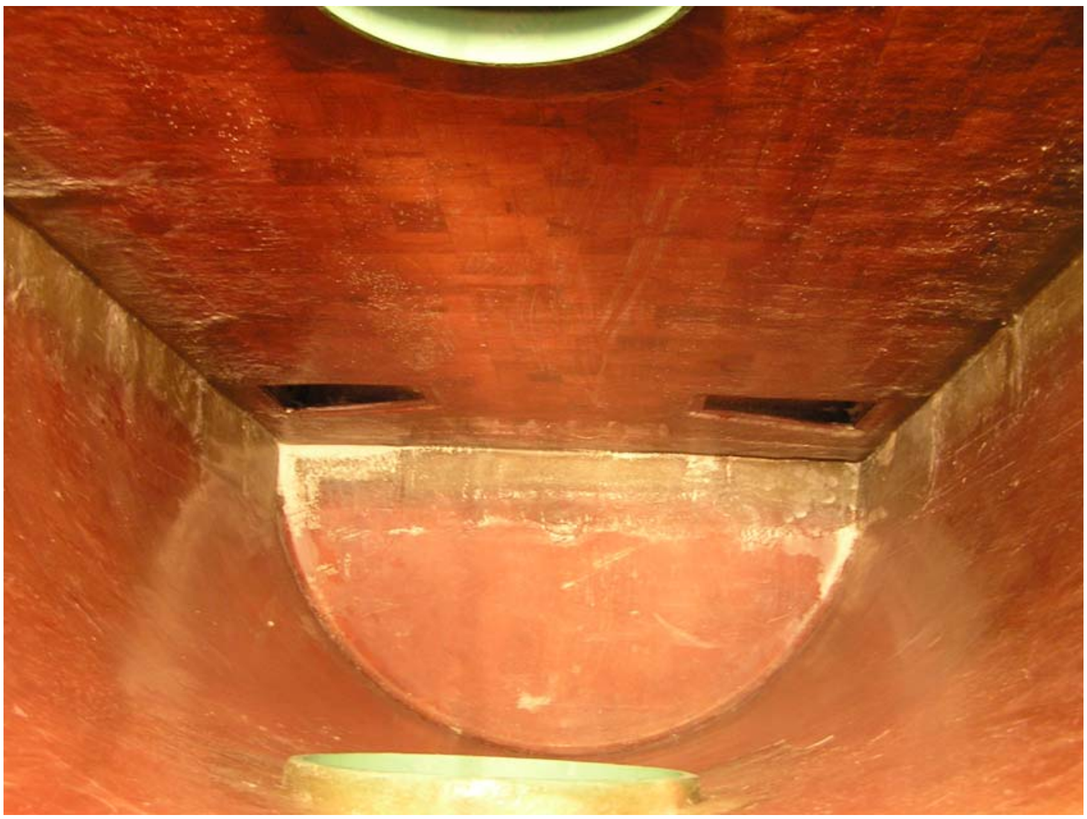

Figure 1.2. View of the baffle wall from the second compartment of the M_2 manhole.

2. Experimental Facility Setup

The test stand was set up on the lowest floor of SAFL. Mississippi River water for the experiment was supplied through a single 12-inch diameter pipe with approximately 45 feet of head which was then expanded into a 20 foot long 15-inch corrugated HDPE pipe. According to the samples taken from the influent pipe, the background concentration varies between 10 to 30 mg/l with mostly organic materials, which cannot be removed by hydrodynamic separators. Nevertheless, a few quasi-mass balance tests were conducted to determine the background concentration. The 20 foot long inflow pipe was set to a slope of 2%. The flow rate for the experiments was controlled using a gate valve on the 12-inch section of the supply pipe (Figure 2.1).

Figure 2.1. The 12-inch supply pipe, the 12-inch gate valve, and the 12-inch PVC to 15-inch HDPE pipe expansion for the inflow pipe.

Total discharge was measured using a pre-calibrated circular weir and submerged pressure transducer probe (Figure 2.2a) located at the end of the outflow pipe. The probe was connected to an ISCO 4120 data logger (Figure 2.2b) to record the data. A desktop computer was connected to the ISCO 4120 data logger to download the data and read real time flow measurements from the submerged probe.

Two sediment feeders were used to control sediment supply rates and concentrations (Figure 2.3). The feeders were calibrated before testing to meet the target concentrations. However, the average influent concentrations were determined by weighing all the sediments fed into the feeders prior to each test, timing of the feeding period, and the measured flow rate.

A set of manometers were connected to the pressure taps mounted on the walls of the manholes and pipes to keep track of hydraulic conditions of the entire system. The pressure taps gave water surface elevations in M_1, both compartments of M_2, in the influent pipe one foot upstream of the entrance, in the effluent pipe one foot downstream of the exit, and in the bypass pipe.

