FULL SCALE LABORATORY EVALUATION OF STORMCEPTOR® MODEL STC 450 FOR REMOVAL OF TSS

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Abstract. Considerable effort is being expended to assess the effectiveness of urban Best Management Practices (BMP) for stormwater quality enhancement. The effectiveness of structural BMP's is typically evaluated based on a limited amount of test data, which has lead some state organizations established programs requiring mandatory testing for these devices. One such program is the Technology Acceptance and Reciprocity Partnership (TARP), which is a group of state environment agencies including New Jersey, California, Illinois, Massachusetts, New York, Pennsylvania and Virginia. The group has formally agreed to a common strategy of evaluating, approving or permitting environmental technologies. To facilitate the implementation, they have created a third party technical group called the New Jersey Corporation for Advanced Technology (NJCAT) to evaluate manufacturer performance claims. The program has two levels, Tier 1 which is an interim approval given with the understanding that a full scale field test (Tier 2) will be conducted in the State of New Jersey.

This paper was prepared for evaluation of total suspended solids (TSS) removal efficiency for a Stormceptor Model STC 900 in accordance with the NJDEP particle size distribution prescribed in their revised laboratory protocol titled "Total Suspended Solids Laboratory Testing Procedure", dated December 23, 2003 for approval in Tier 1 of the TARP program. Full scale laboratory testing was performed on a Stormceptor Model STC 900. The first objective of the testing was to determine the percent TSS removal at various operating rates (i.e. 25%, 50%, 75%, 100%, and 125%) and the overall annual TSS removal once the NJDEP weight factors were applied. TSS tests were performed with an initial sediment loading of 50% of the sediment capacity in the lower chamber. The second objective was to determine if scouring occurs at 125% of the operating rate when the lower chamber is filled to 50% and 100% of the sediment capacity.

INTRODUCTION

An evaluation of total suspended solids (TSS) removal efficiency for a Stormceptor STC 900 was conducted in accordance to the New Jersey Department of Environmental Protection (NJDEP) laboratory protocol titled "Total Suspended Solids Laboratory Testing Procedure", dated December 23, 2003 (NJDEP Protocol). The STC 900 is also known in the American market as the Stormceptor STC 900 and in the Australasian market as the Humeceptor™ STC 3. The remainder of the report will refer to the unit as the STC 900. Procedures, results and conclusions from this full scale evaluation are presented in this paper.

BACKGROUND

The STC 900 is a water quality device installed in-line with the storm sewer to remove hydrocarbon and total suspended solids from stormwater runoff. The unit consists of a circular chamber, 5.9 feet (ft) or 1.8 metres (m) in diameter, mounted with a fibreglass insert. The fibreglass insert separates the Stormceptor System into two chambers: 1) a lower chamber (below the insert); and 2) an upper chamber (above the insert). The permanent volume of water in the lower chamber is approximately 120 cubic feet (ft^3) or 3.4 cubic metres (m^3). The function of the fibreglass insert is to control the flow and velocity in the lower chamber and bypass excess flows from infrequently occurring storm events. Any hydrocarbons and sediment present in the runoff is removed from the water by gravity and floatation in the lower chamber. Cleaner water is displaced through a 24 inch (in.) or 600 millimetres (mm) opening on the insert and released back into the storm drain. The Stormceptor System is designed to treat the majority of the storm (typically 80 to 90 percent (%) of the average annual runoff volume). The 10% to 15% of the annual runoff that exceeds the flow capacity of the system will over top the weir in the upper chamber so that high flows and velocities are prevented from entering the lower chamber. Turbulence and high velocities can cause re-suspension and scouring of previously captured pollutants to occur.

