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FULL SCALE EVALUATION OF THE UPFLO^{TM} FILTER - A CATCHBASIN INSERT FOR THE TREATMENT OF STORMWATER AT CRITICAL SOURCE AREAS

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ABSTRACT

Stormwater runoff from critical source areas, such as parking lots, vehicle fueling and maintenance stations, and public works storage areas, may contain pollutant loadings of hydrocarbons, toxic trace metals, nutrients, pathogens, and/or other toxicants and pollutants that are greater than the loadings of "normal" stormwater runoff (Bannerman, *et al*. 1993; Pitt, *et al*. 1995; Claytor and Schueler 1996). One alternative to end-of- pipe treatment for stormwater runoff is to treat the more contaminated runoff from problem sources before this runoff mixes with the runoff from other areas (Bannerman, *et al*. 1993; Pitt, *et al*. 1995; Claytor and Schueler 1996). Critical source area treatment devices need to incorporate a variety of treatment processes that can be targeted for different classes of pollutants of concern and to respond to the variability of stormwater quality conditions that can originate from different types of critical source areas (Pitt, *et al*. 1999). This paper will describe one such device, the UpFlo^{TM} Filter that has undergone development and testing under the EPA's SBIR and ETV programs.

KEYWORDS

Stormwater, upflow, treatment, critical source areas.

INTRODUCTION

There are many stormwater control practices, but all are not suitable in every situation. It is important to understand which controls are suitable for the site conditions and can also achieve the required goals. This will assist in the realistic evaluation for each practice of: technical feasibility, implementation costs, and long-term maintenance requirements and costs. It is also important to appreciate that the reliability and performance of many of these controls have not been well established, with most still in the development stage. This is not to say that emerging controls cannot be effective, however, they do not have a large amount of historical data on which to base designs or to be confident that performance criteria will be met under the local conditions. The most promising and best understood stormwater control practices are wet detention ponds. Less reliable in terms of predicting performance but showing promise, are stormwater filters, wetlands and percolation basins. Grass swales also have shown great promise during the EPA's Nationalwide Urban Runoff Program (NURP) and during more recent research (EPA 1983; Nara 2005).

Most stormwater needs to be treated to prevent harm either to the surface waters or the groundwaters. One approach is to treat the runoff from critical source areas before it mixes with the runoff from less contaminated areas. Some features of critical source areas include large paved areas, heavy vehicular traffic, and outdoor use or storage of problem contaminants or heavy equipment. The control of runoff from relatively small critical source areas may be the most cost effective approach for 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 effective. Outfall stormwater controls, being located at the outfalls of storm drainage systems, treat all the flows that originate from the watershed. The level of treatment provided, of course, is greatly dependent on many decisions concerning the design of the treatment devices. Source area controls are, of course, physically smaller than outfall controls, and are therefore generally easier to use on a crowded site, but there could be a large number of them located in a watershed. In all cases, questions must be answered about the appropriate level of control that should be provided, and what stormwater control devices should be used.

The first concern when investigating alternative treatment methods is determining the needed level of stormwater control. This determination has a great affect on the cost of the stormwater management program and needs to be carefully made. Problems that need to be reduced range from sewerage maintenance issues to protecting many receiving water uses. Many treatment objectives may need to be examined for a number of source area or ourfall treatment practices. Large levels of stormwater control are likely needed to prevent excessive receiving water degradation through hydromodifications and pollutant discharges. Numeric treatment goals usually specify about 80% reductions in suspended solids concentrations (Hans de Bruijn, *et al*. 2003). In most stormwaters, this would require the removal of most particulates greater than about 10 μm in diameter, about 1% of the 1mm size needed for removal to prevent sewerage deposition problems (Pitt, *et al*. 2005). Obviously, the selection of treatment goals must be done with great care, as large differences in costs can occur.

Upflow filtration, which is the chosen treatment technology for this research, has shown promising results. (See the "Future Research" section of Clark 2000). Extensive research on flow type and potential suitable media for downflow filtration has been carried out by Clark and Pitt (1999) and Clark (2000). But such information is not available for upflow filtration. Pratap (2003) and Gill (2004), further studied and analyzed upflow filtration at a lab scale and evaluated several media for potential treatment effectiveness. The primary objective of this research, funded by SBIRI and SBIR2 research by the US EPA, was to develop and test a full scale upflow filter.

Upflow filtration was selected for this research due to the following drawbacks of downflow filtration:

1. Downflow filters clog at a relatively fast rate, reducing their flow rate potential and treatment capacity. Earlier research on the effects of clogging on the flow rate through sand and mixed media filters has shown that the flow rate of the water through a downflow filter is dependent on the suspended solids loading on the media (Urbonas 1999 and Clark 2000). Clogging does not occur as fast in upflow filtration;the reason being, heavier particles get drawn away from the filtration interface due to gravity and fall into the sump which is an integral part of UpFlo^{TM} filter design.

2. The clogging problem leads to frequent maintenance of a downflow filter which is needed for long-term operation. In locations where the filter is receiving large suspended solids loadings, the filter has to be sized large enough to have a long filter run period before needed maintenance. To reduce the large filter surface area, the stormwater runoff must be pretreated to remove the solids loading prior to entry to the filter, with the filter left to act as a secondary refining step (Pitt, *et al*. 1999 and Pratap 2003).

As part of this current research effort, the Upflo^{TM} Filter has undergone full-scale evaluations near the Tuscaloosa city hall, AL. The major objectives of this research were:

1) To find the effects of head loss during filtration,
2) To find the effects of the flow rate variation on treatment efficiency
3) To develop an UpFlo^{TM} Filter module in WinSLAMM, and
4) To compare different media for head loss and particulate trapping.

TECHNOLOGY DESCRIPTION

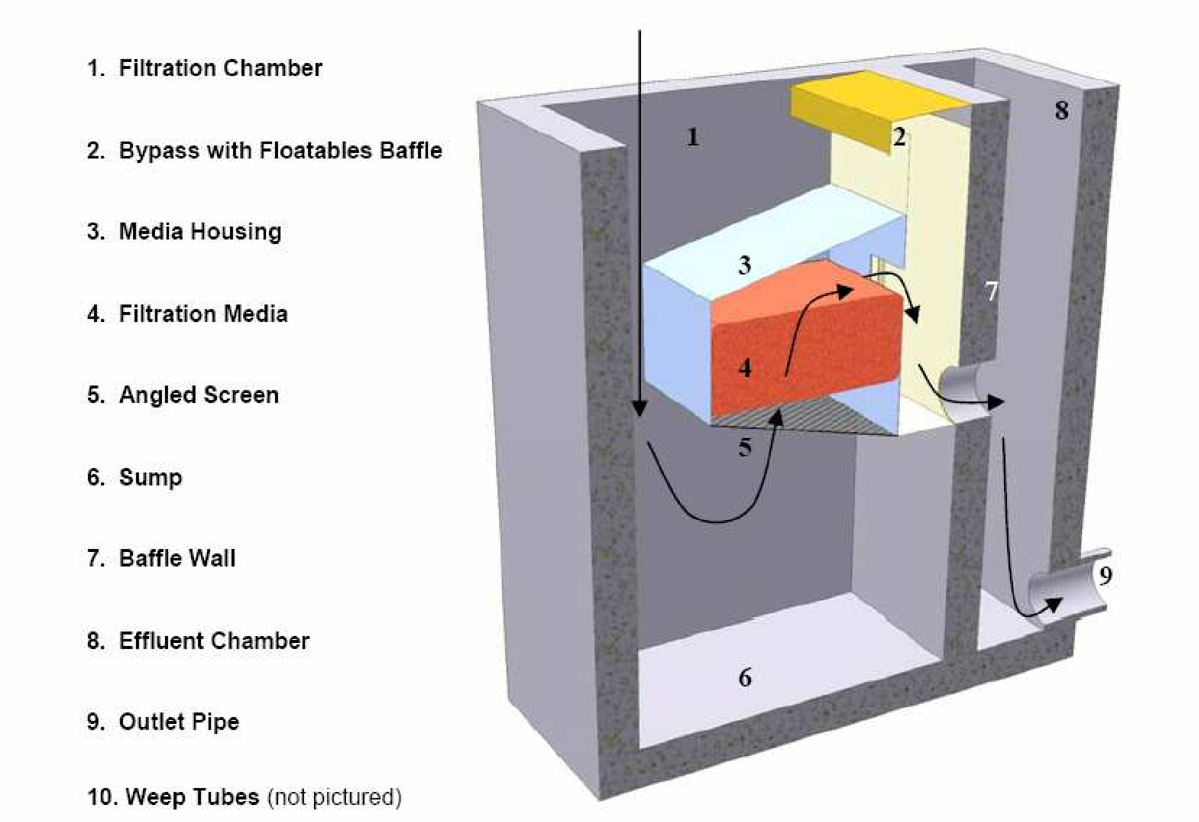
The Up-Flo™ Filter is a compact stormwater quality treatment system that integrates multiple components of a treatment train found by Pitt, *et al*. (1999) to be effective into a single, small-footprint device. Pollutant removal mechanisms in the Up-Flo™ Filter include several processes:

- Buoyant trash is captured by flotation in the chamber and retained by the floatables baffle during highflow bypassing
- Coarse solids and debris are removed by sedimentation and settle into the sump
- Capture of intermediate solids by sedimentation in sump resulting from controlled discharge rates
- Neutrally buoyant materials are screened out by the angled screens
- Fine solids are captured in the filtration media
- Dissolved pollutants are reduced by sorption and ion-exchange in the filtration media

The basic removal of solids is dependent on physical sedimentation in the sump, and by filtration in the filter media.