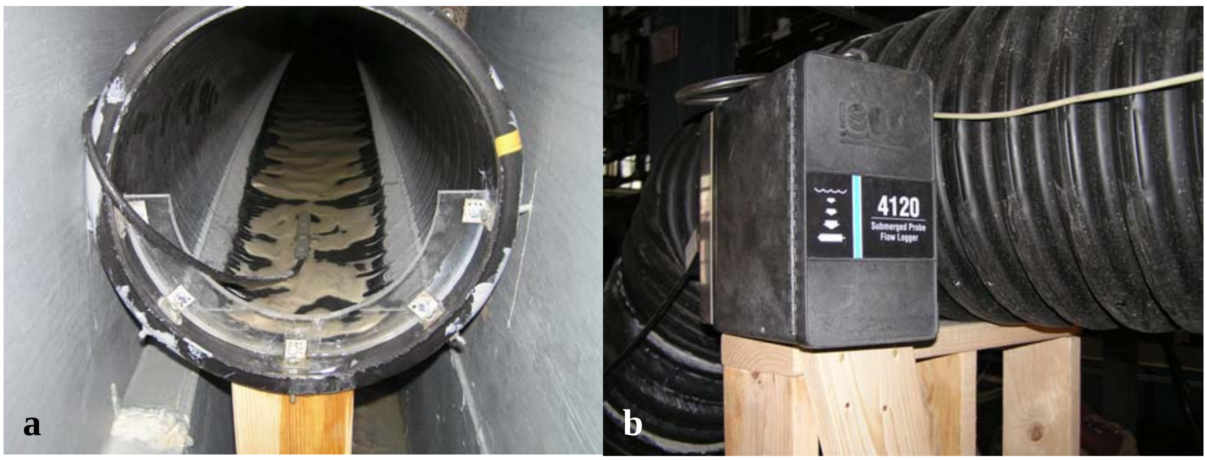

Figure 2.2. (a) The circular weir and submerged pressure transducer probe in the outflow pipe, and (b) an ISCO 4120 data logger to record the flow data.

Figure 2.3. Two sediment feeders were located on the inflow pipe upstream of the M_1 manhole. Clay particles were separately to avoid any coagulation of particles before entering the influent pipe.

3. Load Cells

To conduct a quasi-mass balance assessment of the system, it was decided, while the sumps are preloaded, to use load cells to keep track of the changes in the weight of the manholes.

3.1. Load Cell Specifications and Setup

Total mass of the system was taken using six Tovey Engineering Model FR10-5K load cells. The load cells have a range of 0 – 5000 pounds with a static error band of +/- 0.04% of the rated output, resulting in an accuracy of 2 lbs. The load cells were calibrated at Tovey Engineering before shipping to SAFL. Each manhole was weighed separately on three load cells. A steel triangular platform was constructed and sheeted with a wooden platform to support the weight of each manhole solely on the load cells. This method was used to ensure an equal weight on each load cell. Each load cell was centered on a plate between three leveling bolts to ensure loading along the axis of the load cell (Figure 3.1).

Figure 3.1. The support system of the M_2 manhole

To eliminate shear loading at the loading points, two of the three load cells under each tank were mounted on a plate that rode on a ball bearing transfer plate. The ball bearings were loosely constrained to allow small movements due to loading and temperature changes (Figure 3.2).

Figure 3.2. Load cell mounted on a transfer plate

3.2. Load Cell Data Acquisition System

Data acquisition was conducted using a PC running LabView and a Measurement Computing Corporation PCI-DAS6052 A/D card. The A/D card used for testing was a 16 bit, 8 differential channel board. A screen shot of the program with a schematic of the load cells is shown in Figure 3.3.

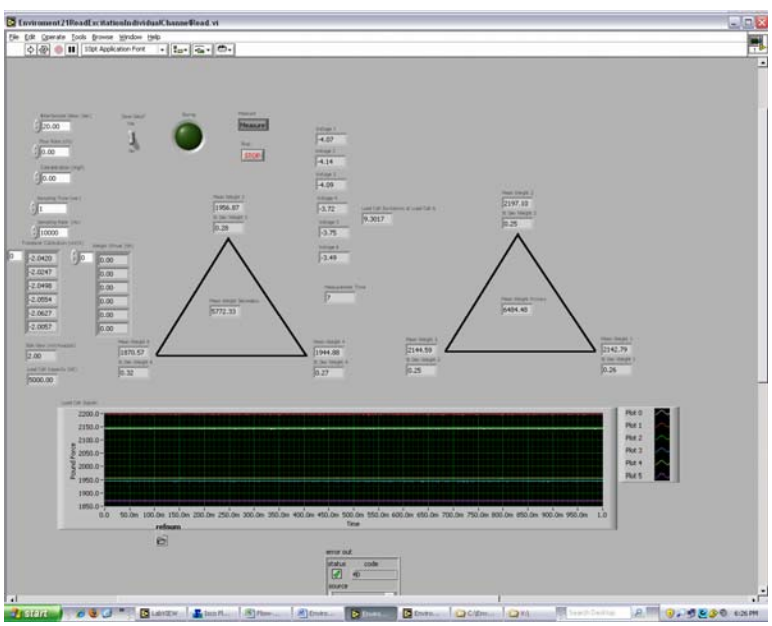

Figure 3.3. Screen view of the LabView program

Load cell signals were amplified by six Interface Model SGA Strain Gauge Transducer Amplifiers set to a gain of 2.00 mV/V. This resulted in full scale output of the load cells. Load cell excitation was measured at each load cell using the voltage sense wires of that load cell. To provide the same excitation voltage to each load cell, an independent linear power supply was used to power all of the load cells. This also allowed the excitation voltage to be set to a value within range of the acquisition board. Since accuracy was more important than speed, readings from each load cell signal and the excitation were taken individually to eliminate errors associated with acquisition board settling time between measurements.

