Enhanced Biofilter Treatment of Stormwater by Optimizing the Residence Time

Redahegn Sileshi[1], Robert Pitt[2] and Shirley Clark[3]

[1]Graduate student, Dept. of Civil, Construction, and Environmental Engineering, Univ. of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487. Corresponding E-mail: rksileshi@crimson.ua.edu
[2]Cudworth Professor, Urban Water Systems, Dept. of Civil, Construction, and Environmental Engineering, Univ. of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487. E-mail: rpitt@eng.ua.edu
[3]Associate Professor, Environmental Engineering, Penn State Harrisburg, 777 W. Harrisburg Pike TL-105, Middletown, PA 17057. E-mail: seclark@psu.edu

Abstract: The treatment of stormwater by biofilters is dependent on the hydraulic residence time in the device for some critical pollutants. The effective use of biofilters for the control of stormwater in combined sewered areas is also related to residence time, as it is desired to retain the water before discharge to the drainage system in order to reduce the peak flows to the treatment plant. This paper will describe the initial results from a series of tests being conducted to determine the hydraulic characteristics of sand-based filter media (having a variety of particles sizes representing a range of median particle sizes and uniformity coefficients) during pilot-scale trench tests. The drainage rate in biofiltration devices is usually controlled using an underdrain that is restricted with a small orifice or other flow-moderating component. These frequently fail as the orifices are usually very small (<10 mm) and are prone to clogging. A series of tests are also being conducted using a newly developed foundation drain material (SmartDrain^{TM}) that offers promise as a low flow control device with minimal clogging potential. A pilot-scale biofilter using a trough 3m long and 0.6 x 0.6m in cross section is being used to test the variables affecting the drainage characteristics of the underdrain material (such as length, slope, hydraulic head, and type of sand media). Current tests are also being conducted to test the clogging potential of this drainage material. This paper describes the initial tests that have investigated the basic hydraulic properties and the clogging potential of this drain material.

Introduction

The principle mechanisms of treatment in biofiltration practices are the slowing of particles to which pollutants are attached, allowing them to settle out and to be retained at the biofilter surface and the trapping of the particulate-bound pollutants as they slowly percolate through the biofilter media, both of which are affected by the release rate from the biofilter. The removal of soluble forms of many stormwater pollutants is also dependent on the contact time of the water with the media. The failure of these systems is mostly associated with clogging, either at the surface, on buried geotextiles, or at the underdrain.

Proper hydraulic design will minimize these problems and enhance the removal of pollutants. Previous studies of filtration theory for rapid and slow sand filters have provided fundamental foundations for understanding of bioretention filtration. First, sand filters usually have relatively steady inflow rates and ponding heads, while the variability of incoming runoff renders bioretention behavior much more dynamic and unsaturated media will occur during dry weather periods. Second, bioretention facilities use significantly different media than sand filters.

A typical biofilter that is 1 m deep, 1.5 m wide and 5 m long would require about 8 hours to drain using the SmartDrain^{TM} material as the underdrain. This is a substantial residence time in the media to optimize contaminant removal and also provides significant retention of the stormwater before being discharged to a combined sewer system. In addition, this slow drainage time will allow infiltration into the native underlying soil, with minimal short-circuiting to the underdrain. SmartDrain^{TM} operates using laminar flow conditions and is advertised as having minimal clogging potential by the fines in the stormwater. The smart drain has many micro channels in an 8 inch width, as shown in Figure 1. The micro channel inlet area comprises over 20% of the active drainage surface of the belt.