SCOPE OF TESTING

The scope of the experiment is to test the STC 900 at various increments of the operating rate (25%, 50%, 75%, 100%, and 125%). The operating rate of the STC 900 is

0.63 cubic feet per second (cfs) or 18 liters per second (L/s). The operating rate refers to the maximum design flow rate of the system before bypass occurs. Flows in excess of the operating rate will bypass the lower chamber and over top the weir, thereby protecting the accumulated material in the lower chamber from re-suspension. The objectives of the experiment are as follows:

Objective 1

To determine the TSS removal efficiency at each increment of the operating rate and to determine the overall removal efficiency based on the NJDEP weighting factors. At each operating rate, the unit was tested at three different sediment loading rates/influent concentrations (100 milligrams per litre (mg/L), 200 mg/L, and 300 mg/L) and with a very fine particle size gradation (Table 1). For each test, the Stormceptor lower chamber was pre-loaded to at least 50% of the sediment capacity.

Note that references to 50% and 100% sediment capacity, throughout the document refers to the sediment capacity calculated based on the recommended sediment depth of the Stormcpetor Model STC 900 before maintenance is recommended. Servicing of the Stormceptor unit tested is recommended when the sediment depth reaches 15% of the total storage volume of the lower chamber. At 15% of the total storage volume in the lower chamber (or at 100% sediment capacity), the depth is 10 in. (244 mm) and the sediment volume is 23 ft^3 (0.64 m^3). Therefore at 50% sediment capacity, the depth is 5 in. (122 mm) and the sediment volume is 11 ft^3 (0.32 m^3).

Objective 2

To test for scouring and re-suspension of accumulated material for two different runs, both at 125% of the operating rate. The first run was completed with the lower chamber pre-loaded to 50% of the sediment capacity (a sediment capacity before maintenance of the system is required). The second run was completed with the lower chamber filled to 100% of the sediment capacity (sediment capacity when maintenance of the system is recommended). For each run, TSS concentrations at the inlet and outlet pipe were determined and an analysis of particle size distribution (PSD) was completed. The purpose of this test is to determine if scouring and re-suspension occurs at flow rates above the rated operating capacity of the unit at an initial sediment capacity of 50% and 100% in the lower chamber.

The testing medium consists of simulated stormwater spiked with sediment of a particle gradation equal or close to the particle gradation prescribed by the NJDEP (2003) Protocol (Table 1).

To determine the overall removal efficiency, a weight factor is assigned to the TSS removal determined for each operating rate. The weight factor was established by the NJDEP (2003) and is based on historical rainfall data from various regions in the state of New Jersey (

Table 2).

Table 1. NJDEP Particle Size Distribution

Particle Size (microns)	Description	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%
8 – 50	Medium / Coarse Silt	25%
2 – 8	Fine / Medium Silt	15%
1 – 2	Clay	5.0%

Table 2. NJDEP Weight Factor for Based on New Jersey Historical Rainfall Analysis

Treatment Operating Rate	NJDEP Weight Factor
25%	0.25
50%	0.30
75%	0.20
100%	0.15
125%	0.10