3.3. Water Surface Elevation Measurements

In a five foot diameter tank, at 68 ^{o}F water temperature, ±0.001 ft error in water level results in ±1.22 lbs error in measuring the weight of the tank. So, for maximum accuracy the water surface elevation difference before and after each test was measured and the weight readings corrected based on the differences.

To accurately measure water surface elevations, initially sonar transducers were employed, however, sonar transducer were sensitive to humidity and were not repeatable within the above limits. To accurately measure the water surface Lory type-C point gages in stilling wells were mounted at each tank. These point gages have a precision of 0.001 ft and it was observed that at least four people using the same technique read a water surface elevation with a repeatability of ±0.001 ft. Figures 3.4 and 3.5 illustrate the draining system as well as the point gage for measuring water depth in M_1. The draining systems were not connected to any other piping therefore they did not adversely affect the weight readings.

3.4. Adjusting and Verifying the Load Cell System Accuracy

Since using load cells can result in a number of electronic and mechanical problems, during the initial setup of the Load Cell system some adjustments were made as described below.

3.4.1 Electronic Adjustments

One of the electronic adjustments made was to establish proper grounding of the excitation voltage in order to minimize the noises picked up by the sensitive load cells. Also, in order to achieve the required accuracy, the samples (measurements) taken from the acquisition board were properly spaced to minimize any settling times within the board. Multiple readings were taken every 20 seconds. The sampling frequency was 10,000 Hz and averaged over one second to reduce any jitter.

3.4.2 Mechanical Adjustments

To improve the repeatability of the system, film rubber which transmits little tension and no compression was used for the connections. Additionally the manholes were disconnected during weighing (i.e., external pipe connections were removed) and the load cells were carefully examined for any eccentric loading. Internal piping between the two manholes was left connected to prevent any sediment loss.

Figure 3.4. Draining system of the manholes

Figure 3.5. Point gage measurement of water surface elevation in the primary manhole

3.4.3 Verifying the Accuracy

Around the clock measurements were taken during the final testing phase of the system to monitor any drift or step changes in the data that would affect the test runs.

The repeatability of the system was checked by incrementally adding 20 lbs weights to each manhole and then weighing each manhole. The final results of the repeatability tests are shown in Figure 3.6.

Because the chambers were connected to each other, the efficiencies were based on the total mass change of the two manholes. This eliminates any concern of load transfer from one manhole to the other, or any creep variance associated with the connection. The net system load measurement accuracy of the two chambers was ±3 lbs.   This is shown in Figures 3.8.

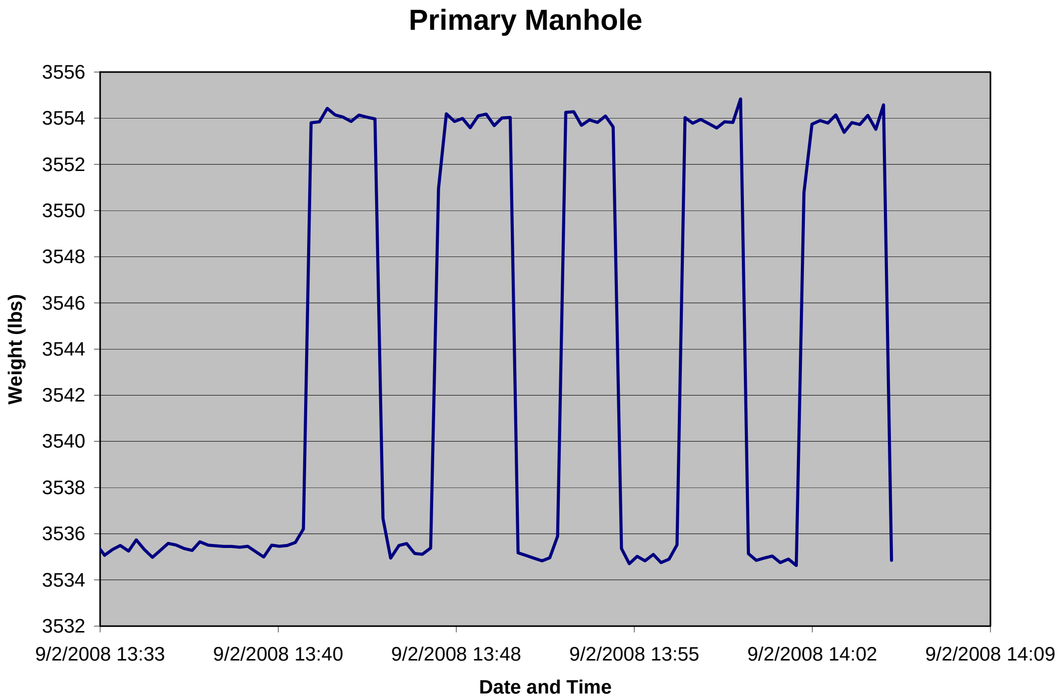

Figure 3.6. The results of the repeatability tests conducted on the load cells of the primary manhole (M_1) by adding and removing 20 lbs weights.

