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High-Rate Stormwater Treatment with Up-Flow Filtration

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The objective of this research is to examine the removal capacities of a high-rate stormwater filtration device, in part developed by engineers at the University of Alabama through a Small Business Innovative Research grant from the U.S. Environmental Protection Agency. The Up-Flo Filter is an efficient high-rate stormwater filtration technology designed for the removal of trash, sediments, nutrients, metals and hydrocarbons from stormwater runoff. Compared with traditional downflow filtration treatment, upflow filtration can minimize clogging problems while providing a high rate of flow. The Up-Flo filter was developed to remove a broad range of stormwater pollutants, especially those associated with particulates. The high flow rate capacities of the Up-Flo filter are accomplished through controlled fluidization of the filtration media, while still capturing very small particulates, that is located in a flexible, but constraining, media container. The Up-Flo filter also drains down between rain events which minimizes anaerobic conditions in the media and which also partially flushes captured particulates from the media to the storage sump, decreasing clogging and increasing run times between maintenance. Gross floatables are captured through the use of an angled screen before the media and a hood on the over-flow siphon, while the sump captures bed load particulates.

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1.1 Introduction

Many types of stormwater controls are available, but most are relatively large or insufficient in their treatment capacity for a range of sediment sizes. Adequate treatment of runoff requires the removal of many types of pollutants, as well as large amounts of debris and floatable materials, over a wide range of flows. Traditional downflow filters, which can provide high levels of treatment, can quickly clog, which reduces their treatment flow rate and overall treatment capacity (Urbonas, 1999). They also usually operate at a low treatment flow rate requiring a large area to treat substantial portions of the runoff from a site. The Up-Flo filter is designed to treat stormwater runoff from critical source areas that discharge especially high levels of pollutants. The commercialized Up-Flo filter minimizes clogging and was developed to remove a broad range of stormwater pollutants at a relatively high rate, and can be easily retrofitted into existing stormwater drainage. This chapter presents the results from a controlled full-scale field evaluation located at a parking lot in Tuscaloosa, Alabama. Treatment flow rates, particle size controls, and suspended solid concentration reductions will be stressed in this presentation.

1.2 Location and Size of Filter

A 2.1 m (7 ft) tall, 1.2 m (4 ft) diameter standard inlet containing a six module Up-Flo Filter has been installed at the Riverwalk parking lot near the riverboat Bama Belle on the Black Warrior River in Tuscaloosa, Alabama. The chamber is a conventional concrete manhole with a sump, with the Up-Flo filter components installed. The filter receives surface runoff from a parking lot, road, sidewalks, and a small landscaped area, as shown in Table 1.1. The total drainage area tributary to the device is approximately 3590 m^2 (0.9 acres). Figure 1.1 shows the drainage area and the location of the test site.

Table 1.1 Drainage area land use.

Land Use	Area (m^2)	% of Land Use
Parking Area	1100	30.5
Other Paved	121	3.4
Side Walks	194	5.4
Entrance Road	1020	28. 5
Green Space	1160	32.2
Total	3590	100.0

Figure 1.1 Site map and drainage area.

1.3 Description of Filter

The full-scale filter system (having a full complement of 6 filter modules) was installed and is being tested to confirm the initial pilot-scale test results under actual rain conditions. Hydraulic capacity and pollutant removal capabilities in the full-scale field installation are being monitored under both controlled and actual runoff conditions. Figure 1.2 shows the main features of the Up-Flo filter, while Figure 1.3 shows the installation of the full-scale test filter at Tuscaloosa. Depending on the selected media, the filtration treatment flow rate varies from 205 L/min/m^2 to 1020 L/min/m^2 (5 to 25 gal/min/ft^2). With 6 modules, each having about 0.09 m^2 (1 ft^2) of filter surface, the total treatment flow rate for this installation is expected to be at least 380 L/min (100 gal/min). Figure 1.4 shows the treatment flow rate requirements for typical southeastern US conditions, based on continuous simulations (Pitt and Khambhammettu 2006). The 380 L/min (100 gal/min) for the test site is expected to treat about 90% of the annual flow for a typical rain year, with about 10% of the annual flow bypassing filtration.