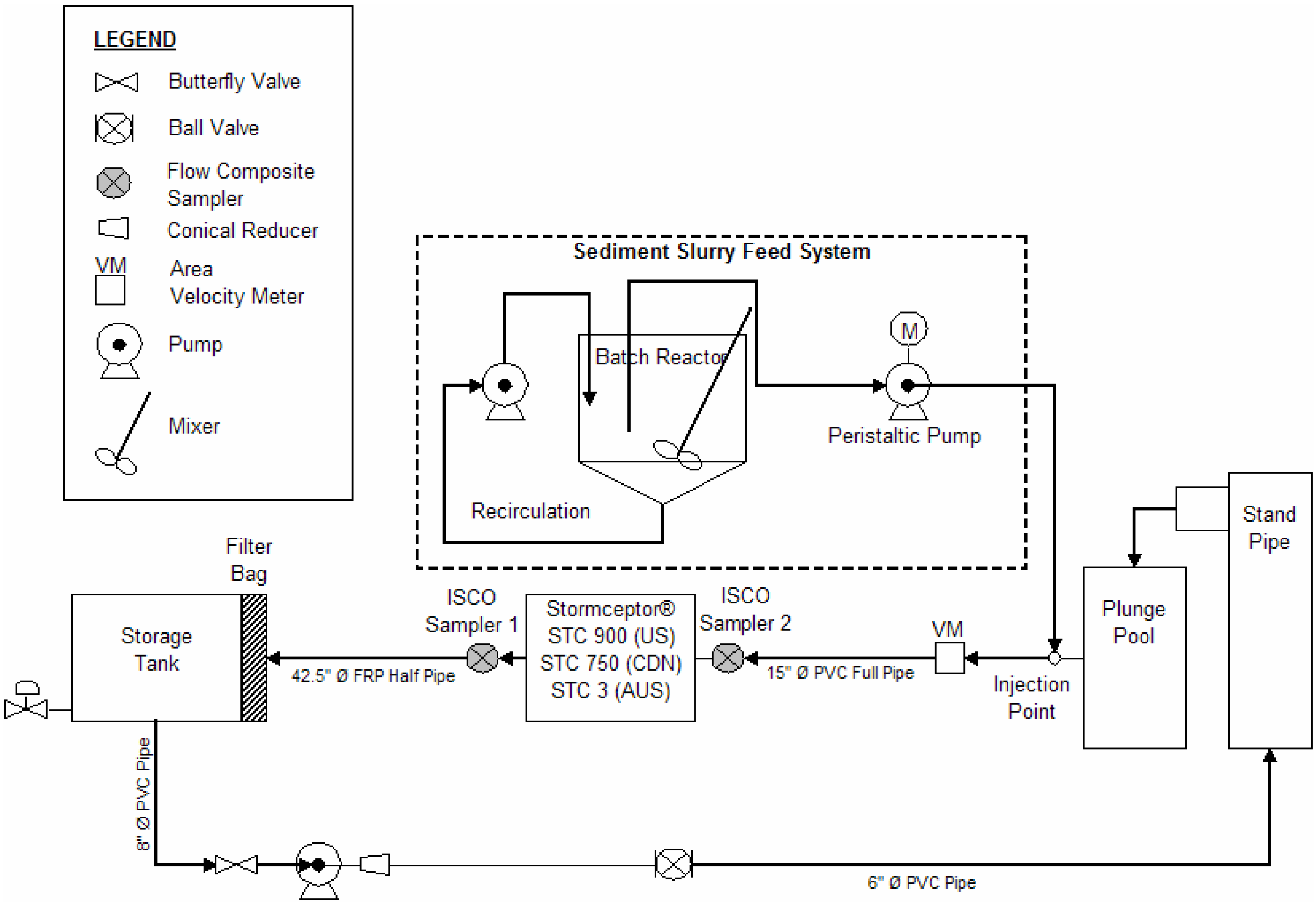

Figure 1. Process Flow Diagram of Laboratory Configuration.

SYSTEM DESCRIPTION

Figure 1 shows the process layout for the laboratory setup for the test subject. All the tanks are filled with water prior to system startup. While the lower chamber of the STC 900 unit is full of water (and 50% of recommended sediment capacity before recommended servicing), the Stand Pipe, Plunge Pool and Storage Tank (all of which are open tanks) are filled with water to the invert of the inlet or outlet pipes. A ball valve located between the pump and stand pipe is adjusted to achieve the desired flow rate for the system. Approximately 10 (ft) (3 m) upstream of the Stormceptor unit, an area velocity flow logger is installed to measure the depth of flows, velocity and flow rate of the influent water.

Water is pumped to the stand pipe and overflows into the plunge pool, where partial pipe flow similar to what is observed in gravity sewers begins to occur. Water exits the plunge pool (a cylindrical tank) through a 15 in. (381 mm) internal diameter PVC pipe directed to the Stormceptor unit.

A slurry mixture, contained in a 65 U.S. gal. (246 L) cone-bottom tank, is introduced to the partial pipe flow near the plunge pool exit pipe via a peristaltic pump. Sediment in the batch slurry mixture is kept in suspension using a mixer and a diaphragm pump. The diaphragm pump draws from the bottom of the cone bottom tank and pumps the slurry back into the top and side of the slurry tank. Turbulent flow within a portion of this 15.8 ft (4.8 m) long pipe provides

mixing of the slurry/water mixture prior to entering the STC 900.