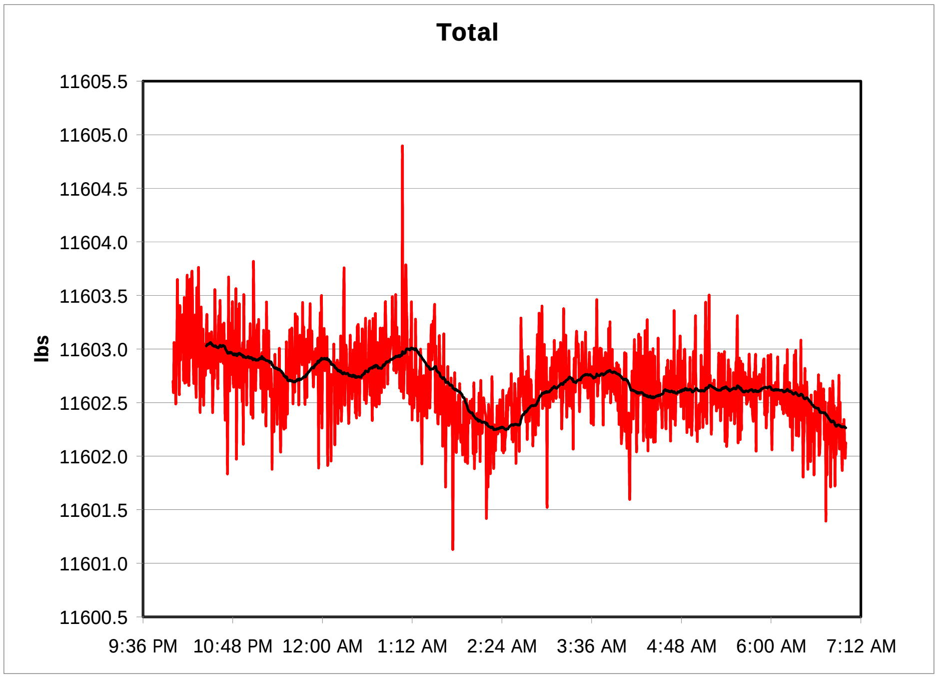

Figure 3.7. The overnight monitoring of the entire system weight in a static state. The dark line is the moving average of the data showing the drift in the all load cells combined.

4. Performance Tests to Meet the NJDEP Requirements

To meet the NJDEP requirements for determining the solid removal efficiency of V2B1 Model 4, it was required to conduct 15 tests at 125%, 100%, 75%, 50% and 25% of the design rate (a.k.a. as the maximum treatment rate) and using three influent concentrations of 100, 200 and 300 mg/l. The design flow rate of the V2B1 Model 4 was set at 0.8 cfs. In order to follow the NJDEP requirements, the tests were conducted at 1, 0.8, 0.6, 0.4 and 0.2 cfs respectively. NJDEP recommends a specific particle size distribution (PSD) with a specific gravity of 2.65. In addition, one of the requirements of the NJDEP laboratory testing is to preload the sump with the recommended materials at 50% of the sump capacity. In the following section, the PSD used for the tests, the specific gravity of the materials, the testing protocol and the results of the tests are presented.

4.1. Particle Size Distribution

The PSD recommended by the NJDEP is shown in Table 4.1. In order to prepare a mix similar to the PSD in Table 4.1, sediments with five different gradations were mixed. For very fine materials, it was decide to use kaolin (clay particles), which was 38% of the total mix.

To check the mix three samples were taken from the mix. However, since adding the clay particles to the mix would coagulate the samples and provide unrealistic distribution of the mix, it was decided not to add the kaolin. The samples were sieved, dried and weighed to determine their size distributions. Figure 4.1 shows the NJDEP target distribution, the theoretical mix, and the three analyzed samples. The theoretical mix in Figure 4.1 includes the clay particles which were added numerically. These results show that the designed and tested mix had a PSD equivalent to the target PSD.

In addition, in order to determine the particle specific gravity (SG) of the mix, and the bulk specific gravity of the mix a total of nine samples were collected from which two samples were for measuring the SG of the mix with no clay, two samples for the SG of the clay particles, and five samples for the bulk SG of the mix. The ASTM D 854 standard test was used to determine the SG of the particles. The particle SG of the mix without the clay particles was measured to be 2.49, and the SG of the kaolin was measured to be 2.59. The bulk SG of the total mix was measured to be 1.60 with a standard deviation of 0.01.

Table 4.1. The NJCAT recommended distribution

Particle Size (microns)	Sandy loam (percent by mass)
500-1000 (coarse sand)	5.0
250-500 (medium sand)	5.0
100-250 (fine sand)	30.0
50-100 (very fine sand)	15.0
2-50 (silt)	(8-50 um, 25%) (2-8 um, 15%)
1-2 (clay)	5.0

