Performance of Upflow Filtration for Treating Stormwater

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Abstract

One approach to the treatment of urban runoff is to treat the runoff from critical source areas before it mixes with runoff from less pollutant areas. Some of the general features of critical source areas appear to be large paved areas, heavy vehicular traffic, and/or exposed heavy equipment, materials or products. The control of runoff from relatively small critical source areas (such as loading docks, fueling areas, small maintenance yards, etc.) may be the most cost effective approach for the treatment/reduction of stormwater toxicants. However, in order for a treatment device to be usable, it must be inexpensive, both to purchase and to maintain, and be effective.

Upflow filtration of stormwater was tested during both controlled tests, and under actual rainfall conditions, during SBIR1 (Small Business Innovative Research) and SBIR2 research funded by the US EPA. This paper summarizes the work presented by Pitt, *et al.* (2005) and Khambhammettu (2006). Upflow filtration was originally developed to overcome some of the problems associated with conventional filtration. The most serious problem is that downflow filters clog relatively quickly, reducing the treatment flow rate potential and total treatment capacity, potentially causing large amounts of the stormwater to bypass the treatment units. Clogging does not occur as fast with upflow filtration. One reason is that the heavier particles get drawn away from the filtration interface due to gravity and fall into the sump which is an integral part of the upflow filter design. Figure 1 is a schematic of the UpFlow™ filter, showing the treatment and bypass flow paths.

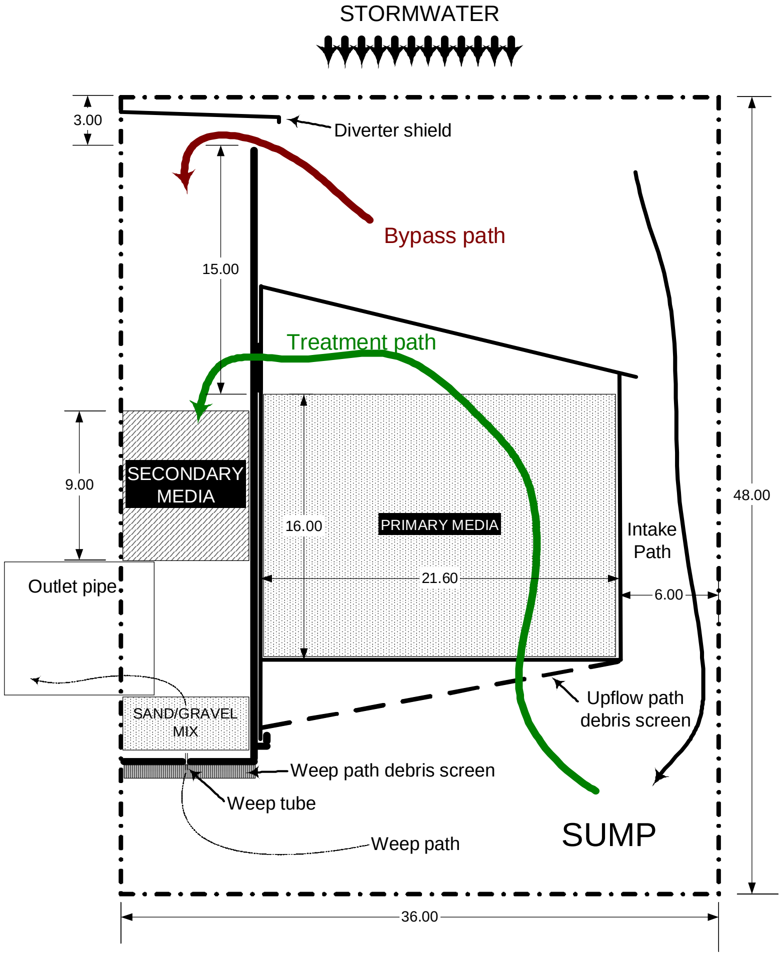

Figure 1. Side view of UpFlow™ filter.