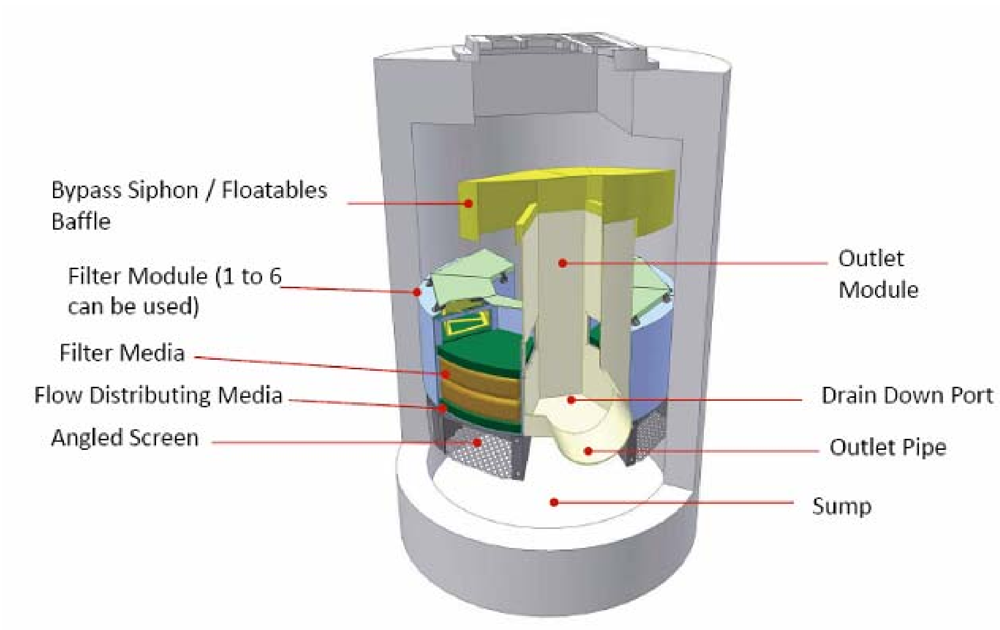

Figure 1.2 Up-Flo Filter components (drawing from Hydro International).

Figure 1.3 Installation of Tuscaloosa Up-Flo Filter.

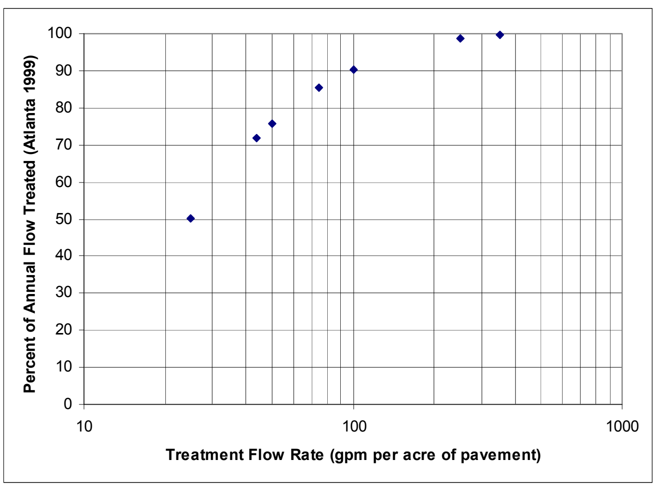

Figure 1.4 Treatment flow rate requirements for southeast US paved conditions (example shown for continuous simulation results for Atlanta, Georgia).