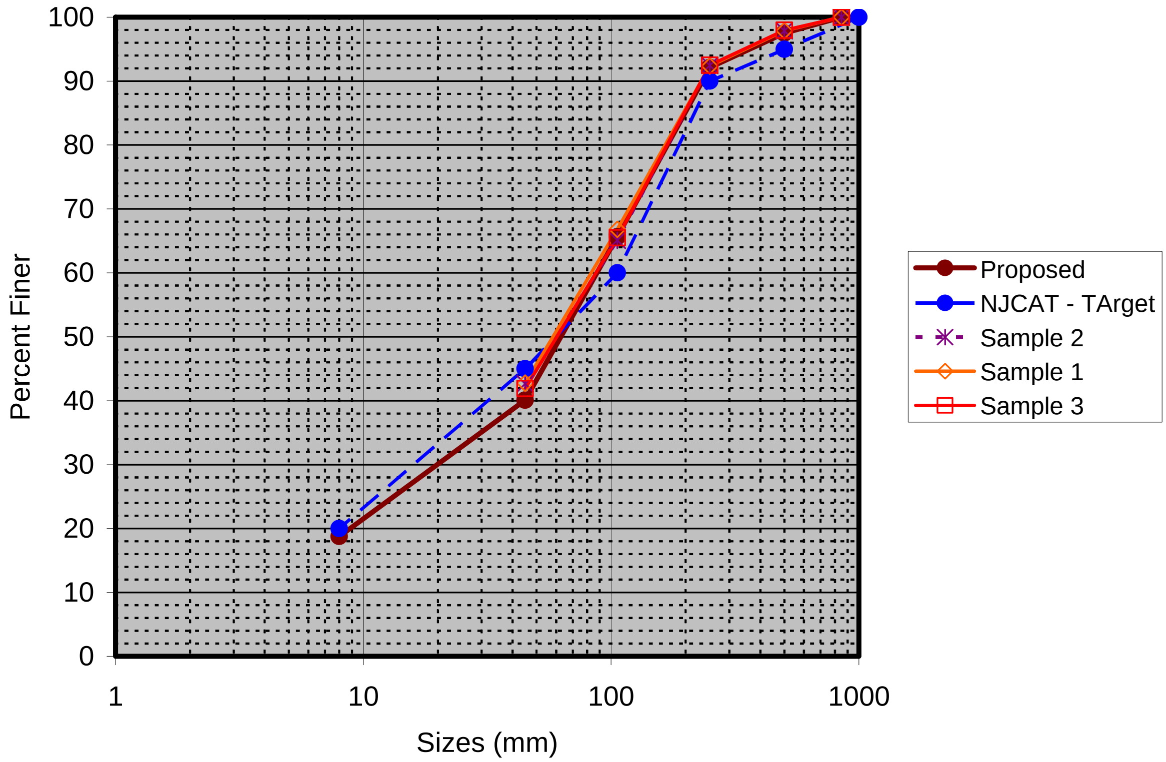

Figure 4.1. The target particle size distribution (PSD), the proposed (theoretical) PSD, and the PSD of three samples from the mix.

4.2. Testing Methodology

4.2.1. Influent Concentration

The influent sediment concentration was controlled by the feed rate of a Schenke Accurate and a Tecweigh sediment feeder. Since kaolin (clay particles) could easily coagulate under very low moist condition and artificially increase the removal efficiency of the unit, it was decided to feed kaolin separately into the system. The solids were fed into the system at the downstream end of the 15-inch PVC pipe attached into the manhole supplied by the fiberglass manufacturer. Water was fed by a hose with the inputted sediment to create a slurry mixture through a funnel into the inflow pipe. The feed rate of the feeder was determined beforehand by the following formula,

$$f = \frac{28.32QC}{1000} \qquad (4.1)$$

where f is the feed rate in grams per second, Q is the target flow rate in cfs, C is the desired concentration in milligrams per liter and 28.32 is a conversion factor.

The speed of the feeder was set to match the desired feed rate by weighing a sample of the desired sediment metered out over a recorded period of time. To verify the average feed rate, before an experiment started, a known mass of sediments was weighed and placed in the hopper of the feeder. Then any sediments remaining in the hopper after the feeder was turned off were weighed. The difference between the two masses gave the total mass that was fed into the system. The period that the feeder operated was also recorded. The ratio of the mass to the recorded period gives the average feed rate, *f*. Rearranging Equation 4.1, results in equation 4.2 which determines the average influent concentration.

$$C = \frac{1000 f}{28.32Q} \qquad (4.2)$$

4.2.2. Testing Procedure

The mass balance testing procedure was developed after a series of conference calls with Richard Magee, the NJCAT representative. The testing procedure was based on a preloaded sump. It was decided to preload the sump by feeding sediments while there was a flow through the sump. Below is the description of the step by step testing procedure.

- The background concentration was determined by flowing Mississippi water through the device at 0.1 cfs for a period of one hour. The particles removed from the sumps were collected using a shop vac, dried and weighed. This test was repeated four times. The average weight of the materials was less than 0.037 lbs (17 grams). The background concentration impacting the results of the tests was calculated to vary from 1.1 to 1.7 mg/l.[2]

- About 1000 lbs of the proposed mix was prepared and mixed using a mixer. The clay particles were fed separately to avoid coagulation among particles.

- The valve was opened and the manholes were filled with water until some discharge was observed through the effluent pipe. Then the valve was closed and the system was drained to a target elevation (about 3 ft above the sump floor). The weight of each manhole was recorded using the load cells. Water levels in the manholes were different.

- The system was then fed at a concentration of about 3 g/l of the proposed gradation for a period of about 4 hours. The goal was to feed the system until about 490 lbs of sediments were removed by the device, which is equivalent to 50% capacity. The loading cycle was more than one hour at 25% of the design rate (MTR), more than 0.5 hours at 50% MTR, 33 minutes at 75% MTR, 28 minutes at 100% MTR, and 24 minutes at 125% MTR. Since the previous tests had shown that under 125% and

[2] Originally, it was intended to use the load cells to measure the background concentration. However, the background concentration of inorganic materials was too small to be detected by the load cells. Therefore, the background concentration was measured as explained above.