Figure 1 is a schematic showing the main components of the Up-Flo™ Filter prototype used in the field monitoring program and the treatment flow path through the unit.

Figure 1. Schematic of Up-Flow™ Filter and treatment flow path



The prototype Up-Flo™ Filter was constructed to fit in the modified inlet at the City Hall parking lot in Tuscaloosa, AL.

Figure 2. Aerial photograph showing the 0.9 acre test site – City Hall, Tuscaloosa, AL

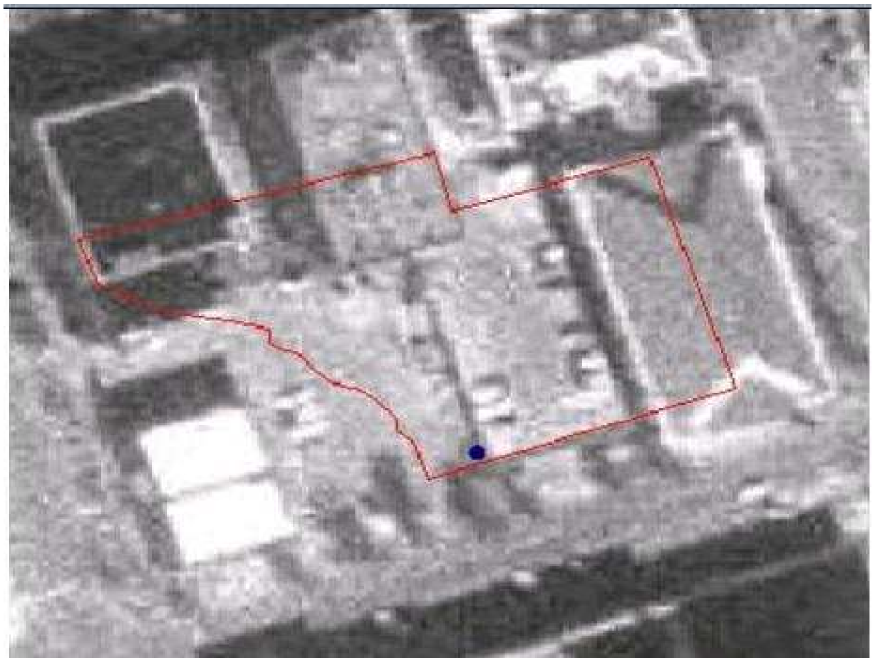


Figure 3. Different views of test site

Figure 4. Inlet before and after modifications

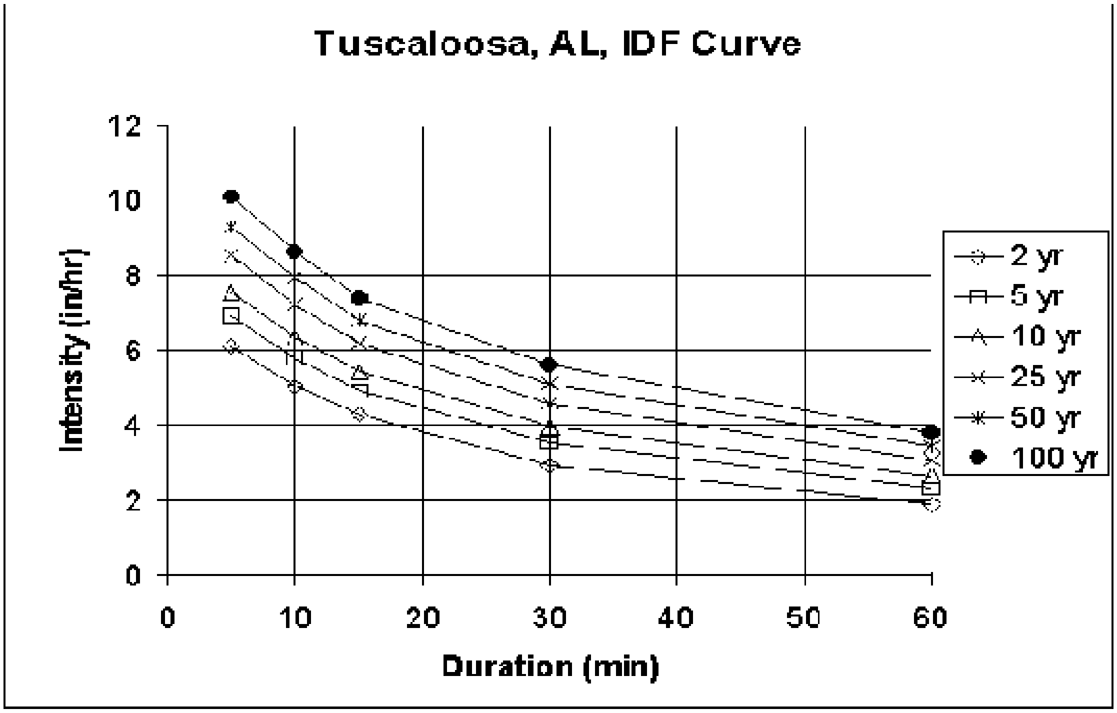
TEST SITE DESCRIPTION

The test site is a catchbasin located in the parking lot at the Tuscaloosa City Hall, Alabama. The catchbasin receives flows from the 0.9 acre drainage area shown on Figure 2. The grated inlet to the catchbasin is denoted by the dot. The site is comprised of parking, roofs, and adjacent storage areas (Figure 3).

The depth of the catchbasin system was 5-ft, making it suitable for a retrofit installation of the Up-Flo™ Filter prototype. A 3-in thick baffle wall was installed to divide the catchbasin into a filtration chamber and an effluent chamber (Figure 4). After the installation of the baffle wall, the Up-Flo™ Filter prototype was retrofitted onto the baffle wall in the filtration chamber. After the retrofit installation, the filtration chamber had a sump depth (the depth between the bottom of the outlet from the filtration media chamber and the floor of the filtration chamber) of 2.5 ft. A full-size inlet grating was installed to allow access to the entire inlet area to the filtration chamber (Figure 5).

Figure 5. Prototype UpFlo™ filter shown along with inlet grate cover

Figure 6. Tuscaloosa AL, IDF curve (Alabama Rainfall Atlas)

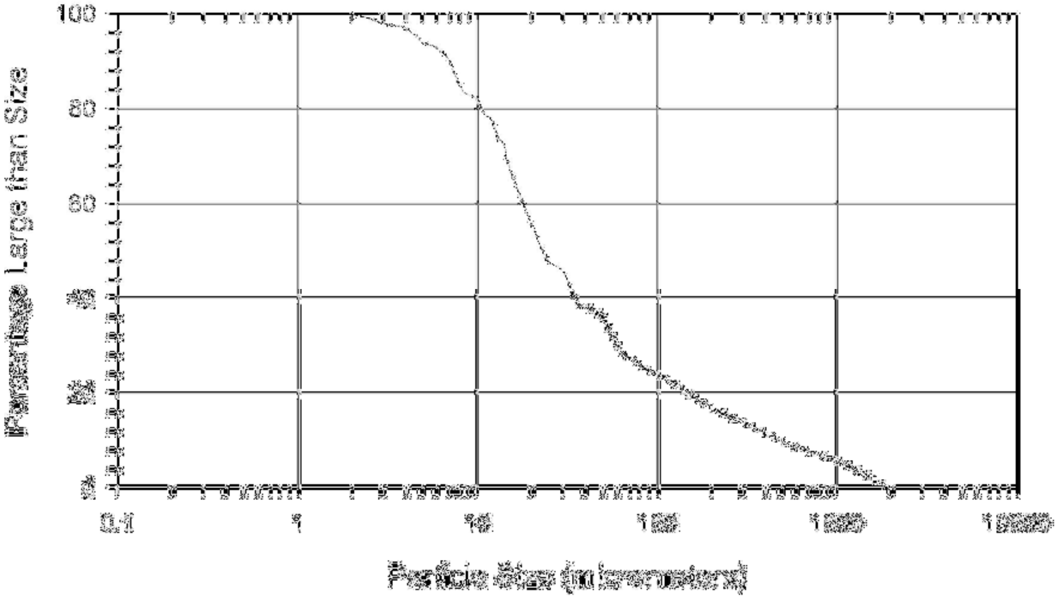


TEST SITE RAINFALL AND RUNOFF CONDITIONS

Figure 6 is a Tuscaloosa, AL, IDF (intensity-duration-frequency) curve that describes the characteristics of rare rain events at the test site, normally used for drainage design, prepared using the *Alabama Rainfall Atlas* software program developed by Dr. S. Rocky Durrans of the University of Alabama. For Tuscaloosa and the short time of concentration of the test site, these rainfall intensities can be quite large, ranging from about 6 in/hr for rains having about a 50% chance of occurring in any one year (the so-called “2-year” storm), to about 10 in/hr for rains that may only occur with a 1% chance in any one year (the “100-year” storm). Except for the smallest events, these design storms are usually not suitable for water quality treatment, but the inlet and any inserts must be capable of accommodating the peak flow rates that may be expected for the designated critical design storm for the site. Figures 14 and 15 later in this paper describe treatment flow rates needed for treating different fractions of the annual runoff volume, a more suitable way of sizing stormwater filters.