The semi-circular weir on the STC 900 insert directs the flow to the lower chamber through an orifice plate and drop tee arrangement. The semi-circular weir and orifice plate restrict the quantity of flow entering the lower chamber up to the operating rate. The drop tee channels the flow around the inside circumference of the lower chamber. The head differential between the inlet and outlet of the unit allows water to exit the bottom chamber through a riser pipe. Automatic samplers are placed at the inlet and outlet pipes of the STC 900 unit to collect influent and effluent samples, respectively. Water exiting the STC 900 is channeled via a 42.5 in. (1072 mm) diameter half pipe, modified with a circular insert designed to simulate a 15 in. (375 mm) outlet pipe. This pipe feeds effluent into the storage tank. A 120 in. (3000 mm) diameter, 1- µm filter bag covers the storage tank and functions to filter out sediment that may be in the effluent prior to re-circulating back into the system from the storage tank.

RESULTS AND DISCUSSION

Automatic Sampler Results

Table 3 presents a summary of average TSS results of water/sediment samples collected by the automatic samplers and resulting removal efficiencies at 25% to 125% of the operating rate. Figure 2 presents a graph of the average removal efficiencies measured from automatic samplers over each of the five operating rates. General trends suggest a slight reduction in removal efficiency as the flow rate or the operating rate increases. Since the STC 900 was tested with an initial 50% sediment capacity in the lower chamber, the results strongly suggest that minimal or no scouring of the sediment in the tank occurred during any of the runs, and sediment removal is steadily maintained throughout the runs at the five operating rates without a significant drop in removal efficiency.

Table 3. Summary of Automatic Sampler TSS Concentrations and Removal Efficiencies

Influent Target	Parameter	Units	Operating Rate (%) 25	50	75	100	125	Overall Ave.
100 mg/L	Ave. Inlet Conc.	mg/L	203	129	147	187	98	153
	Ave. Outlet Conc.	mg/L	25	34	42	31	16	30
	Ave. Removal Efficiency	%	88	74	71	83	84	80
200 mg/L	Ave. Inlet Conc.	mg/L	355	218	266	303	223	273
	Ave. Outlet Conc.	mg/L	50	68	85	90	114	82
	Ave. Removal Efficiency	%	86	69	68	70	49	68
300 mg/L	Ave. Inlet Conc.	mg/L	599	416	381	425	486	461
	Ave. Outlet Conc.	mg/L	79	106	135	148	108	115
	Ave. Removal Efficiency	%	87	75	65	65	78	74
Overall Ave. Removal Efficiency		%	87	72	68	73	70	n/a