100% MTR, less than 1% of clay materials can be removed by the device, the clay materials were not fed under those two flow conditions. The final weight of the system was recorded by the load cells to increase by 464 lbs (Table 4.2). However, this increase in the weight was not equivalent to the weight of the sediment, because a volume of water equal to the volume of sediments was removed from the device. Assuming a SG of 2.49 for the sediments, during the preloading 775 lbs of sediments were captured by the device to an average thickness of 4.7" covering the entire bottom.

- A total of 15 tests were to be conducted under five flow conditions at 125%, 100%, 75%, 50% and 25% MTR and influent concentrations of 100, 200 and 300 mg/l. The water flow rates were set initially at the desired rate and were verified after a minimum of two residence times and then maintained throughout each individual test.

- Each test took more than one hour. To ensure the results are meaningful, an error calculation was conducted prior to each test to provide an estimate of the test duration. During each test, sediments were fed using a pre-calibrated feeder as explained above. In addition, the total amount of sediment fed into the feeder was weighed prior to the test to determine the actual average concentration throughout each test. At the end of each test, the valve was closed and the manholes were drained to the target elevation and weighed. The difference in water elevations were measured using the point gages and the additional weight of water was incorporated to determine the added weight of the system.

- During each test the following parameters were measured:

  - Discharge was measured continuously using a pressure transducer upstream of the pre-calibrated circular weir.

  - Temperature was measured inside the sump at the beginning and the end of each test.

  - Water surface elevations were recorded upstream of the inlet inside the influent pipe, inside both sumps, and downstream of the exit inside the effluent pipe.

  - The starting and ending time of the test as well as the beginning and ending times of the constant discharge were recorded to determine the exact duration of each test.

- The removal efficiency (η) was calculated as follows:

$$\eta = \frac{\left(W_f - W_i\right) SG}{W_{fed}\left(SG - 1\right)} \tag{4.3}$$

Where W_f and W_i are the final and initial weights of the system after the correction for the difference in water surface elevations, W_{fed} is the weight of the dry sediment fed into the system, and SG is the specific weight of the sediment.

Table 4.2. The preloading of the sump over a 3.25 hour period.

General test Information						Water Elevations (feet above M1 floor)					Sediment				Weight			
Run	Test Type	Water Temp (F)	Duration of test inputting sediment (sec)	Average Height Above Weir (ft)	Flow Rate (CFS)	Inflow (ft)	M1 (ft)	M2a (ft)	M2b (ft)	Outflow (ft)	NJCAT (no clay) Mix Feed (g/sec)	Clay Feed (g/sec)	Average Sediment Concentration (g/L)	Target Sediment Concentration (g/L)	Primary Manhole Start and End Weight (lbs)	Secondary Manhole Start and End Weight (lbs)	Primary Manhole Weight Gained (lbs)	Secondary Manhole Weight Gained (lbs)
1	125% MTR	65.8	1440	0.505	1.06	6.43	6.42	6.03	6.02	5.76	61.3	0.0	2.041	2.17	2628	2558		
2	25% MTR	66.1	4200	0.218	0.198	6.305	6.34	5.68	5.68	5.575	12.5	7.5	3.567	3.5				
3	50% MTR	65.9	2520	0.311	0.404	6.34	6.375	5.785	5.78	5.64	24.9	15.0	3.488	3.5				
4	100% MTR	65.7	1680	0.443	0.815	6.39	6.4	5.94	5.93	5.705	50.0	0.0	2.167	2.17				
5	75% MTR	65.7	1980	0.375	0.585	6.355	6.38	5.86	5.85	5.675	34.6	20.0	3.296	3.5	3054	2596	426	38

4.3. Test results

The results of the tests are shown in Table 4.3. The result of one of the tests (test # 7) seem to be an outlier and it was repeated to ensure accuracy; therefore, a total of 16 tests were conducted as shown in Table 4.3.

The duration of the tests increased to minimize the errors associated with the load cells. The duration of the tests varied from approximately 3 hours to 12 hours. The results of the tests show more consistency in the tests at higher flow rates, i.e. the removal efficiency under different concentrations do not vary at 125% MTR or 100% MTR. This discrepancy can be due to change in temperature as well as the smaller amount of material fed at lower flow conditions. The settling velocity of particles drop significantly as water temperature drops, therefore, it is more likely that removal efficiency of the device drops as water temperature drops. At 125% MTR tests, water temperature varied by less than 1.5 ^{o}F and it was only about 2 or 3 ^{o}F cooler than the air temperature. At 25% MTR, however, water temperature varied by more than 3 ^{o}F and it was about 20 ^{o}F cooler. At 125% MTR and with a concentration of 300 mg/l, the amount of sediment fed and removed were 179.8 lbs and 86.1 lbs, respectively. At 25% MTR and with a concentration of 100 mg/l, the amount of sediment fed and removed were 53.9 lbs and 34.1 lbs, respectively.