Pre-installation runoff monitoring was conducted to characterize the runoff from the test site drainage area. Figure 7 is the particle size distribution measured at the test site during preliminary monitoring. Runoff samples were taken manually at the inlet using a dipper sampler to collect water that was cascading from the gutter into the inlet, ensuring that all particulates would be captured in the sample. The sample was sieved using a 1,500 µm screen to remove any large material. This large material was then washed from the screen and analyzed separately. The rest of the sample was split using a Dekaport/USGS cone sample splitter and the separate split fractions were sieved using a 200 µm sieve and a 0.45 µm filter. The sample fraction between 0.45 and 200 µm was analyzed using a Coulter Counter Multisizer 3. The size information was then combined to produce this plot which is only for finer particulate matter and did not include any large debris (leaves or litter) larger than 1,500 µm, or dissolved solids less than 0.45 µm. The median particle size of the particulate matter in the runoff was about 25 µm, and about 15% of the particulates (by mass) were larger than 250 µm (but smaller than 1500 µm). During the initial testing in late fall, a substantial amount of leaves (about 5 ft^3), and several large pieces of litter (soda cans, plastic bags, and Styrofoam cups) were accumulated in the sump. The mass of the large debris was relatively small compared to the total amount of runoff solids that flowed into the system, and would have had an insignificant effect on the particle size distribution.

Figure 7. Observed particulate matter size distribution in runoff water at Tuscaloosa test site



METHODOLOGY

Two sets of experiments were conducted in Tuscaloosa: 1) controlled tests using a known mixture of finely ground silica and coarser sands under varying concentrations and flow rates, and 2) monitoring pollutant trapping during actual runoff conditions to verify the particulate trapping model developed during the controlled tests.

During the controlled tests, known concentrations ranging from 50 to 500 mg/L suspended solids was tested at three different flow rates representing the maximum flow for the filter media possible with the low head conditions available at the test site (about 11 inches) (high), about half that flow (medium), and about one-forth the maximum flow (low). The influent solids mixture was made up of a combination of ground silica from U.S. Silica Co (Sil-Co-Sil 106 and 250) plus sieved sand, covering the particle size range from about 2 to 400 µm. The mixed media material (comprised of bone char carbon, Mn-coated zeolite, and peat moss), was tested using four different influent sediment concentrations (500 mg/L, 250 mg/L, 100 mg/L, and 50 mg/L) at each of the three different flow rates. The highest flow tested for the mixed media was 29 gpm. Three other media were also tested to compare to the mixed media, but only at the 500 mg/L concentration and the three flow rates.

Each experiment was conducted for 30 minutes. An initial blank sample was collected from the upflow effluent location to measure any background solids in the test water before the additional solids were added. An effluent sample was collected every 1 minute and composited for the test period using a manual dipper sampler. Each sample was placed in a churn sample splitter during the test. At the test completion, the churn splitter was used to prepare three replicate samples of 1000 mL each, representing each experiment. Samples of the added solids for the influent water were also collected to verify the particle size distributions and concentration additions.

Laboratory analyses involved preparing an additional set of duplicate samples using a USGS Dekaport cone splitter (shown in Figure 8) from each of the three subsamples, resulting in six replicate analyses for each test. The cone splitter was used to separate the subsamples into aliquots for further laboratory analyses: total solids, dissolved solids, particulate solids >106 µm, suspended solids, turbidity, and particle size analyses using a Coulter Counter Multi-Sizer 3.

The maximum flow rates ranged from about 30 GPM for the mixed media to about 50 GPM for the coarser bone char. The effluent TSS concentrations were lower during lower influent tests compared to the higher concentration tests, indicating that irreducible concentrations were not strictly being observed. Generally, the effluent was better during the lower flow rate tests than for the higher flow tests, but the differences were small. Figure 9 shows the flow vs. head curve for mixed media.

In addition to the controlled tests, influent and effluent samples were also collected and analyzed during actual runoff events. ISCO 6712 automatic samples, area-velocity flow sensors, stage recorders, YSI 6600 water quality sondes, and an on-site recording rain gage were used to monitor the UpFlo^{TM} Filter. From March through November, 2005, about 25 pairs of samples were collected during 12 storm events. Statistically significant differences between the effluent (lower) and influent (higher) at the $p<0.01$ level were noted for turbidity, suspended solids, total solids, COD, *E. coli* and total coliforms, and at the $p<0.05$ level for dissolved phosphate and ammonia, zinc, dissolved copper and dissolved lead.

Figure 8. Decaport cone splitter

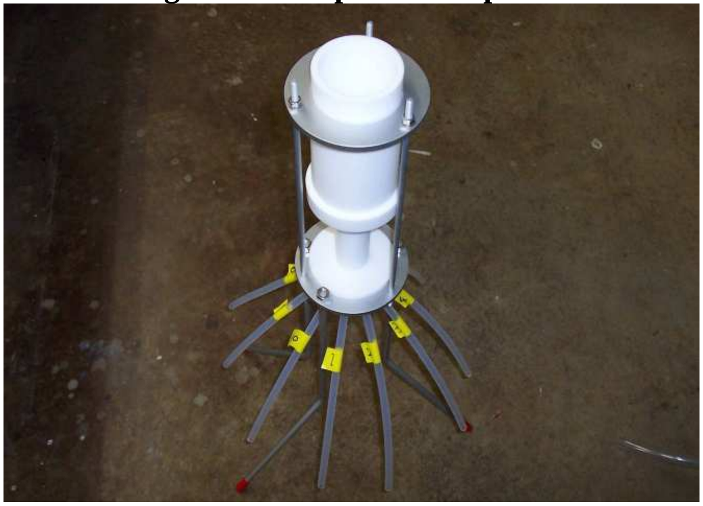
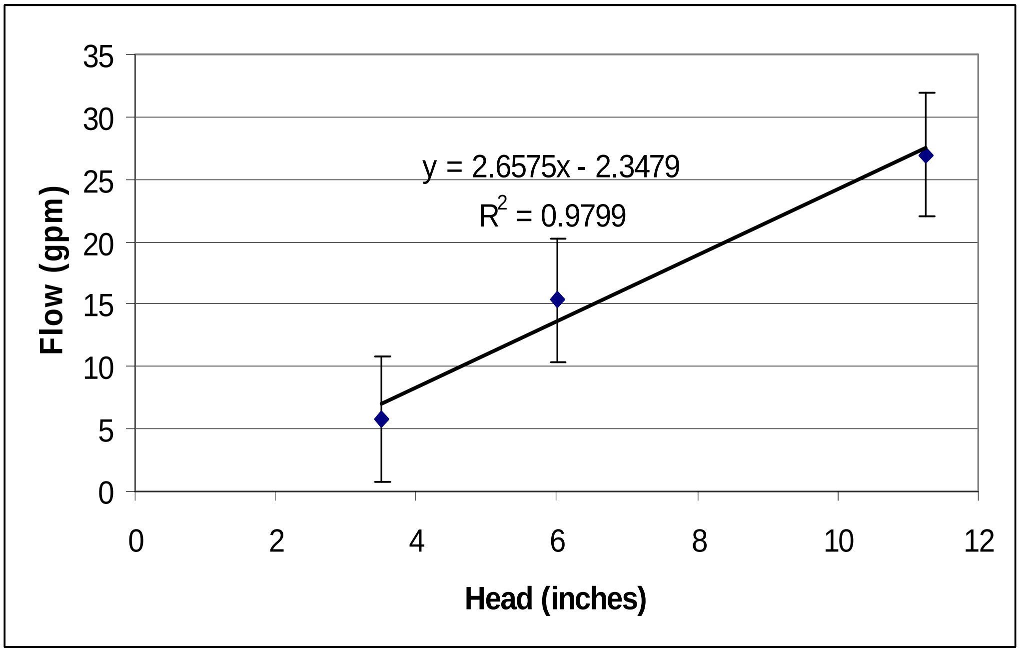


Figure 9. Flow vs. head graph for mixed media



RESULTS & DISCUSSION

Statistically significant reductions of 90% and greater were observed for suspended solids during the controlled tests, while the actual runoff event monitoring indicated somewhat less percentage reductions (about 70%), due to lower influent concentrations and an abundance of very small particles having lighter specific gravities. The controlled tests resulted in almost complete capture (>95%) of all particles greater than 30 µm at all flow rates tested, and reductions of about 80% for particles in the size range of 20 to 30 µm. Particle concentrations in the 1 to 20 µm size range were reduced by at least half. Statistical evaluations of the data indicate that the UpFlo^{TM} Filter is more sensitive to initial sediment concentrations than the treatment flow rates. Every storm evaluated had a hyetograph (rainfall pattern) and hydrograph (runoff pattern) prepared with the treatment flow capacity marked for that particular event. An example is shown in Figure 10 for Hurricane Katrina

The percentage reductions for suspended solids for the mixed media tests and high influent concentrations (485 to 492 mg/L) were 84 to 94%, with effluent concentrations ranging from 31 to 79 mg/L for flows ranging from 15 to 30 GPM. During the low concentration tests (54 to 76 mg/L), the reductions ranged from 68 to 86%, with effluent concentrations ranging from 11 to 19 mg/L. The coarser bone char and activated carbon media tests had slightly poorer solids removal rates (62 to 79% during the highest flow tests), but with much higher flow rates (46 to 50 GPM). At flows similar to the mixed media (21 to 28 GPM), these coarser materials provided similar removals (about 79 to 88% for suspended solids). The flow rates therefore seemed to be more important in determining particulate solids capture than the media type. However, dissolved constituent removals are expected to be enhanced by the mixed media (having the peat component).