1.4 Controlled Flow Test and Controlled Particle Capture Test

This section describes the initial controlled performance monitoring that was conducted at the Riverwalk parking lot near the Bama Belle in Tuscaloosa, Alabama. The first flow test was conducted for the purpose of determining the hydraulic capacity and the pollutant removal capabilities in a full-scale field installation under controlled conditions. In the test, the filtration rate of the CPZ Mix filter medium, a proprietary mixture of bone char activated carbon, peat moss, and manganese-coated zeolite was evaluated. Based on results of prior lab scale testing, the mixed medium is expected to have high pollutant removal at relatively high filtration rates (Clark and Pitt 1999). The Up-Flo Filter was fitted with two media bags in each of the 6 chambers, for a total of 12 bags, as well as the flow distribution material placed above and below the media bags.

1.5 Methodology for the Evaluation of Filtration Rate

Flow tests were conducted in the field with the cooperation of the Tuscaloosa Department of Transportation by using a pump to deliver Black Warrior River water to a flow splitter/flow controlling barrel. The water flow rate was measured by recording the time needed to fill a known volume (Figure 1.5). When the rate was established, the volume tray was removed, directing the known and steady flow to the gutter immediately above the Up-Flo intake. For each flow rate, measurements were taken of the steady-state water depth in the filter and the reported flow rate from the area-velocity sensor that was used to monitor the flow during rain events. The measurements were repeated 5 times for each flow to reduce the errors. Figure 1.6 shows a flow vs. head graph developed during these tests.

Figure 1.5 Pumped river water is discharged from splitter barrel to the 42 L (11 gal) plastic tray.

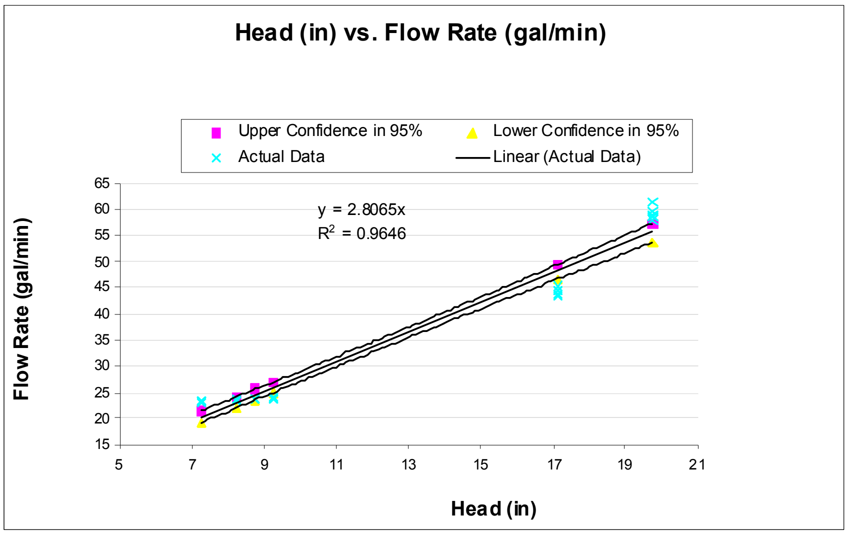

Figure 1.6 Example of a flow vs. head graph for mixed media filters, showing repeatable measurements.

1.6 Particle Size Distribution of Tested Media and Test Sediment

The test sediment in the stormwater simulation used a mixture of SIL-CO-SIL 250, SIL-CO-SIL 106 (both from U.S. Silica Co.), and coarse and fine concrete sands. The mixture was made by mixing the four components in specific ratios to obtain a relatively even particle size distribution representing the complete range from about 20 to 2,000 µm. This mixture was not intended to represent actual stormwater (which usually has a smaller median particle size), but to ensure sufficient amounts of large particles so they could be accurately monitored to quantify their removal. As shown later, all of the results of these controlled tests were presented based on many narrow particle size ranges so they could be applied to any expected particle size distribution of the flowing water. Since the samples were all analyzed using sieves and a Coulter Counter, the results are much more useful than if total "event" SSC (suspended sediment concentration) analyses alone were conducted representing all sizes combined. If a single analysis was conducted, then the particle size distribution (PSD) of the challenge water would have to match the stormwater PSD, a difficult objective given the highly variable particle size characteristics of stormwater, and the results could not be easily extrapolated to other PSD conditions. Figure 1.7 shows the particle size distributions of two of the test mixtures that were used during the tests.