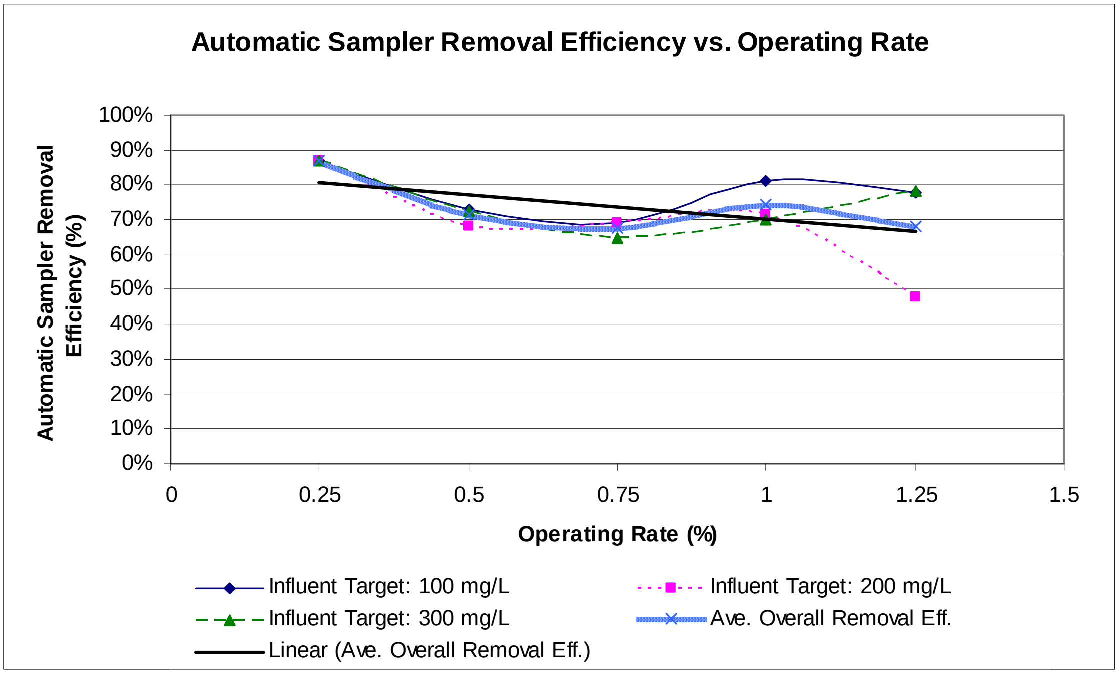

Figure 2. Graph of Removal Efficiency Trends Analyzed from the Automatic Samplers at 25%, 50%, 75%, 100% and 125% of the Operating Rate.

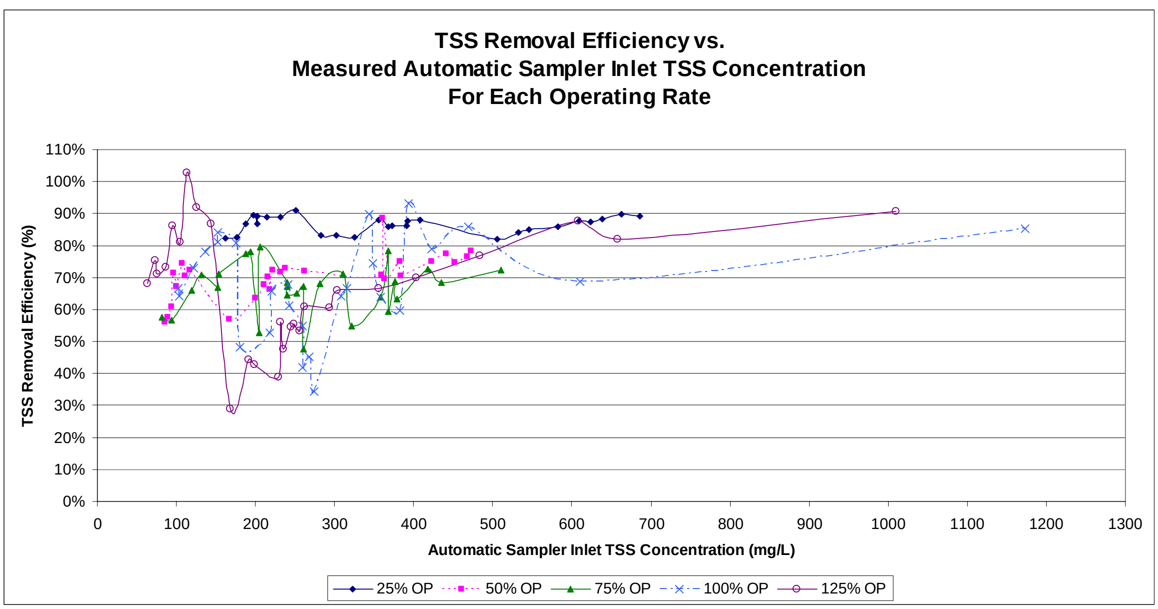

Figure 3. Removal Efficiency vs. Automatic Sampler TSS Concentration for Each Operating Rate.

Another trend noted is an increase in removal efficiency with increase loading rate, however the trend is not dramatic or pronounced. Figure 3 compares the inlet concentration of the individual sample set against the removal efficiency.