Figure 10. Hyetograph and Hydrograph for Hurricane Katrina

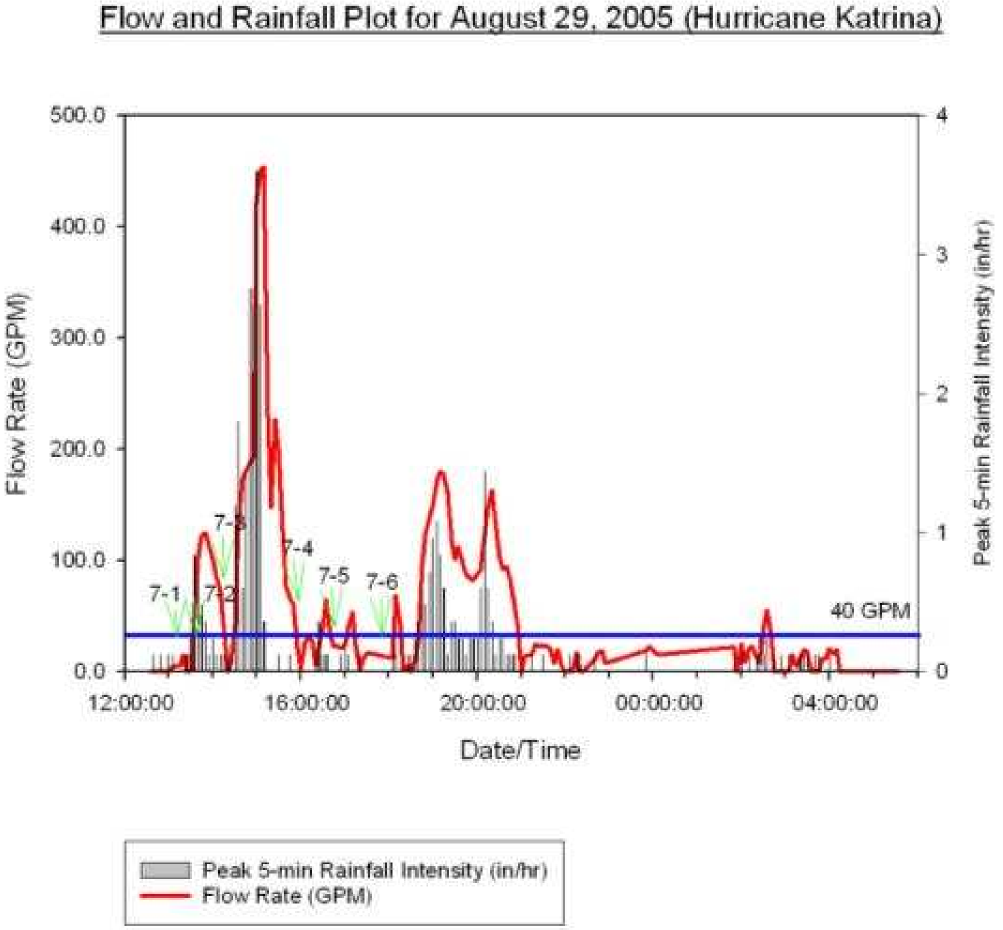


Figure 11 shows the performance plots for the controlled flow Sil-Co-Sil challenge tests. These plots are for the mixed media tests which provided maximum flow rates of about 25 GPM/ft^2 (38 GPM). During actual storms, treatment rates ranging from 35 to 50 GPM were observed for the prototype UpFlo^{TM} filter. These plots show excellent control of solids with the prototype UpFlo^{TM} filter for a wide range of flow and concentration conditions. Figure 12 shows the performance plot of particle size distribution for the mixed media.

Figure 11. Performance plot for mixed media

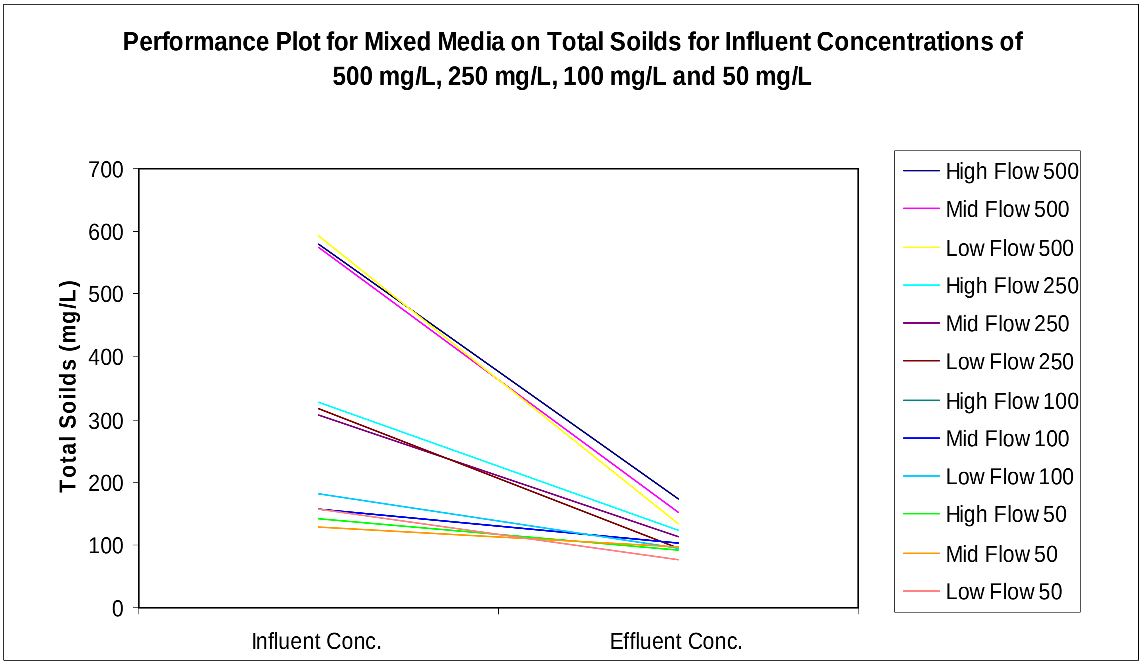
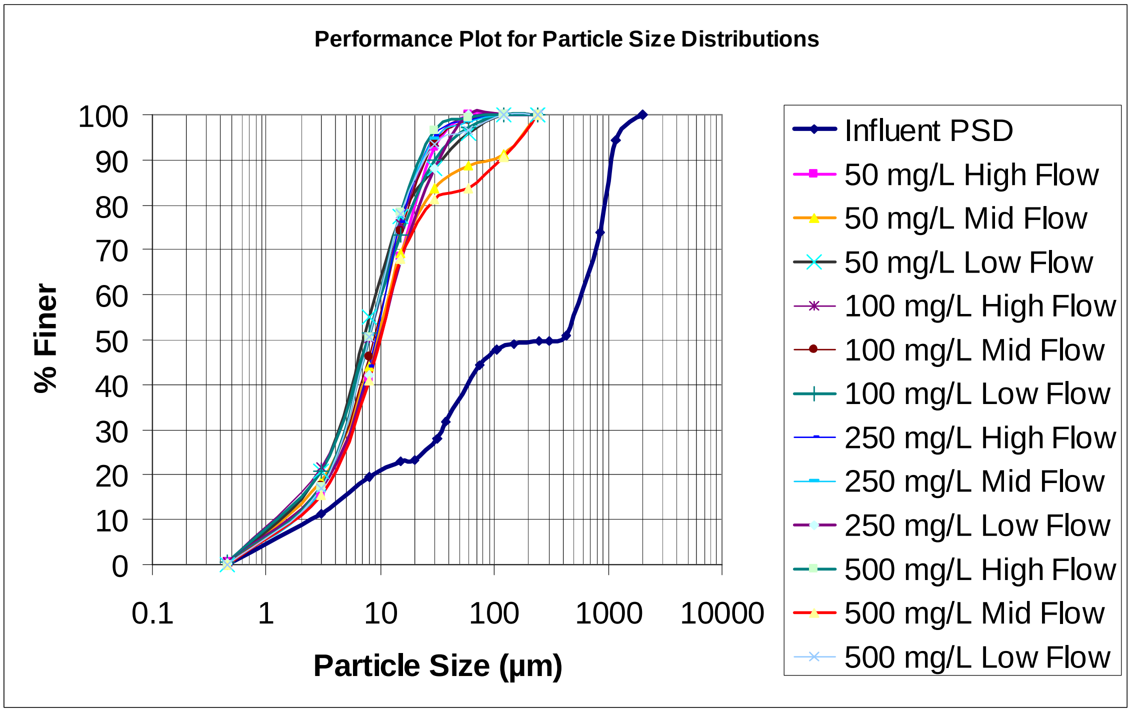


Figure 12. Performance of particle size distribution for mixed media



Thirty-one separate rains occurred during the 10 month monitoring period from February 2 to November 21, 2005. The monitoring period started off unusually dry in the late winter to early summer months. However, the mid summer was notable for severe thunderstorms having peak rain intensities (5-min) of up to 4 inches per hour. The late summer was also notable for several hurricanes, including Hurricane Katrina on August 29, 2005 that delivered about 3 inches of rain over a 15 hour period, having prolonged peak rain intensities as high as 1 in/hr in the Tuscaloosa area.