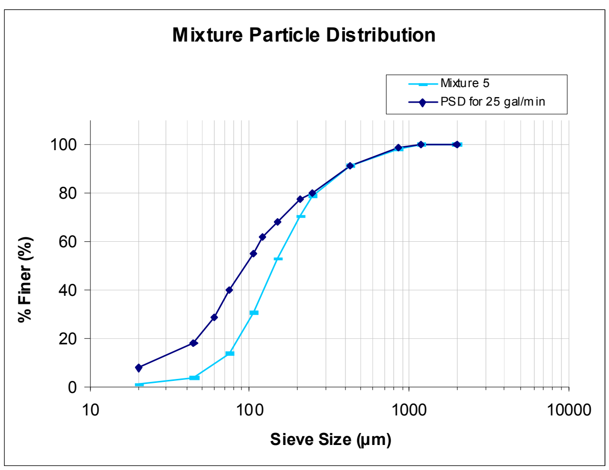

Figure 1.7 Particle size distribution of mixture used for the flow test.

1.7 Test Methodology for Controlled Sediment Capture Tests

The tests described below used several known concentrations of particulate solids over a wide range of particle sizes and an influent flow rate that averaged 91 L/min (24 gal/min) (having a standard deviation of 0.3 gal/min). Each experiment was conducted for 30 minutes, during which time measured aliquots of the dry sediment were constantly poured into the pumped influent “river flow” from the Black Warrior River. River water was also collected before any sediment was added to measure the background solids in the test water to determine the background conditions. Effluent samples were collected using a dipper grab sampler every 1 minute and composited in a churn sample splitter during the 30 minutes test period. The effluent was sampled at a completely mixed cascading flow exiting the filter in a specially constructed sampling chamber. Using the churn splitter, two samples of 1000 mL each were placed in sample bottles for duplicate laboratory PSD and SSC analyses for each test.

In preparation for the tests, test sediment portions were pre-weighed in 50 mL polyethylene bottles. The sediment was manually fed into the influent water over the whole period of each experiment, according to the desired particulate solids concentration for the specific flow rate for each test (Figure 1.8). This method ensured that all of the sediment and all particle sizes entered the test chamber. Depth readings of the water levels were also taken during each experiment to determine the head loss during the Up-Flo Filter operation. Also, after completion of each experiment, additional multiple flow and depth readings were taken to determine the final flow rate and available head to detect any change in filtration rate during the test. During these tests, four different influent sediment concentrations were tested: 50 mg/L, 100 mg/L, 250 mg/L and 500 mg/L. Later tests also examined other flow rates and other treatment media.

Figure 1.8 Sediment mixture was manually and consistently added to the Influent water over the 30 minutes test period.

1.8 Initial Controlled Test Result of Filter

Controlled tests can measure the filter behavior under known conditions. Mixtures of ground silica available from U.S. Silica Co. were used for these initial tests, reflecting filter performance for a variety of particle sizes. Figures 1.9 to 1.18 show the influent and effluent concentrations during tests using 50 to 500 mg/L influent conditions. Further controlled tests are being conducted, along with measurements conducted during actual rain conditions. Tables 1.2 and 1.3 summarize the average influent and effluent concentrations, along with the percentage reductions for 100 and 500 mg/L influent conditions (including river water additions). Table 1.4 shows the average influent and effluent concentration of total dissolved solids (TDS) concentrations.