Controlled Flow Tests

The maximum flow capacities for each media were determined using calibrated flows. The controlled tests were then conducted at high, medium and low flow rates (full flow, ½, and ¼ of the maximum flow rates) with varied influent sediment concentrations (500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L). Flow tests were conducted in the field with the cooperation of the Tuscaloosa Water Department by using a fire hose connected to a fire hydrant adjacent to the test site. The flows were measured using their calibrated meter, and also checked at the test rates by timing the filling of large containers. Maximum flow rates of about 30 GPM (1700 m/day) were obtained during the tests, for a filter area of about 1.5 ft^2. Figure 2 shows how the flows varied for different hydraulic heads over the media.

The sediment in the stormwater stimulant was based on the following mixture: Sil-Co-Sil 250, Sil-Co-Sil 106 (both from the U.S. Silica Co.), coarse sand, and fine sand. The mixture was made by using equal weight fractions of each of the four components. The test sediment particle size ranged from 0.45 µm to 2,000 µm.

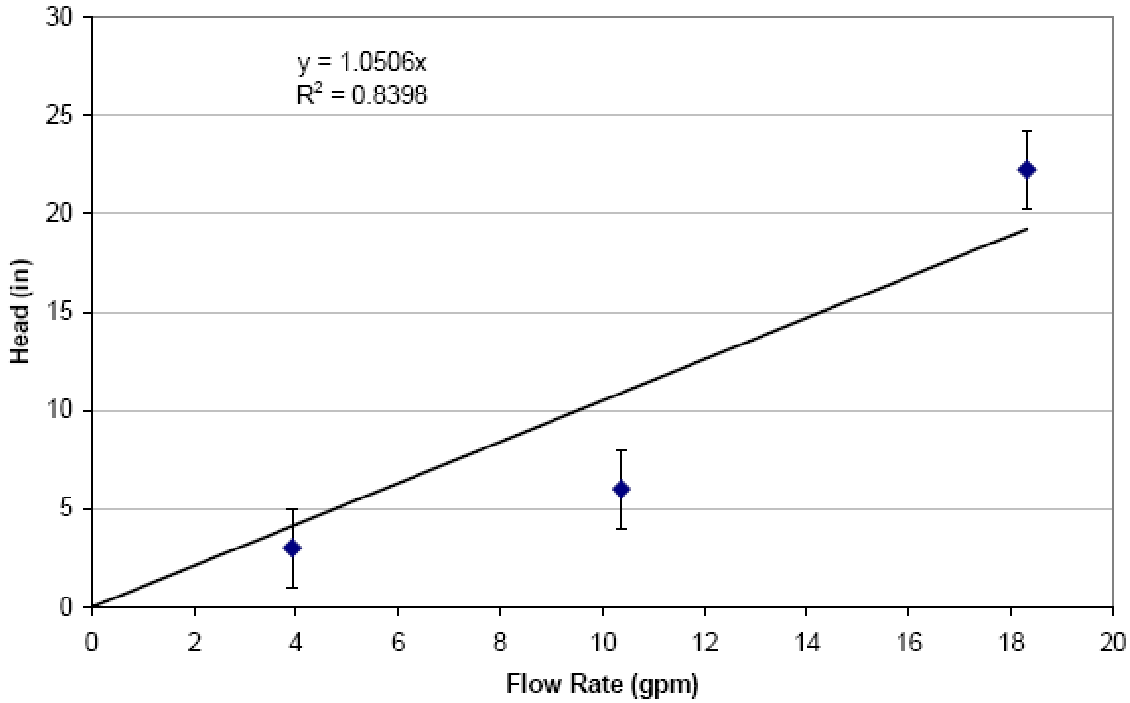

Figure 2. Flow characteristics for tested media.

A total of 21 separate controlled experiments were conducted resulting in the collection of 84 samples, including the blank samples for each experiment. Total solids, suspended solids, total dissolved solids (by difference), and particle size distribution (PSD) analyses were carried out for each sample and its duplicate. Therefore, the total number of samples analyzed during the controlled tests was 168. Before conducting the analyses, each sample was split into 10 equal volumes of 100 mL each using a Decaport/USGS cone splitter. These split subsamples were analyzed for total solids, suspended solids, and PSD.