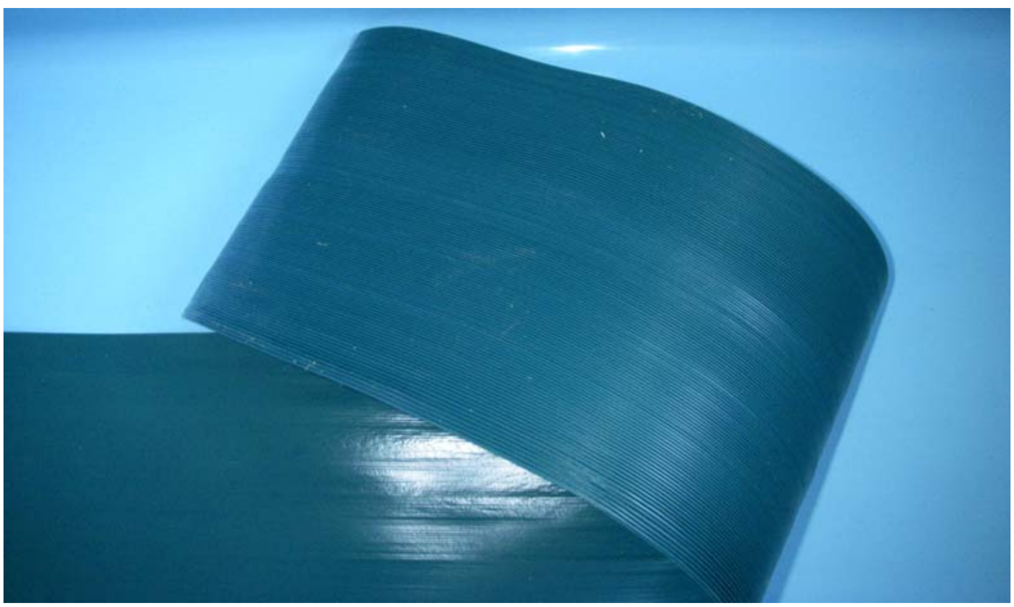


Figure 1. Close-up photograph of SmartDrain^{TM} material showing the microchannels on the underside of the 8 in wide strip.

The on-going controlled tests will determine the drainage characteristics of the SmartDrain^{TM} material under a range of typical biofilter conditions. A sand filter media purchased locally is being used for the pilot-scale test setup to measure the hydraulic characteristics of the drainage material. The particle size distributions of the sand filter media, and the US Silica Sil-Co-Sil 250 ground silica material that is being used in the clogging tests, are shown in Figure 2.

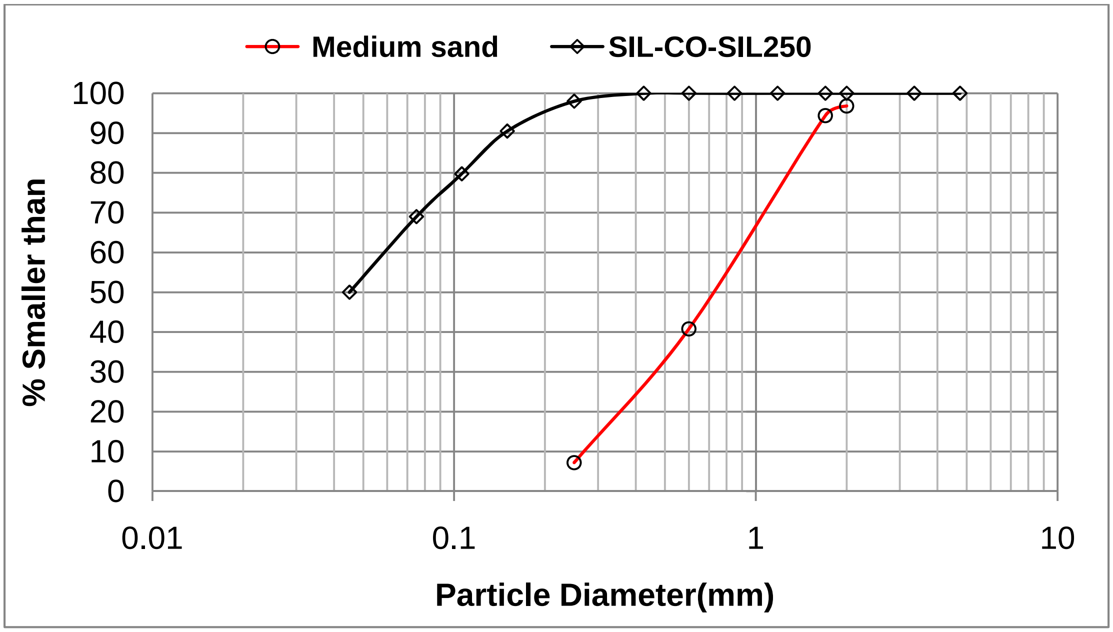
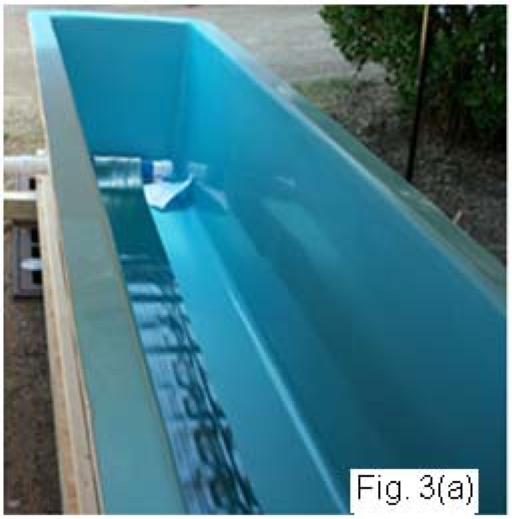