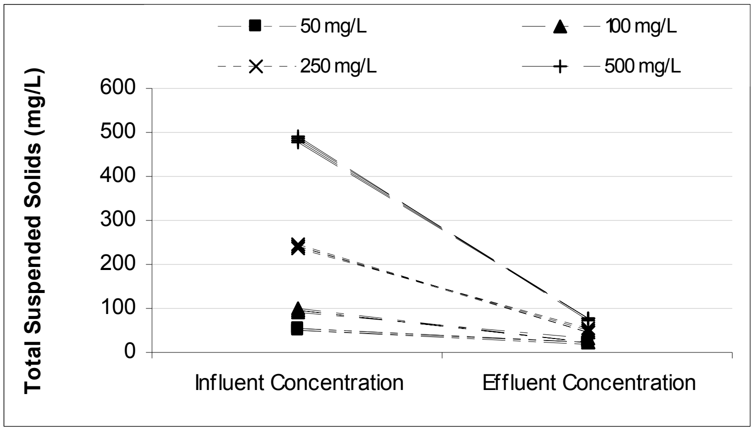

Figure 1.9 Performance Plot for Mixed Media on Total Suspended Solids for 25 gallon/min Flow Rate.

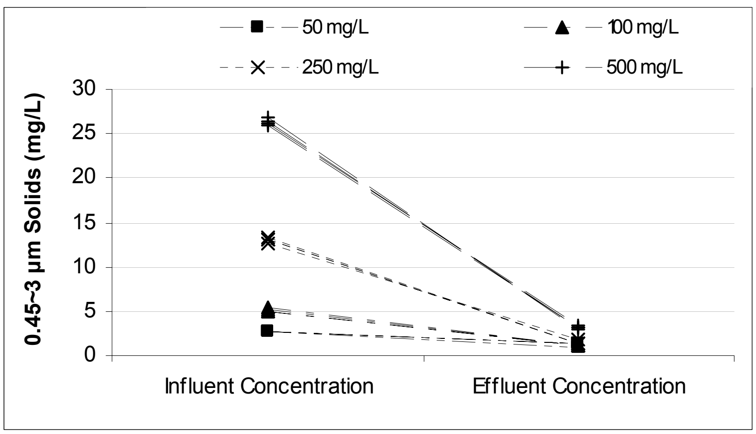

Figure 1.10 Performance Plot for Mixed Media on 0.45~3 µm Particulate Solids for 25 gallon/min Flow Rate.

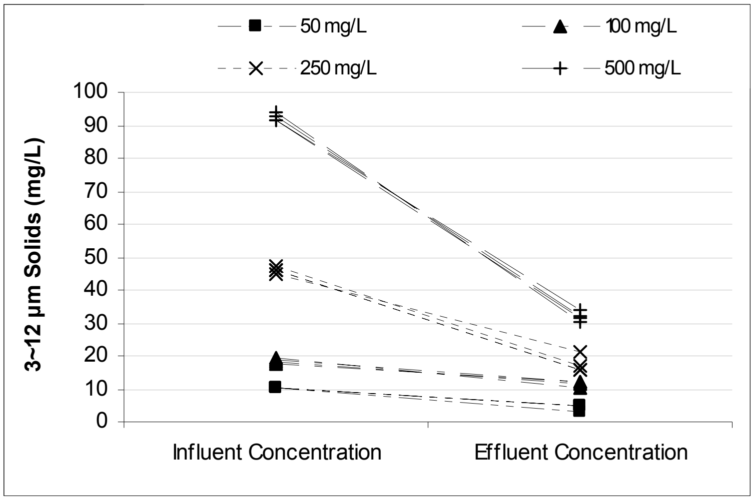

Figure 1.11 Performance Plot for Mixed Media on 3~12 µm Particulate Solids for 25 gallon/min Flow Rate.