Figures 3 and 4 are representative data plots from the controlled tests. Figure 3 shows the particle size distribution plots for the influent test mixture, and the measured effluent particle size distributions. Very few particles larger than 30 µm were found in the effluent. Also, influent concentration and flow rate had little effect on the effluent particle size distributions.

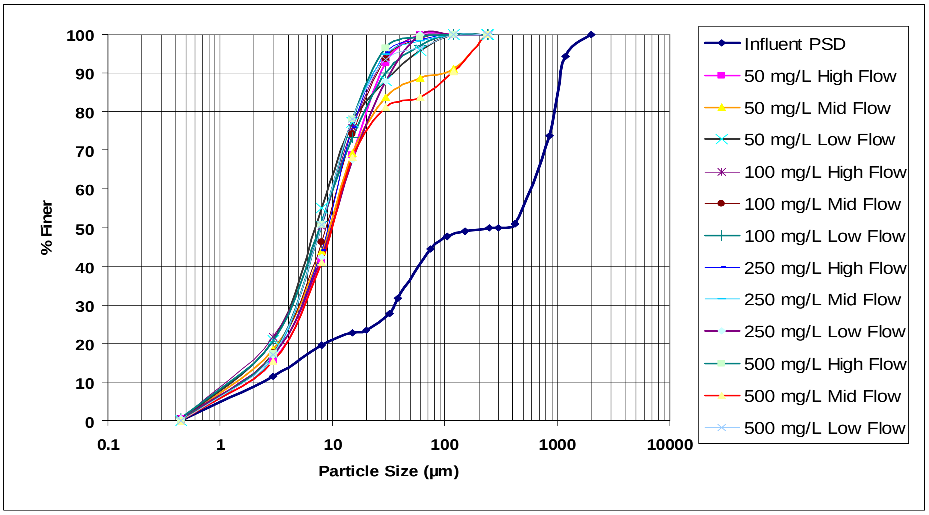

Figure 3. Performance plot of particle size distribution for mixed media

Figure 4 indicates some very small improved levels of performance for lower flows at each concentration tested. The effluent concentrations were also about the same, but the lowest effluent concentrations were associated with the lowest concentration, lowest flow tests.

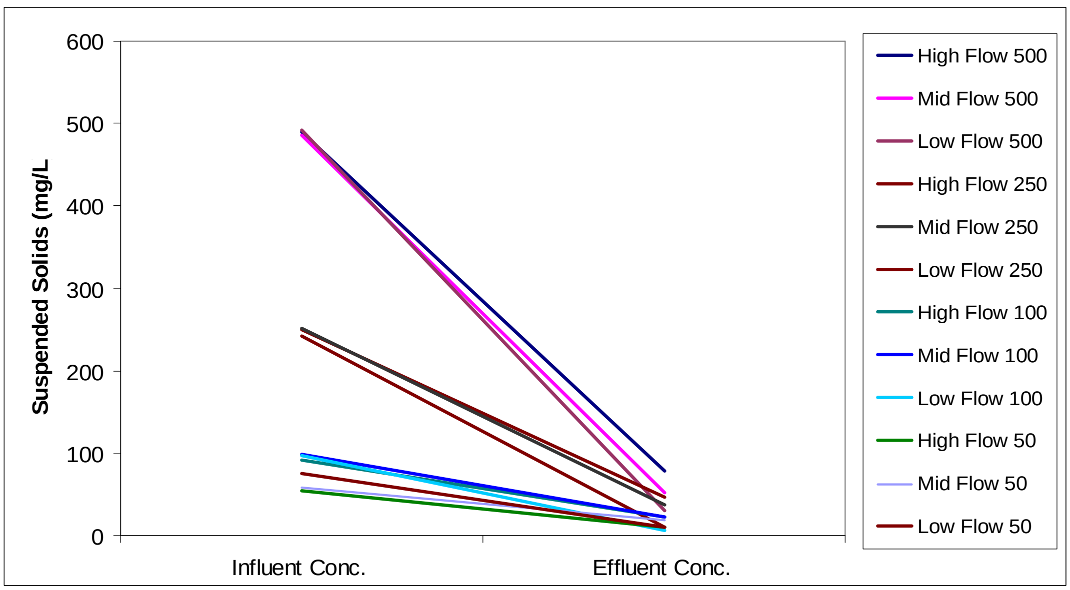

Figure 4. Performance plot for mixed media for suspended solids at influent concentrations of 500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L.