In order to determine the removal efficiency of V2B1 Model 4 under the recommended runoff hydrograph (i.e. using the discharge factor) and incorporating the potential errors in using load cells, it was decided to assume ±3 lbs of cumulative error from both manholes and recalculate the removal efficiencies and tabulate the minimum, maximum and average removal efficiency for at each flow condition. The results are summarized in Table 4.4. It is evident that under the worst case scenario, V2B1 Model 4 with a design rate of 0.8 cfs (MTR) under the recommended NJDEP flow hydrograph can remove at least 56% of the sediments with the PSD given in Table 4.1. The average removal efficiency of the device is about 65% (Table 4.3). It is noteworthy, that the performance function developed for this device predicts a 58% removal efficiency under the tested conditions.

Table 4.3. Summary of the test results

General test Information										Water Elevations (feet above M1 floor)					Sediment										Weight									
Run	Test Type		Water Temp (F)	Air Temp (F)	Duration of test inputting sediment (sec)	Average Height Above Weir (ft)	Average Flow Rate (CFS)	Target Flow Rate (CFS)	MTR of System (CFS)	Inflow (ft)	M1 (ft)	M2a (ft)	M2b (ft)	Outflow (ft)	Target Sediment Concentration (g/L)	Target SCS Feed (g/sec)	Target Clay Feed (g/sec)	Target Duration (min)	Total SCS Mix Needed (g)	Total Clay Mix Needed (g)	Actual SCS Mix Feed Duration (min)	Actual Clay Feed Duration (min)	Actual SCS Mix Fed (g/sec)	Actual Clay Fed (g/sec)	Primary Manhole Start Weight (lbs)	Secondary Manhole Start Weight (lbs)	Primary Manhole End Weight (lbs)	Secondary Manhole End Weight (lbs)	Primary Manhole Weight Gained (lbs)	Secondary Manhole Weight Gained (lbs)	Manholes Sum (lbs)	Sediment Removed (lbs)	Sediment Fed (lbs)	Removal Efficiency
1	125%	Start	63.4	65.6	18600	0.518		1.000	0.8	6.440	6.410	6.070	6.050	5.720	0.1	1.76	1.08	360	37921.9	23242.5	310	300	2.039	1.291	6140.3	5646.8	6158.6	5667.4	18.3	20.6	38.9	65.0	134.8	48.23%
		End	62.9	64.2		0.517				6.450	6.420	6.070	6.050	5.720																				
2	125%	Start	62.1	61.1	13080	0.518		1.000	0.8	6.450	6.430	6.060	6.050	5.710	0.2	3.51	2.15	240	50562.6	30990.0	200	218	4.214	2.369	6000.8	5612.8	6024.9	5633.9	24.1	21.1	45.2	75.5	179.8	42.01%
		Middle	62.1	61.9		0.52				6.460	6.440	6.070	6.060	5.710																				
		End	61.9	61.5																														
3	125%	Start	63.1	61.8	9600	0.513		1.000	0.8	6.440	6.430	6.065	6.050	5.720	0.3	5.27	3.23	160	50562.6	30990.0	150	184	5.618	2.807	6119.7	5664.1	6147.1	5688.3	27.3	24.2	51.6	86.1	179.8	47.92%
		Middle	63.1	59.5		0.518																												
		End	62.9	59.8		0.522				6.455	6.430	6.070	6.055	5.720																				
4	100%	Start	61.0	64.1	10200	0.444	0.82	0.800	0.8	6.400	6.380	5.955	5.950		0.3	4.21	2.58	180	44995.0	27578.0	170	165	4.411	2.786	6024.7	5662.9	6074.9	5667.9	50.2	5.1	55.2	92.3	160.0	57.66%
		Middle	61.1	64.3						6.395	6.380	5.955	5.950																					
		End																																
5	100%	Start	61.1	62.6	16320	0.442	0.812	0.800	0.8	6.395	6.380	5.950	5.945	5.705	0.2	2.81	1.72	270	45506.3	27891.0	255	272	2.974	1.709	6070.2	5672.2	6116.3	5682.7	46.1	10.5	56.7	94.7	161.8	58.52%
		Middle	61.0	63.1						6.395	6.380	5.955	5.950	5.715																				
		End	60.5	62.8						6.395	6.380	5.950	5.945	5.715																				
6	100%	Start	60.6	64.1	24840	0.444	0.82	0.800	0.8	6.395	6.380	5.955	5.950	5.715	0.1	1.40	0.86	405	34129.7	20918.2	376	414	1.513	0.842	6123.7	5690.8	6155.0	5698.8	31.3	8.0	39.3	65.7	121.4	54.10%
		Middle	58.6	62.3						6.395	6.380	5.950	5.945	5.720																				
		End	58.7	64.4						6.395	6.380	5.955	5.950	5.715																				
7	75%	Start	60.2	58.0	12540	0.392	0.64	0.600	0.8	6.370	6.355	5.895	5.892	5.700	0.3	3.16	1.94	208	39438.8	24172.2	209	196	3.145	2.055	6143.9	5716.2	6187.7	5735.7	43.8	19.4	63.2	105.7	140.2	75.34%
		Middle	59.4	52.6																														
		End	59.6	54.0						6.370	6.355	5.895	5.892	5.700																				
8	75%	Start	57.2	55.4	18840	0.392	0.64	0.600	0.8	6.370	6.350	5.889	5.880	5.700	0.2	2.11	1.29	312	39438.8	24172.2	292	314	2.251	1.283	6189.4	5720.9	6235.1	5726.9	45.7	6.0	51.7	86.3	140.2	61.56%
		Middle	56.2	54.1						6.370	6.350	5.885	5.880	5.700																				
		End	56.2	54.2						6.370	6.350	5.900	5.880	5.700																				
9	75%	Start	53.8	55.3	26280	0.39	0.634	0.600	0.8	6.380	6.350	5.885	5.880	5.700	0.1	1.05	0.65	468	28899.1	18129.1	438	420	1.100	0.719	6216.3	5725.7	6245.1	5732.0	28.9	6.4	35.2	58.9	103.7	56.77%
		Middle																																
		End	53.9	49.7						6.380	6.350	5.883	5.880	5.695																				
10	50%	Start	53.2	54.8	16500	0.315	0.414	0.400	0.8	6.350	6.330	5.804	5.801	5.655	0.3	2.11	1.29	270	34129.7	20918.2	252	275	2.257	1.268	6242.6	5728.1	6285.0	5733.7	42.4	5.6	48.0	80.2	121.4	66.11%
		Middle	53.3	54.2						6.350	6.330	5.802	5.800	5.655																				
		End	53.3	54.6						6.350	6.330	5.802	5.800	5.655																				
11	50%	Start	54.4	72.8	24720	0.314	0.410	0.400	0.8	6.355	6.335	5.815	5.812	5.655	0.2	1.40	0.86	400	33708.4	20660.0	382	412	1.471	0.836	6336.8	5750.1	6382.1	5758.0	45.3	7.9	53.2	88.9	119.9	74.13%
		Middle																																
		End	52.8	73.9						6.352	6.331	5.807	5.805	5.625																				
12	50%	Start	52.2	72.8	37440	0.312	0.405	0.400	0.8	6.353	6.331	5.809	5.807	5.651	0.1	0.70	0.43	600	25281.3	15495.0	597	624	0.706	0.414	6354.6	5755.2	6385.5	5761.6	31.0	6.5	37.4	62.5	89.9	69.56%
		Middle	51.8	71.8						6.350	6.330	5.802	5.800	5.651																				
		End	52.2	69.9						6.350	6.330	5.801	5.800	5.650																				
13	25%	Start	50.3	69.3	26220	0.218	0.199	0.200	0.8	6.325	6.298	5.702	5.701	5.950	0.3	1.05	0.65	440	27809.4	17044.5	452	437	1.025	0.650	6379.8	5759.8	6420.2	5763.7	40.5	3.8	44.3	74.1	98.9	74.90%
		Middle																																
		End	48.8	68.0						6.321	6.298	5.700	5.700	5.950																				
14	25%	Start	49.2	65.7	40980	0.219	0.2	0.200	0.8	6.320	6.298	5.702	5.702	5.950	0.2	0.70	0.43	660	27809.4	17044.5	663	683	0.699	0.416	6425.0	5766.0	6462.4	5769.2	37.4	3.3	40.6	67.9	98.9	68.69%
		Middle	47.2	65.1						6.321	6.298	5.702	5.702	5.950																				
		End	47.8	65.6						6.320	6.283	5.702	5.702	5.950																				
15	25%	Start	47.5	64.8	44280	0.218	0.199	0.200	0.8	6.322	6.282	5.702	5.702	5.590	0.1	0.35	0.22	720	15168.8	9297.0	738.00	701.00	0.343	0.221	6452.1	5761.2	6471.7	5762.0	19.5	0.8	20.4	34.1	53.9	63.15%
		Middle	47.1	66.7						6.325	6.280	5.705	5.705	5.595																				
		End	47.9	64.4						6.323	6.280	5.701	5.701	5.590																				
Repeat of	75%	Start	55.6	72.1	12660	0.385	0.618	0.600	0.8	6.380	6.355	5.895	5.890	5.698	0.3	3.16	1.94	208	39438.8	24172.2	211	206	3.115	1.956	6284.5	5736.6	6335.4	5743.6	50.9	7.0	57.9	96.8	140.2	68.99%
Run 7		Middle																																
		End	54.2	71.2						6.380	6.355	5.891	5.888	5.696																				