Figure 13 is a plot showing the relationship between the observed 5-minute peak rain intensities and the instantaneous peak runoff rates for this 0.9 acre site. The time of concentration for this site is very short (< 5 minutes) and there is no significant hydraulic routing of the flows to the inlet. Most of the flows occur as sheetflows and shallow concentrated flows, with the roof drainage coming off the City Hall roof in large downspouts. The steep roof does not provide any storage, so excess flows would cascade over the rain gutters directly to the elevated concrete parking deck. The flows across the concrete parking deck are mostly as sheetflows and enter several downspouts to the lower asphalt parking area, and the inlet. This simple drainage pattern resulted in a fairly consistent relationship between rain intensity and runoff rate. The Rational formula coefficient “C” shown on this plot is about 0.35, much less than what would be expected. The volumetric runoff coefficient “Rv” (the ratio of the runoff volume to the rain volume) is about 0.65, also somewhat smaller than one would expect for the site conditions. These average coefficients are relatively low because most of the storms monitored were much smaller than drainage design events. The 3.5 to 4.5 in/hr 5-min rain intensities observed during the most intense events were associated with rainfalls in the Tuscaloosa area that would be expected to occur several times a year, according to the local IDF curves, as they did occur. The 2-year event has a 5-min peak rain intensity of about 6 in/hr, while the 25-yr event has a 5-min peak rain intensity of about 8.5 in/hr. It is expected that the runoff coefficients (both C and Rv) would increase as these design storm conditions are reached. What was most unusual about the monitoring period was the absence of typical small events, with only these larger events occurring. The hurricanes did not result in such high rainfall intensities in the Tuscaloosa area, but they lasted for very long periods with moderate intensities. With larger drainage areas and longer times of concentration, they were responsible for design storm flows. As an example, the 3.6 inch/hr peak rain intensity observed during Katrina would be associated with a 25-yr design storm if the time of concentration was about 40 minutes (assuming this peak lasted for this duration), which would be the case for many of the local urban streams.

Figure 13. Peak 5-minute rain intensities and peak runoff rates observed

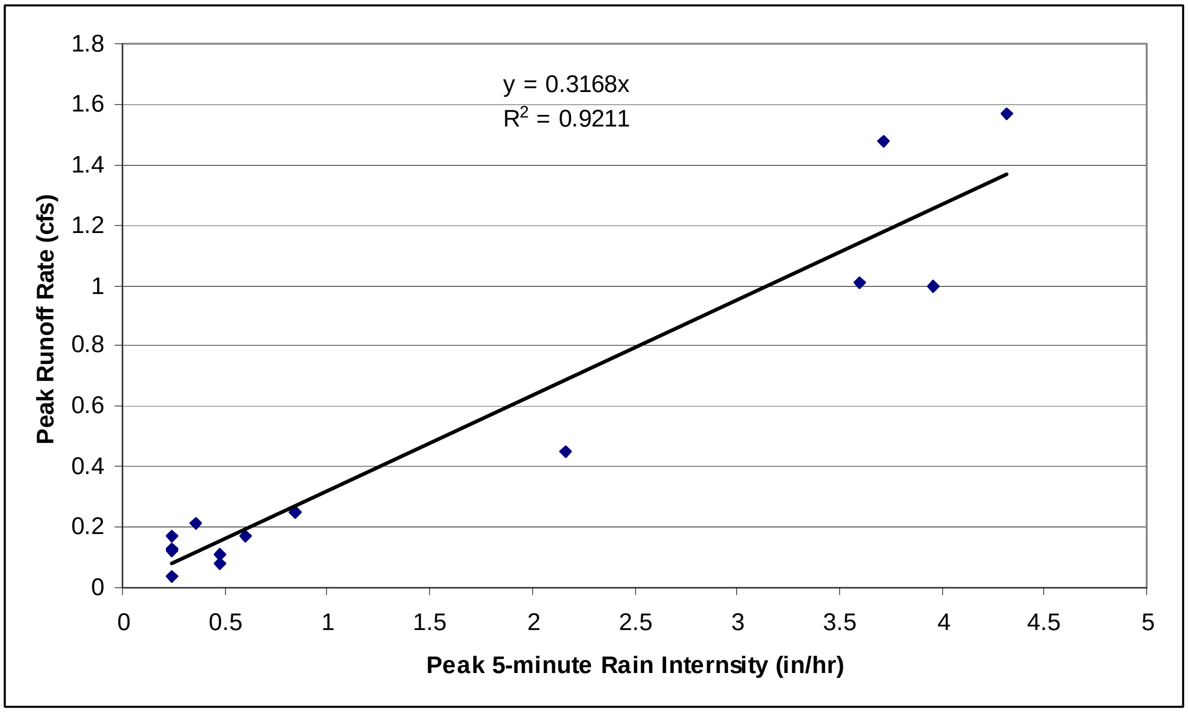


Figure 14 is a plot showing the amount of the annual flow associated with different percentage values of occurrence for the Tuscaloosa, AL, test site. These were calculated using WinSLAMM for the 0.9 acre test site (0.4 acre roof and 0.5 acre paved parking), and for the first nine months of the 1999 typical rain year. The continuous simulation calculated the flows for every 6 minute increments during this period. With a treatment flow rate of 44 GPM (the average value for the observed events), the total events would be treated if the peak flows were less than this value. During periods of peak flows greater than this value, the base 44 GPM would be treated by the UpFlo^{TM} filter, while higher flows would bypass the filter unit. About 25 to 30% of the annual flows are expected to be less than or equal to the observed 44 GPM treatment flow rate, as shown on Figure 14. However, a larger fraction of the annual flows were actually treated at the test site. Figure 15 is a plot of the expected fraction of the annual flows that would be treated by the UpFlo^{TM} filter for different treatment flow rates. For the observed 44 GPM treatment flow rate, about 60% of the annual flows were likely treated during the test period, and about 40% of the runoff volume bypassed the filter unit. This value compares favorably to the estimates made using the observed hydrographs. In order to treat about 90% of the annual flows at this site, the treatment flow rate should be about 100 GPM. Therefore, the prototype unit was about ¼ the optimal size, assuming a 25 GPM design flow rate. Table 1 summarizes the actual storm event monitoring results.

Figure 14. Percentage of annual flows at Tuscaloosa test site

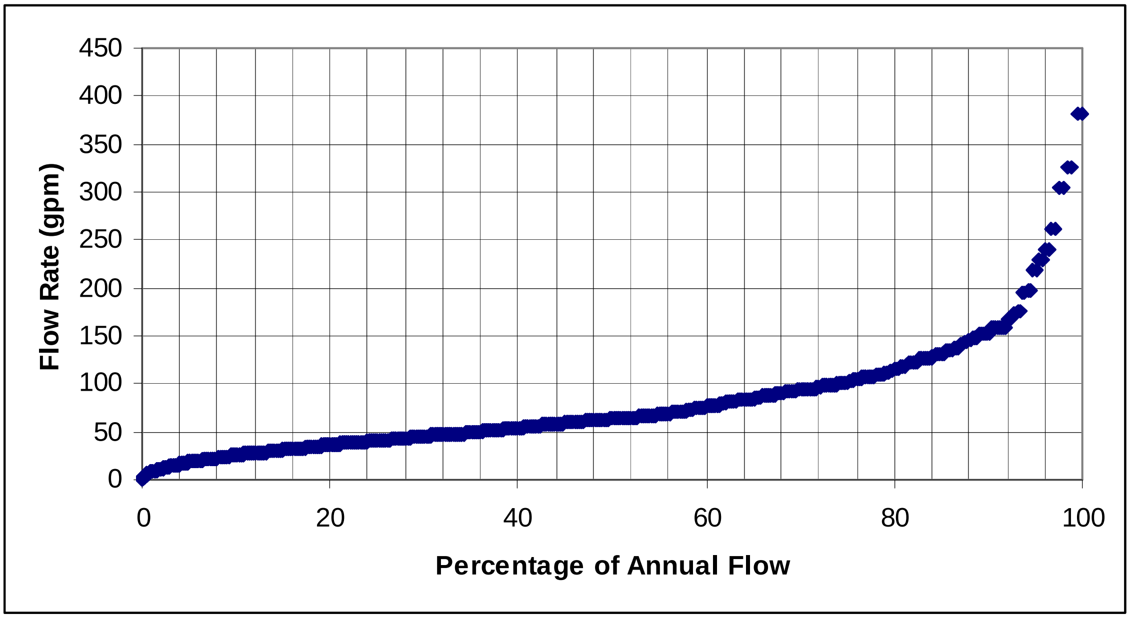


Figure 15. Treatment flow rate and percentage of annual flow treated for Tuscaloosa, AL, test site