Overall suspended solids removal efficiencies of 85 to 90% were observed for all of the controlled tests. As shown on Table 1, the larger particles were removed most effectively, as expected. The removals of the 0.45 to 30 µm particles were about 50%, while the removals of particles larger than 30 µm were 95 to 100%. The 0.45 to 30 µm particle sizes indicated some irreducible concentration effects, below which no further removals were observed.

Table 1. High Flow Rate (20 gpm/ft^2) Controlled Test Results

Size Range (µm)	Effluent quality (y = effluent concentration; x = influent concentration, both in mg/L of particulate solids in designated size range)	Approx. irreducible concentration in size range (mg/L)
0.0 to 0.45 (TDS)	y = x	na
0.45 to 3	y = 0.6057x + 1.2409	2.0
3 to 12	y = 0.6371x + 0.5216	1.4
12 to 30	y = 0.6279x + 1.5312	4.1
30 to 60	y = 0.0414x	0
60 to 120	y = 0.0154x	0
120 to 240	y = 0	0
>240	y = 0	0

Evaluations during Actual Rains

From March through December, 2005, a total 24 pairs of inlet and outlet samples were also collected during 10 different storm events. Sampling at the test site was conducted using two ISCO 6712 automatic samplers. The flow rates were determined using two ISCO 4250 area-velocity meters which also measured the stage both in the influent sump (the catchbasin sump) and in the effluent pipe. The rainfall intensity and amount was measured using a standard tipping bucket rain gauge. A small totalizing rain gauge was also used as a cross check. YSI 6600 water quality sondes were used to measure the real time water quality data (temperature, dissolved oxygen, pH, ORP, turbidity, conductivity, and water depth) of the influent and the effluent flows at 1minute intervals during storm flows and at 5 minute intervals during interevent periods. The samples were evaluated for total solids, suspended solids, E. coli, total coliforms, nitrates, phosphorus, COD, heavy metals (focusing on copper, lead, and zinc), and particle size distributions.

Once the appropriate samples were selected for analyses, the samples were divided using a Dekaport/USGS cone splitter (Rickly Hydrological Company). A minimum sample volume of 400 mL was required to conduct the analyses. All the constituents were measured for both corresponding influent and effluent samples.

The following Tables 2 and 3 and Figures through 10 summarize the performance of the UpFlow™ filter during the actual monitored storms for suspended solids. Similar analyses were conducted for the other pollutants, and for each particle size range. This set of illustrations presents a comprehensive review of the performance of the filter. Simple statements concerning the percentage control, for example, are inaccurate, as that indicator of performance is highly dependent on the influent concentrations.

Table 2. Observed Suspended Solids Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	Sample Number	Influent (mg/L)	Effluent (mg/L)
1-1	17	4	6-4	17	3
2-1	53	36	6-5	21	3
2-2	50	37	7-1	83	36
3-1	6	0	7-2	43	30
3-2	3	1	7-3	29	33
4-1	1	0	7-4	23	6
4-2	1	0	7-5	5	2
5-1	80	37	7-6	4	4
5-2	15	17	8-1	913	150
6-1	5	6	8-2	41	18
6-2	11	8	9-1	29	2
6-3	15	13	10-1	72	17