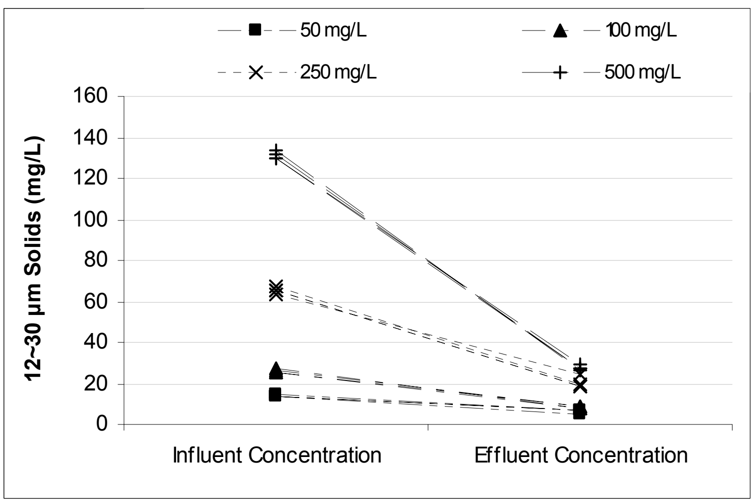

Figure 1.12 Performance Plot for Mixed Media on 12~30 µm Particulate Solids for 25 gallon/min Flow Rate.

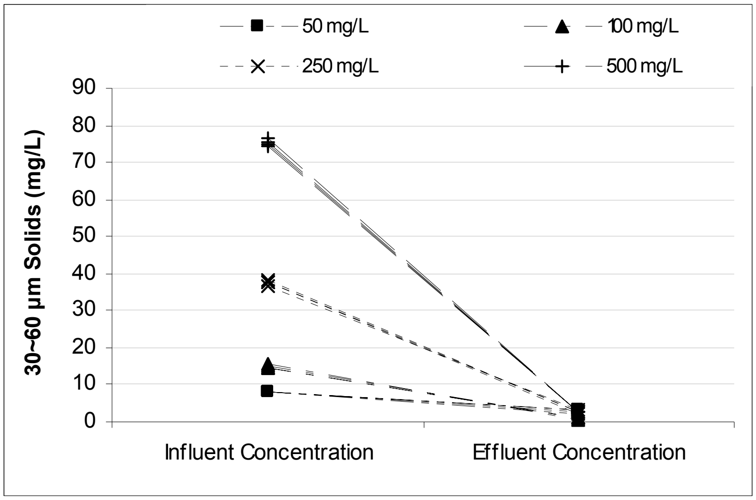

Figure 1.13 Performance Plot for Mixed Media on 30~60 µm Particulate Solids for 25 gallon/min Flow Rate.

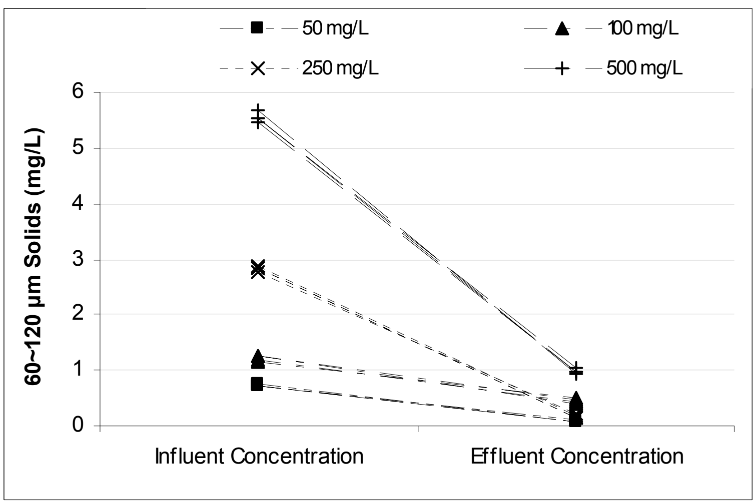

Figure 1.14 Performance Plot for Mixed Media on 60~120 µm Particulate Solids for 25 gallon/min Flow Rate.