Table 4.4. Minimum, maximum and average removal efficiencies of V2B1 Model 4 using the NJCAT hydrograph.

%MTR	Min	Max	Ave	Factors	Min	Max	Ave
125%	40.3%	50.5%	46.1%	0.1	4.0%	5.0%	4.6%
100%	51.6%	60.4%	56.8%	0.15	7.7%	9.1%	8.5%
75%	53.9%	71.1%	68.6%	0.2	10.8%	14.2%	13.7%
50%	63.6%	76.6%	69.9%	0.3	19.1%	23.0%	21.0%
25%	57.6%	77.9%	68.9%	0.25	14.4%	19.5%	17.2%
Total Removal Efficiency					**56%**	**71%**	**65%**

4. Summary

A V2B1 Model 4 was tested at the St. Anthony Falls Laboratory to determine its removal efficiency according to the NJCAT requirements. The sumps were gradually preloaded using sediments with the particle size distribution (PSD) recommended by the NJDEP and flow rates varying from 25% to 125% of the design flow (a.k.a. maximum treatment rate). A total of 16 tests, including one repeat test, were conducted. A total of 6 load cells with a repeatability of ±0.04% of their maximum capacities, i.e. ±2 lbs, were used to weigh the manholes prior to and after each test. The average removal efficiency of the V2B1 Model 4 tested was measured to be 65% using the NJDEP recommended PSD and runoff hydrograph.