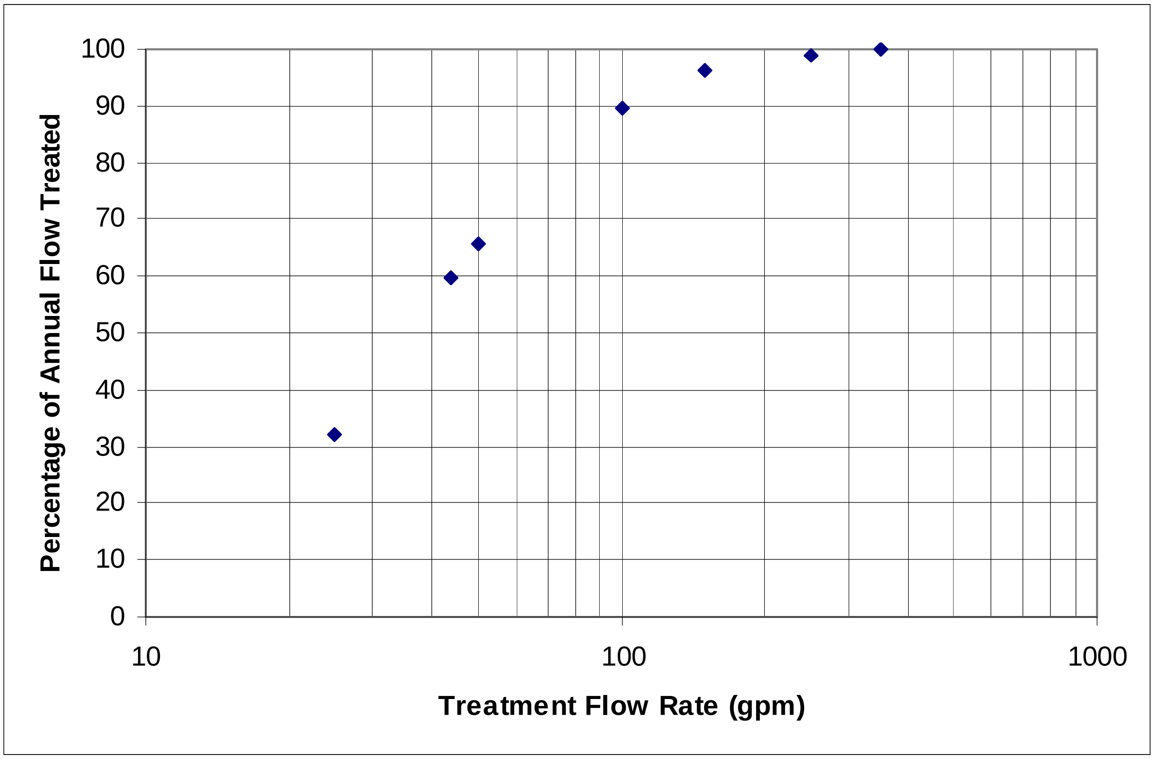


Table 1. Summary of UpFlow^{TM} filter actual storm event monitoring results (filter alone, no sump benefits)

	Average influent concentration (all mg/L, except for bacteria that are #/100 mL, turbidity that is NTU, and metals that are µg/L) (and COV)	Average effluent concentration (all mg/L, except for bacteria that are #/100 mL, turbidity that is NTU, and metals that are µg/L) (and COV)	Calculated percentage removal based on average influent and average effluent concentrations (median of individual sample pair reductions)	Probability that influent ≠ effluent (nonparametric sign test) (significant reduction at 95% level?)
Turbidity (NTU)	43 (2.4)	15 (1.3)	65 (45)	>99% (significant reduction)
Suspended solids	64 (2.9)	19 (1.6)	70 (58)	>99% (significant reduction)
Total solids	137 (1.7)	90 (1.3)	34 (17)	>99% (significant reduction)
COD	111 (1.6)	81 (1.4)	27 (18)	>99% (significant reduction)
Phosphorus	0.94 (1.1)	0.77 (1.4)	18 (13)	98% (significant reduction)
Nitrates	0.7 (1.2)	0.7 (1.3)	0 (0)	93% (not significant reduction)
Ammonia	0.44 (1.5)	0.24 (1.30)	45 (24)	97% (significant reduction)
E. coli	4,750 (0.8)	3,290 (0.8)	31 (21)	>99% (significant reduction)
Total coliforms	12,400 (1.0)	6,560 (0.7)	47 (37)	>99% (significant reduction)
Total Zinc (µg/L)	169 (1.2)	130 (1.3)	23 (23)	>99% (significant reduction)
Dissolved Zinc (µg/L)	103 (0.5)	116 (1.3)	-13 (17)	3.7% (not significant reduction)
Total Copper (µg/L)	13 (1.5)	8.7 (1.2)	33 (26)	64.1% (not significant reduction)
Dissolved Copper (µg/L)	5.7 (0.6)	5.7 (1.0)	0 (35)	97.9% significant reduction)
Total Cadmium (µg/L)	1.7 (2.0)	2.6 (3.2)	-53 (-20)	0% (not significant reduction)
Dissolved Cadmium (µg/L)	7.6 (3.5)	2.2 (2.1)	71 (9)	0% (not significant reduction)
Total Lead (µg/L)	15.5 (1.9)	5.5 (1.9)	65 (50)	90.8% (significant reduction)
Dissolved Lead (µg/L)	11.3 (2.7)	2.8 (2.2)	75 (58)	97.8% (significant reduction)
<0.45 µm	0.087 (3.1)	0.69 (4.6)	-690 (60)	90.4% (not significant reduction)
0.45 to 3 µm	4.4 (1.7)	1.7 (1.6)	61 (65)	98.9% (significant reduction)
3 to 12 µm	13.4 (3.3)	3.9 (1.5)	71 (67)	90.7% (not significant reduction)
12 to 30 µm	28.7 (3.6)	6.1 (2.2)	79 (65)	>99% (significant reduction)
30 to 60 µm	12.0 (2.1)	4.5 (1.9)	63 (72)	>99% (significant reduction)
60 to 120 µm	3.1 (1.7)	1.5 (2.0)	52 (47)	97.4% (significant reduction)

These data indicate that the performance of the UpFlo^{TM} filter is dependent on influent concentrations.

Figure 16 is a scatterplot of the observed influent concentrations vs. the effluent concentrations, while Figure 17 is a line plot that connects paired influent and effluent concentrations. These plots show generally large reductions in TSS concentrations for most events.

Figure 16. Scatterplot of observed influent and effluent suspended solids concentrations (filled symbols are events that had minor filter bypasses)

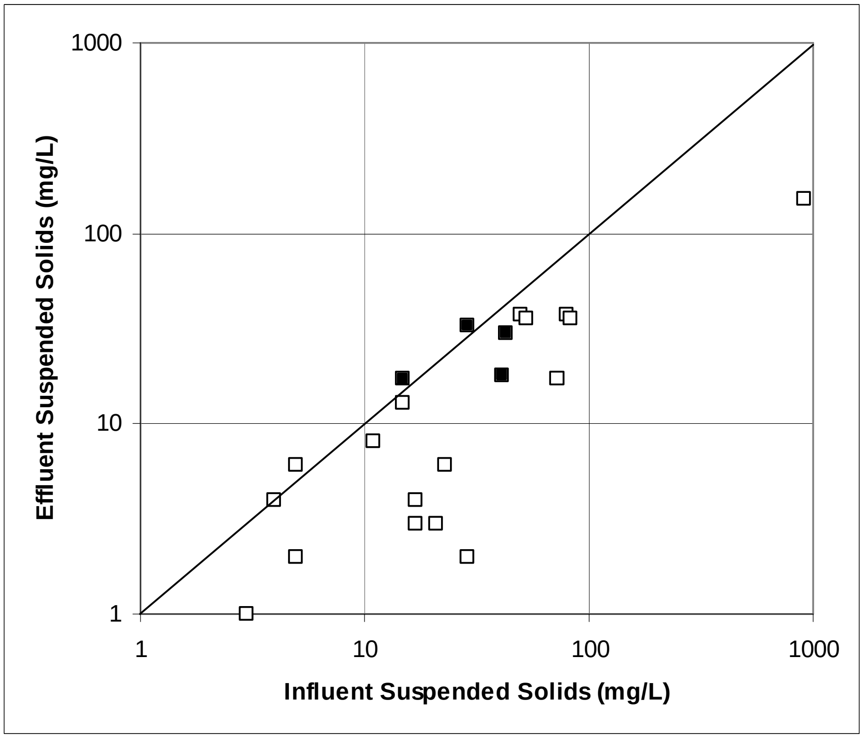
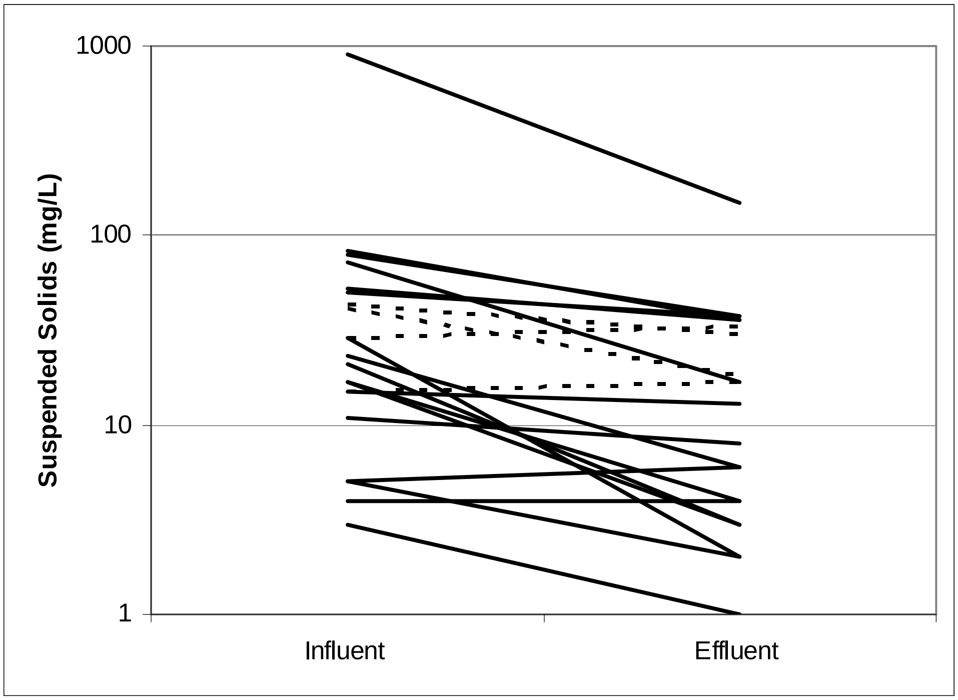


Figure 17. Paired influent and effluent suspended solids concentrations



The nonparametric sign test was also used to calculate the probability that the influent equals the effluent concentrations. For the TSS data, $P < 0.01$, indicating with >99% confidence that the influent does not equal the effluent concentrations. Therefore, the test was statistically significant at least at the α 0.05 level.