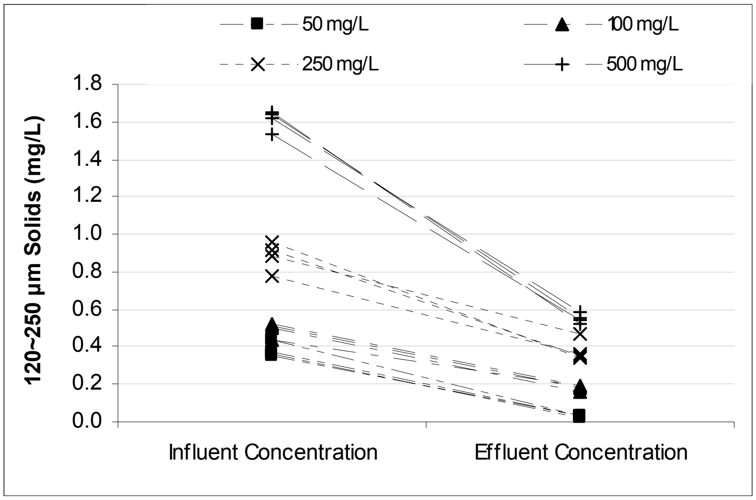

Figure 1.15 Performance Plot for Mixed Media on 120~250 µm Particulate Solids for 25 gallon/min Flow Rate.

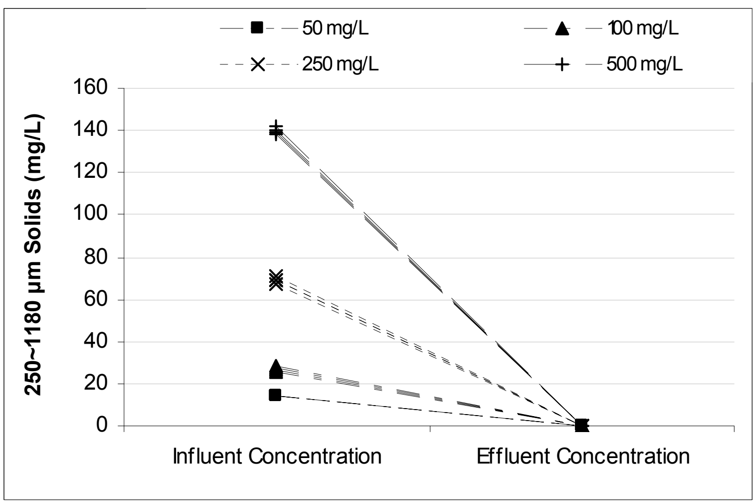

Figure 1.16 Performance Plot for Mixed Media on 250~1180 µm Particulate Solids for 25 gallon/min Flow Rate.

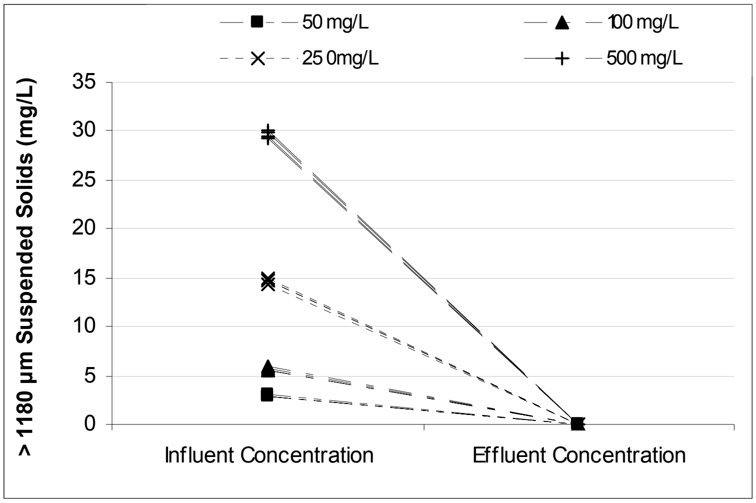

Figure 1.17 Performance Plot for Mixed Media on > 1180 µm Particulate Solids for 25 gallon/min Flow Rate.