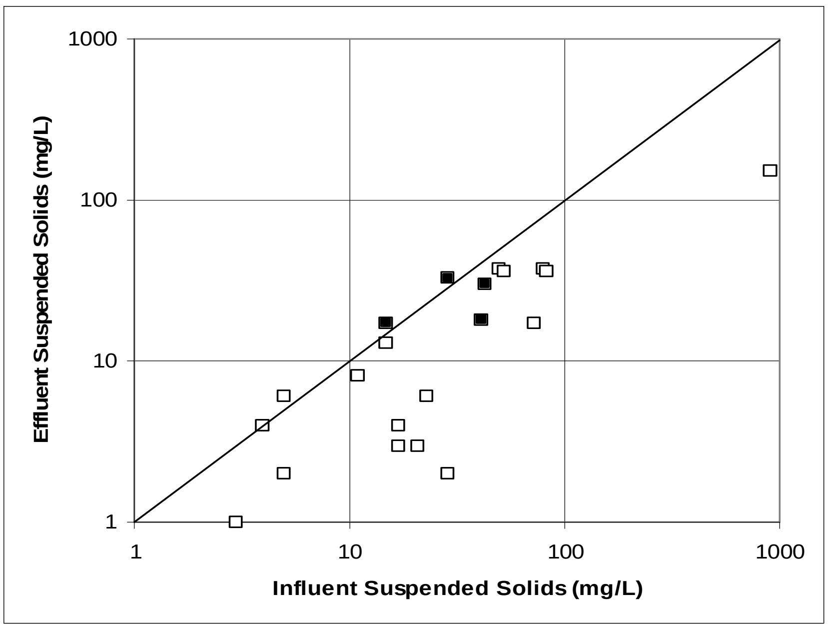

Figure 5. Scatterplot of observed influent and effluent suspended solids concentrations (filled in symbols indicated events that had minor bypass around filter).

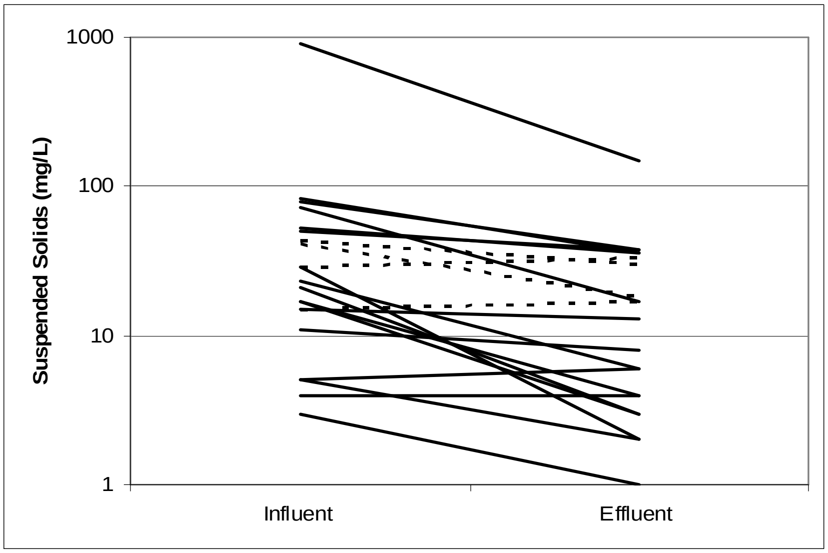

Figure 6. Paired influent and effluent suspended solids concentrations.

Fitted Equation:

Effluent Suspended Solids, log mg/L = 0.730 * (Influent Suspended Solids, log mg/L)

Table 3. Regression Statistics on Observed Influent vs. Effluent Suspended Solids, log mg/L

Multiple R	0.94
R Square	0.89
Adjusted R Square	0.85
Standard Error	0.37
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	25.4	25.4	187	3.11E-12
Residual	23	3.12	0.136		
Total	24	28.55			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
X Variable 1*	0.730	0.053	13.7	1.56E-12	0.620	0.841