These data were fitted to regression equations to predict the effluent concentrations from the influent conditions (without the sump benefits considered). In all cases, the data needed to be log-transformed in order to obtain proper residual behavior. As an example using TSS, the following equation was found to be very significant, according to the ANOVA analyses:

Eq 1: Effluent Suspended Solids, log mg/L = 0.730 * (Influent Suspended Solids, log mg/L)

Table 2. 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

Table 3. ANOVA for suspended solids

	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			

Table 4. Suspended solids regression P-value

	Coefficients	Standard Error	t-Stat	P-value	Lower 95%	Upper 95%
Influent Suspended Solids	0.730	0.053	13.7	1.56E-12	0.620	0.841

- the intercept term was determined to be not significant

As indicated during the ANOVA analyses, the intercept term was not significant when included in the model, so that term was removed, and the statistical test repeated. The overall significance of the model is very good (F<<0.001), and the adjusted R^2 term is 0.85. The P-value for the slope term of the equation is also highly significant (P<<0.001) and the 95% confidence limit of the calculated coefficient is relatively narrow (0.62 to 0.84). Figure 18 is a plot of the fitted equation along with the observed data, while Figure 19 contains the residual plots, all showing acceptable patterns. The results of the ANOVA analysis for suspended solids are tabulated in Tables 2 through 4.

Figure 18. Fitted equation and data points for influent and effluent suspended solids

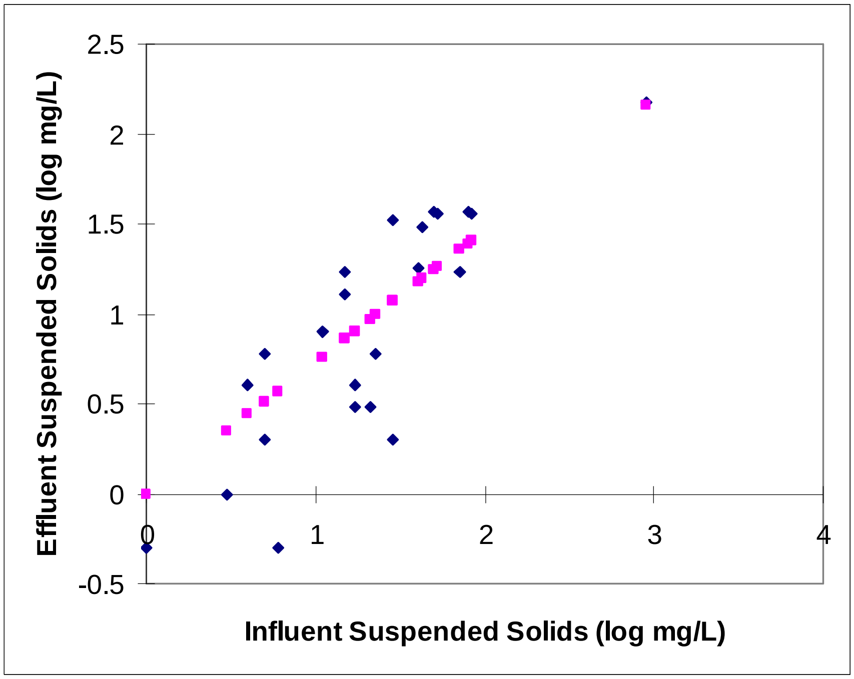
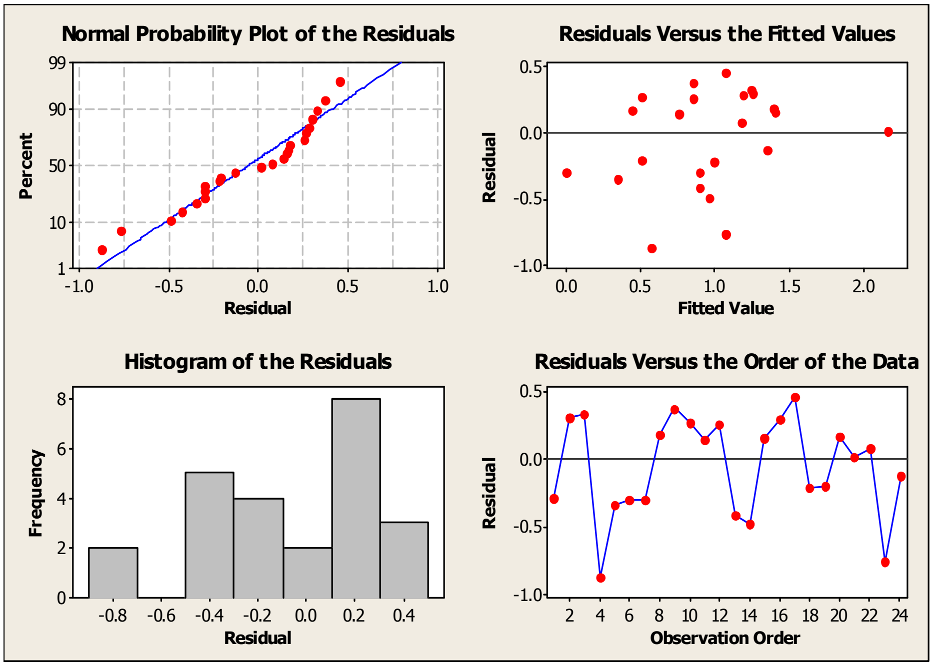


Figure 19. Residual analyses of fitted equation for suspended solids influent vs. effluent



Confidence intervals of the influent vs. effluent plots are shown on Figure 20, while Figure 21 shows the confidence intervals for calculated percentage reduction values. As indicated in Figure 21, the TSS reductions would be >70% when influent concentrations exceeded about 80 mg/L, >80% when influent concentrations exceeded about 300 mg/L, and >90% when influent concentrations exceeded about 1000 mg/L. Again, these results do not consider the benefits of the sump.

Figure 20. Predicted effluent concentrations for different influent concentrations, with 95% confidence limits

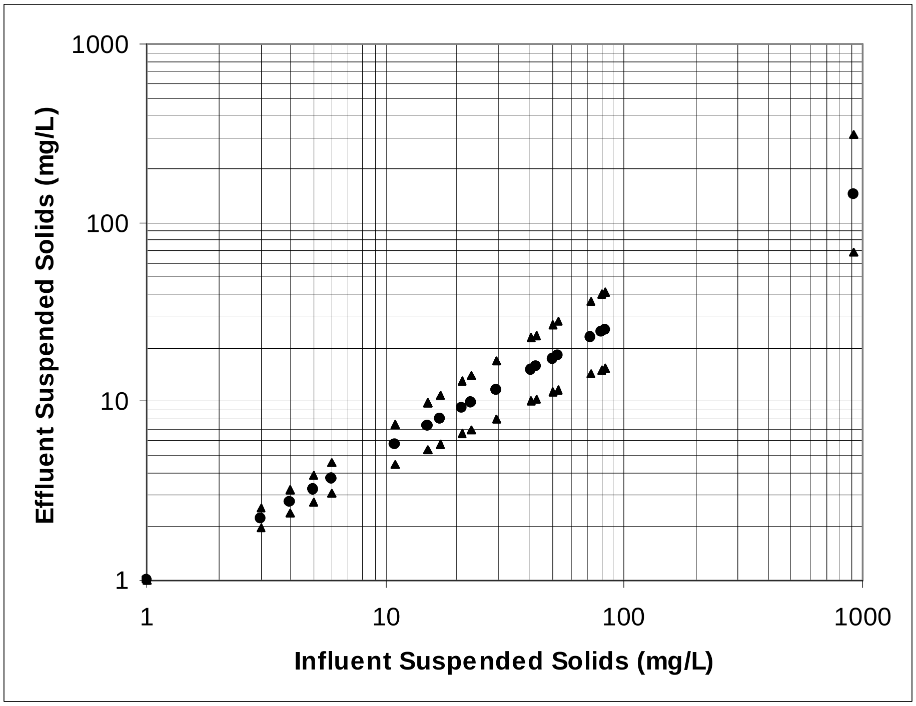


Figure 21. Percentage reductions as a function of influent concentrations, with 95% confidence limits