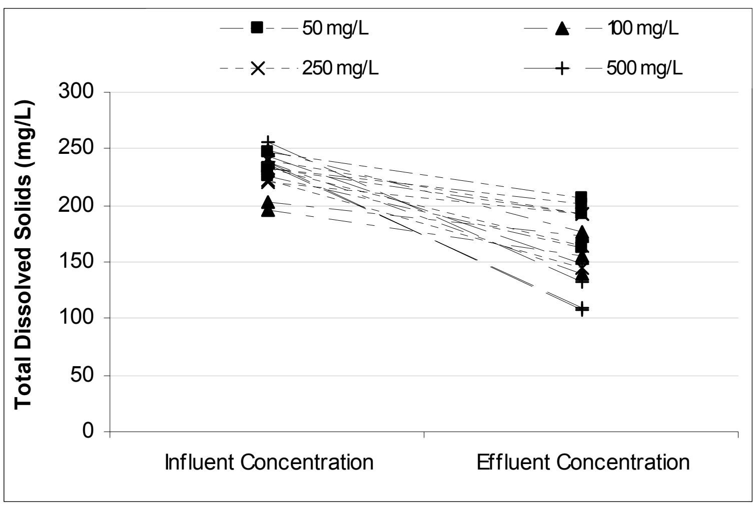

Figure 1.18 Performance Plot for Mixed Media on Total Dissolved Solids for 25 gallon/min Flow Rate.

Table 1.2 Average influent and effluent concentration for 25 gal/min and 100 mg/L concentration.

Particle Size (µm)	Average Influent Concentration (mg/L)	Average Effluent Concentration (mg/L)	Average Reduction (%)
< 0.45	220	160	27
0.45 to 3	5.2	1.1	78
3 to 12	19	11	38
12 to 30	26	8.3	68
30 to 120	16	1.3	92
120 to 1180	28	0.18	99
> 1180	5.7	0	100
sum >0.45 µm	99	21.9	78

Table 1.3 Average influent and effluent concentration for 25 gal/min and 500 mg/L concentration.

Particle Size (µm)	Average Influent Concentration (mg/L)	Average Effluent Concentration (mg/L)	Average Reduction (%)
< 0.45	240	120	49
0.45 to 3	26	3.2	88
3 to 12	92	32	65
12 to 30	130	28	79
30 to 120	81	3.9	95
120 to 1180	142	0.55	100
> 1180	30	0	100
sum >0.45 µm	500	67.7	86

Table 1.4 Average influent and effluent concentration for 25 gal/min and total dissolved solids.

Test (SSC Concent.)	Average Influent TDS Concent. (mg/L)	Average Effluent TDS Concent. (mg/L)	Average Reduction (%)	Maximum Reduction (%)	Minimum Reduction (%)
50	230	190	19	28	13
100	220	160	27	42	15
250	230	170	25	35	13
500	240	120	49	55	39

1.9 Conclusion

The Up-Flo filter is an efficient high-rate filtration device designed for the treatment of stormwater runoff from critical source areas. In this chapter, the hydraulic capacity and the particulate removal capabilities under controlled conditions are examined.

During the controlled sediment tests of the full-sized treatment system, 90 to 100% of the particles larger than 30 µm, and from 40 to 90% of the smaller particles were captured, irrespective of the influent concentrations. These are similar results to those observed during the prior pilot-scale tests during actual rains (Pitt and Khambhammettu 2006). During the tests having about 100 mg/L influent SSC, the effluent averaged about 20 mg/L, with removal rates of about 80%. During tests using 500 mg/L SSC influent, the effluent averaged about 65 mg/L, with about 85% removal rates. During these initial tests, the treatment flow rates vs. head were very repeatable, with maximum flows being about 55 gal/min with 20 inches of head with the tested media mixture. Later tests examined treatment flow rates greater than 100 gpm with similar particulate removal results.

Additional controlled tests have been conducted using other media, SSC concentrations, and flow rates, but the results are not available to present in this paper. In the future, pollutant removal including sediment, particle sizes, metals, nutrients, and bacteria will be tested during actual storm events.

References

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