It is noted that there appears to be three main regions where results congregate around an average performance. The first region applies to inlet concentrations up to approximately 170 mg/l. In this region there is a congregation of performance results with an average removal efficiency around 80%. This result is confirmed by the actual data in Table 3. The second region exists between 170 mg/l and 280 mg/l, where a much greater variation in results occurs with an average efficiency around 70%. Finally, the third region for inlet concentrations greater than 280 mg/l does show a much stronger trend indicating that for higher loading rates, the removal efficiencies generally increase, with an average efficiency around 75%. The removal efficiencies indicated by this graph and the three regions described are broadly indicative of the three target inlet concentrations and the average efficiencies noted above is in accordance with those documented in Table 3.

The overall TSS removal efficiency is dependent on rainfall patterns as well as site conditions when applied to a particular area. The NJDEP protocol specified weight factors specific to the State of New Jersey based on the analysis of historical rainfall data from various regions within the state. After applying the NJDEP prescribed weight factors over the five operating rates, the overall TSS removal efficiency is 75% (

Table 4). This value shows correlation with the mass balance result of 72% (presented in the next section).

Table 4. Full Scale TSS Removal Efficiency with NJDEP Weighting Applied

Treatment Operating Rate	NJDEP Weight Factor	Average Overall TSS Removal Efficiency (%)	Weighted TSS Removal Efficiency (%)
25%	0.25	87%	22%
50%	0.30	72%	22%
75%	0.20	68%	14%
100%	0.15	73%	11%
125%	0.10	70%	7%
Total			**75%**

Mass Balance

A mass balance was completed in order to confirm the findings from the automatic samplers by comparing the inlet and outlet sediment loading. The inlet sediment loading is determined by multiplying the average slurry concentration by the injection rate and dividing it by the total injection time to obtain the total mass of sediment injected during the entire run. The outlet sediment loading is determined by drying the filter bag after the applicable runs and subtracting the initial filter bag weight from it. This dry weight of sediment represents the sediment that was not captured by the Stormceptor unit during the run. The TSS removal performance is determined by taking the difference between the inlet and outlet sediment loading and dividing it by the total sediment injected (i.e. the inlet sediment loading).

The average TSS removal performance based on the mass balance compared to the removal efficiencies determined by the automatic samplers as presented in Table 5. While there are some variations in removal efficiency between the two methods at individual operating rates, overall, the mass balance results appear to correlate well with the performance determined using the automatic sampler data.

Table 5. Comparison of Performance Results between Mass Balance Analysis and Automatic Sampler Analysis after NJDEP Weight Factors are Applied

Treatment Operating Rate	NJDEP Weight Factor	Average % Removal: Mass Balance	Average % Removal: Samplers
25%	0.25	75%	87%
50%	0.30	75%	72%
75%	0.20	70%	68%
100%	0.15	63%	73%
125%	0.10	72%	70%
Total		**72%**	**75%**

Theoretical Model Comparison

A numeric settling model was used to determine the theoretical removal efficiency based on particle size distributions analyzed from the influent automatic sampler at the respective operating rates. The influent mean particle size collected from the automatic sampler was found to be 97µm. In order to perform calculations using the theoretical settling model, a completely mixed and steady state system was assumed. The PSD measured by the automatic samplers were applied to a theoretical model at each operating rate and weighted using the NJDEP weight factors. This approach resulted in an overall removal efficiency of 76% (Table 6). This overall theoretical removal efficiency of 76% correlates well with both the 75% overall TSS removal determined using the automatic sampler results and the 72% efficiency determined from the mass balance approach.

Table 6. Theoretical Removal Efficiency Based on PSD from Automatic Sampler

Treatment Operating Rate	NJDEP Weight Factor	Average % Removal
25%	0.25	86%
50%	0.30	74%
75%	0.20	74%
100%	0.15	76%
125%	0.10	58%
Total		76%

Scour Test

Table 7 summarizes results from the scour test performed at 125% operating rate. The overall outlet TSS concentration was 0 mg/L when the lower chamber contained sediment at 50% of its sediment capacity. Minimal TSS concentration was observed in the 100% sediment capacity scour test, where the average outlet concentration was 3.3 mg/L.