* The intercept term was determined to be not significant

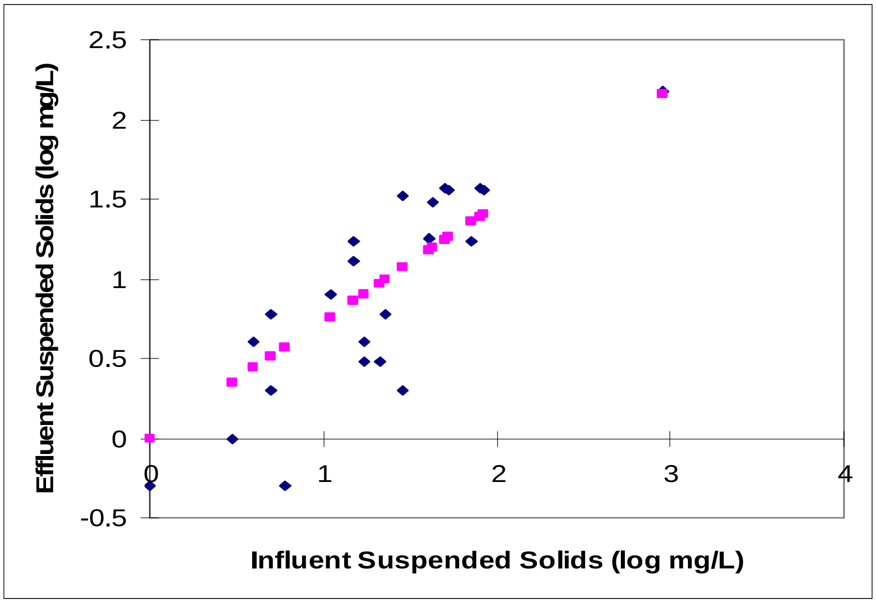

Figure 7. Fitted equation and data points for influent and effluent suspended solids.

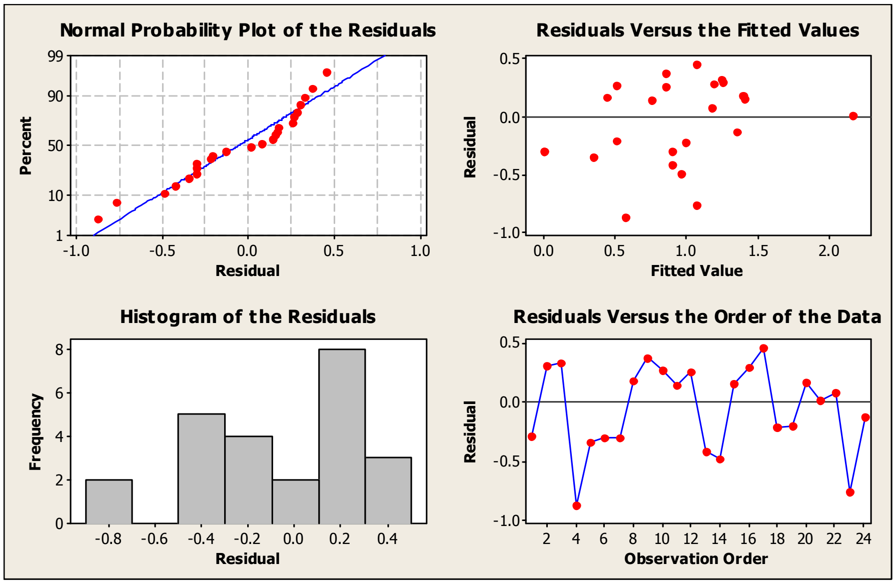

Figure 8. Residual analyses of fitted equation for suspended solids influent vs. effluent.

As expected, the upflow filter performance followed traditional patterns, with greater percentage reductions as the influent concentration increased (Figure 10). However, effluent quality is likely a more important consideration for many analyses, as shown in Figure 9. The effluent suspended solids was found to be less than 30 mg/L for all influent SS concentrations less than about 100 mg/L, and the effluent SS was less than 100 mg/L when the influent was less than about 600 mg/L. The measured percentage reductions for SS was found to be greater than 70%, when influent concentrations were greater than 90 mg/L.