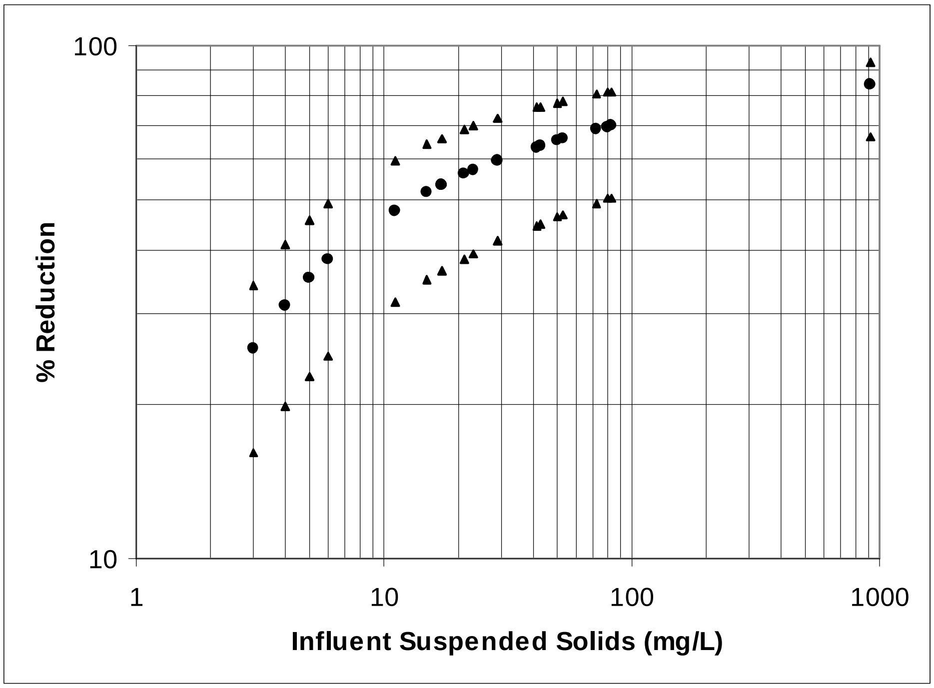


Table 5 summarizes particulate solids removed by the UpFlo™ filter by particle size, during the sampling period, considering both the measurements from the automatic samplers (for suspended material <150µm in size) and the larger material retained in the sump, assuming all the runoff was treated by the filter, with no bypass, and all material greater than about 250µm would be retained in the filter and sump. Figure 22 shows the measured particle size distributions for the influent and effluent water, considering both the water samples collected in the automatic samplers, plus the bed load material captured in the sump. The suspended solids removal rate is expected to be about 80%, while the removal rates for the other monitored constituents are expected to be about 72 to 84%, depending on their associations with the different particle sizes. Tables 6 – 8 provide the removal rate equations for different flow rates. Figure 23 shows the commercial UpFlo™ filter unit.

Table 5. Particulate Solids Removal by Particle Size During Monitoring Period

Particle Size Range (µm)	SS Influent Mass (kg)	SS Effluent Mass (kg)	SS Removed (kg)	% Reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

Figure 22. Particle size distributions for influent and effluent solids

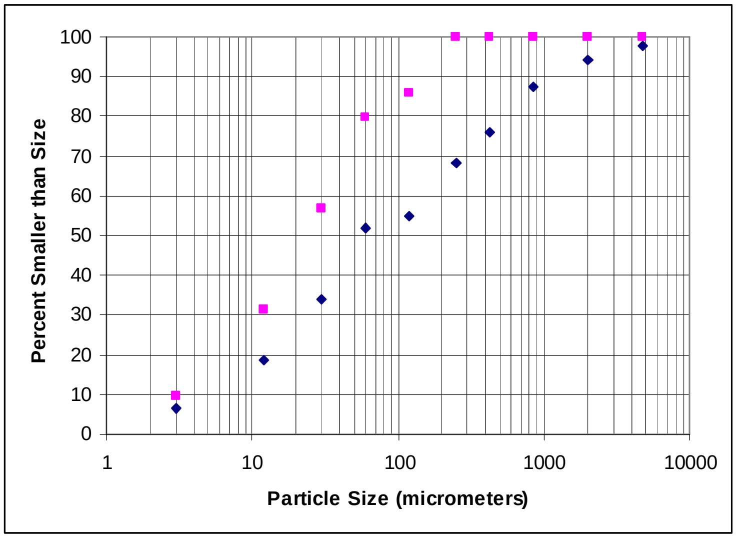


Table 6. Low Flow Rate (6 GPM/ft^2 or less)

Size Range (µm)	Removal rate equation (y = effluent concentration; x = influent concentration, both in mg/L of particulate solids in designated size range)	Approx. irreducible concentration
0.0 to 0.45 (TDS)	y = x	0
0.45 to 3	y = 0.1898x + 0.8289	1
3 to 12	y = 0.2036x + 1.0793	1.4
12 to 30	y = 0.1891x + 0.459	0.6
30 to 60	y = 0.0202x	0
60 to 120	y = 0.0185x	0
120 to 240	y=0	0
>240	y=0	0

Table 7. Medium Flow Rate (13 GPM/ft^2)

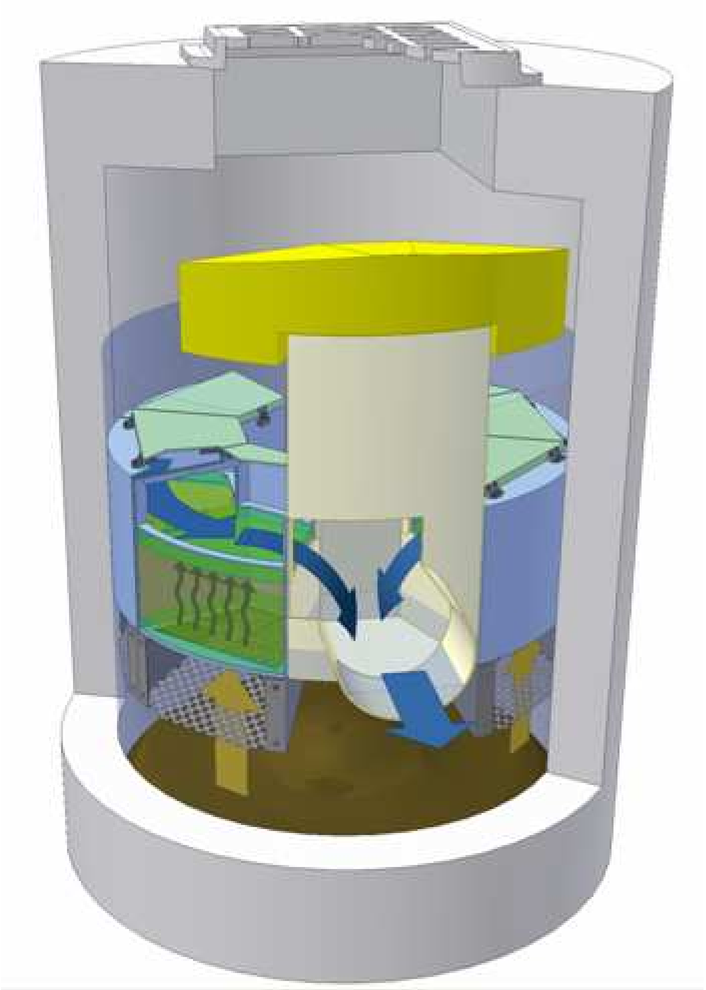
Size Range (µm)	Removal rate equation (y = effluent concentration; x = influent concentration, both in mg/L of particulate solids in designated size range)	Approx. irreducible concentration
0.0 to 0.45 (TDS)	y =x	0
0.45 to 3	y = 0.2328x + 3.2022	4.2
3 to 12	y = 0.2497x + 5.3282	7.1
12 to 30	y = 0.1382x + 3.3539	3.9
30 to 60	y = 0.0248x	0
60 to 120	y = 0.0686x	0
120 to 240	y =0	0
>240	y=0	0

Table 8. High Flow Rate (20 GPM/ft^2 (to overflow)

Size Range (µm)	Removal rate equation (y = effluent concentration; x = influent concentration, both in mg/L of particulate solids in designated size range)	Approx. irreducible concentration
0.0 to 0.45 (TDS)	y=x	0
0.45 to 3	y = 0.6041x + 1.2461	2
3 to 12	y = 0.6419x + 0.2788	0.8
12 to 30	y = 0.6254x + 1.5779	4.2
30 to 60	y = 0.0414x	0
60 to 120	y = 0.0151x	0
120 to 240	y=0	0
>240	y=0	0

Effluent = influent for all influent up to and equal to the irreducible concentration (the effluent can never be greater than the influent; the irreducible concentration is where the removal rate equation crosses the 45o line indicating equivalent influent and effluent concentrations). The removal rates are based on least squares regressions for controlled tests for 50 to 500 mg/L influent SS and flows up to bypass conditions.

Figure 23. UpFlo™ filter drawing showing normal filtering operation (Hydro International, Ltd.).



CONCLUSIONS

The objective of a stormwater treatment device should have the following performance characteristics:

- not prone to flooding due to clogging with debris;
- reduce the discharge of pollutants into the downstream system

- minimize the losses of previously captured solids due to scour;
- do not have unacceptable hydraulic head loss properties; and
- require inexpensive and infrequent maintenance.

Recent research on filtration examined alternative media and ways to reduce clogging. Upflow filtration was examined as a way to accomplish this goal, at the same time as providing a much greater treatment rate. The UpFlo^{TM} Filter was conceived as a treatment device to allow many of the treatment train components of the Multi-Chambered Treatment Train (MCTT) (Pitt, *et al*. 1999) to be used in a smaller area, while providing much faster unit area stormwater flow treatment rates. Pollutant removal mechanisms in the UpFlo^{TM} filter include several processes:

- Coarse solids and litter removal in sump and by screens
- Capture of intermediate solids by sedimentation in sump by controlled discharge rates
- Capture of fine solids in primary filtration media
- Sorption and ion-exchange capture of dissolved pollutants in primary and secondary media

The basic removal of solids is therefore dependent on physical sedimentation in the sump, and by filtration in the media. An important aspect of the field tests was to verify the lab-scale flow capacity tests conducted during earlier project phases.

As expected, the UpFlo^{TM} filter was found to be most effective in reducing the pollutants that were mostly associated with particulate matter, and less effective for removing dissolved constituents. These data indicated that the performance of the UpFlo^{TM} filter is dependent on influent concentrations. The TSS reductions would be >70% when influent concentrations exceeded about 80 mg/L, >80% when influent concentrations exceeded about 300 mg/L, and >90% when influent concentrations exceeded about 1000 mg/L, plus the reductions of the large debris in the sump.

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