Table 7. Scour Test TSS Results

Scour Test at 125% Operating Rate			
Sediment Capacity in STC Unit	**Average Inlet Concentratn**	**Average Outlet Concentratn**	**Adjusted Outlet Concentratn**
50%	59 mg/L	56 mg/L	0 mg/L
100%	21 mg/L	25 mg/L	3.3 mg/L

Outlet PSD collected by the automatic sampler generally show minimal re-suspension of particles. When the Stormceptor unit was filled to 50% of its sediment capacity, no re-suspension of particles from the tank was observed since the inlet and outlet mean particle size results remained the same (inlet and outlet mean PSD was 5 µm). When the Stormceptor unit is filled to 100% of its sediment capacity, the automatic sampler results indicated a slightly larger particle size distribution exiting the Stormceptor unit (mean PSD is 8 µm at the inlet of the unit and 20 µm at the outlet of the unit). This may indicate a minimal amount of scouring when the lower chamber is filled to 100% of its sediment capacity, the point at which maintenance is recommended.

CONCLUSION

Full scale testing was performed on a STC 900. The first objective of the testing was to determine the percent TSS removal at various operating rates (i.e. 25%, 50%, 75%, 100%, and 125%) and the overall annual TSS removal once the NJDEP weight factors were applied. The NJDEP weight factors were determined by the NJDEP based on historical rainfall data. TSS tests were performed with an initial sediment loading of 50% of the sediment capacity in the lower chamber. The second objective was to determine if scouring occurs at 125% of the operating rate when the lower chamber is filled to 50% and 100% of the sediment capacity. Samples were taken at the inlet and outlet pipe of the Stormceptor unit via automatic samplers.

Laboratory results show that 75% overall TSS removal is achieved by the STC 900 when the NJDEP weight factors are applied to the results from the five operating rates (

Table 4). A general trend shows that the TSS removal efficiency decreases only slightly as the operating rates increase. Conversely, as the concentration in the influent increased, the TSS removal efficiency also increased. The overall average TSS concentration in the influent is 295 mg/L.

A mass balance approach was taken to confirm the sampler results and for quality control. The mass balance performed for this test estimates a removal efficiency of 72% (Table 5). Despite challenges associated with drying the filter bags and estimating the mass of sediment injected to the system, the 72% closely correlates with the 75% overall TSS removal determined using automatic sampler results.

Finally, a numeric settling model was used to determine the theoretical removal efficiency based on particle size distributions analyzed from the influent automatic sampler at the respective operating rates. In order to perform calculations using the theoretical settling model, a completely mixed and steady state system was assumed. The PSD measured by the automatic samplers were applied to a theoretical model at each operating rate and weighted using the NJDEP weight factors. This approach resulted in an overall removal efficiency of 76% (Table 6). This overall theoretical removal efficiency of 76% correlates well with both the 75% overall TSS removal determined using the automatic sampler results and the 72% efficiency determined from the mass balance approach.

A comparison of removal efficiency results from the automatic sampler with the mass balance results and the theoretical results gives confidence in the conclusions from the monitoring exercise.

Lastly, two scour tests were conducted at 125% of the STC 900 operating rate with an initial loading of 50% and 100% of the sediment capacity in the lower chamber. Results indicated no scouring at 50% of sediment capacity, and very slight re-suspension of particles at 100% capacity, the condition where servicing is recommended. Based on these results, it can be concluded that minimal or no scour occurs even at the 125% of the operating rate.

From the above, it can be concluded that the STC 900 provided a TSS removal efficiency of 75% (as per NJDEP treatment efficiency calculation methodology) of simulated stormwater runoff with an average influent concentration of 295 mg/L and average d_{50} particle size of 97 µm where the PSD ranged from 1 to 1000 µm. TSS removal testing was conducted with an initial sediment loading of 50% of the sediment capacity in the lower chamber. The test demonstrated that the an internal bypass feature of the STC 900 unit prevents the re-suspension of previously captured material when the lower chamber contains up to 100% of the sediment capacity.

REFERENCES

New Jersey Department of Environmental Protection (NJDEP) 2003. Total Suspended Solids Laboratory Testing Procedure (Draft), New Jersey Department of Environmental Protection, New Jersey.

DOCUMENT CONTROL
10-06-2005 PT