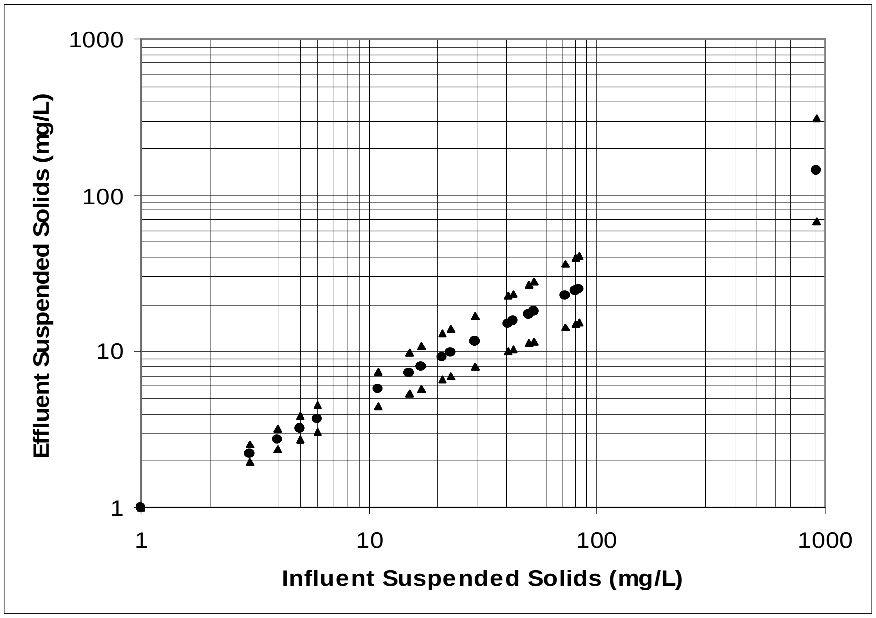

Figure 9. Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.

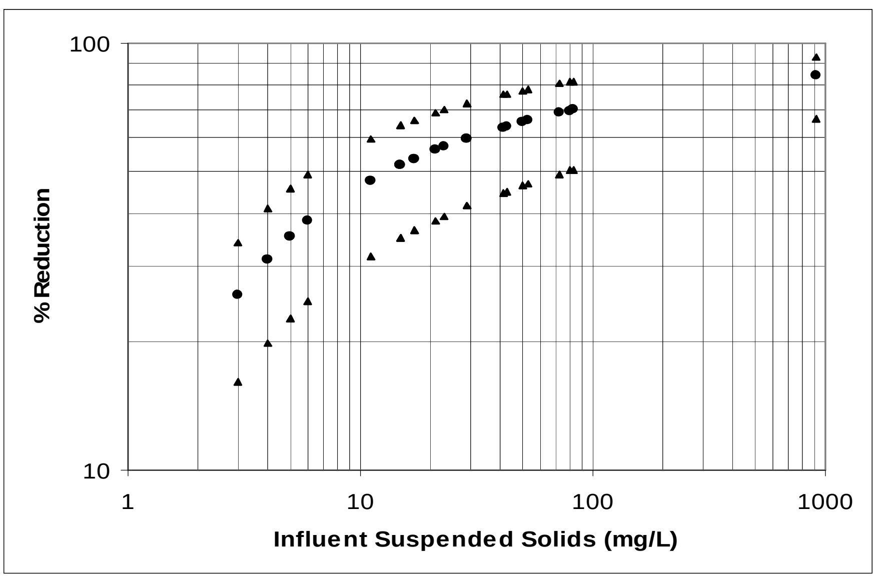

Figure 10. Percentage reductions as a function of influent concentrations, with 95% confidence limits.

Conclusions

As expected, the UpFlow™ filter is most effective in reducing pollutants mostly associated with particulate matter and less effective for dissolved constituents. The following table summarizes the overall performance of the UpFlow^{TM} filter for the 24 sets of samples evaluated:

Table 4. Summary of UpFlow^{TM} filter actual storm event monitoring results

	Average influent concentration (all mg/L, except for bacteria that are #/100 mL and turbidity that is NTU) (and COV)	Average effluent concentration (all mg/L, except for bacteria that are #/100 mL and turbidity that is NTU) (and COV)	Probability that influent ≠ effluent (nonparametric sign test) (significant reduction at 95% level?)
Turbidity	41 (2.5)	15 (1.4)	>99% (significant reduction)
Suspended solids	64 (2.9)	19 (1.6)	>99% (significant reduction)
Total solids	137 (1.7)	94 (1.2)	>99% (significant reduction)
Ammonia	0.44 (1.47)	0.24 (1.30)	97% (significant reduction)
E. coli	4,750 (0.8)	2,710 (0.8)	>99% (significant reduction)
Total coliforms	12,600 (1.0)	6,700 (0.7)	>99% (significant reduction)

Acknowledgements

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