Figure 2. Particle size distribution for medium sized sand and SIL-CO-SIL250.

Experimental procedure

The experimental apparatus for the pilot-scale biofilter tests consists of a fiberglass trough 3 m long having a 0.6 x 0.6 m cross section. The outlet end of the SmartDrain^{TM} is inserted into a slit cut in the PVC collection pipe and secured with screws and silica sealant (Fig. 3(a)). The SmartDrain^{TM} material is installed with the microchannels on the underside of the strip. The SmartDrain^{TM} directs the collected water into the PVC pipe, with a several inch drop to enhance siphoning action (Fig. 3(b)). The SmartDrain^{TM} was installed on top of a 4”(102mm) layer of the drainage sand, and another 4” layer of the sand was placed on top of the SmartDrain^{TM}. The PVC pipe is 2” (5.1cm) in diameter and is placed 1 inch (2.54cm) above the trough bottom. A hole was drilled through the side of the trough for an extension of this pipe. The pipe outlet is located so the flows can be measured and water samples collected for analyses. During the tests, the trough is initially filled with water to a maximum head of 22 inches (56cm) above the center of the pipe. A hydraulic jack and blocks are used to change the slope of the tank. Different lengths of the SmartDrain^{TM} were tested for a range of slopes. Each test was also repeated several times and regression analyses were conducted to obtain equation coefficients for the stage vs. head relationships for these different conditions.



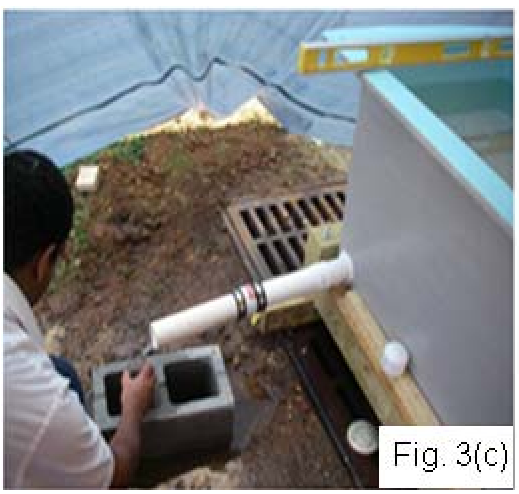


Figure 3, SmartDrain^{TM} installations procedures in the trough.

The second phase of the on-going testing is examining the clogging potential of the SmartDrain^{TM}. Sil-Co-Sil 250, having a median particle size of about 45 µm, is mixed with the test water for the clogging tests. Figure 4(a) shows the tall lined box that was used to verify the head vs. discharge relationships for deeper water and used for the clogging tests. This Formica-lined plywood box is 3ft (91.4cm) by 2.8ft

(85.3cm) in cross sectional area and 4ft (122) cm tall. The box is filled with tap water using a hose to produce a maximum head of 4ft (1.22cm) above the filter, and Sil-Co-Sil 250 is added to the water to provide a concentration of 1g/L (1,000 mg/L).

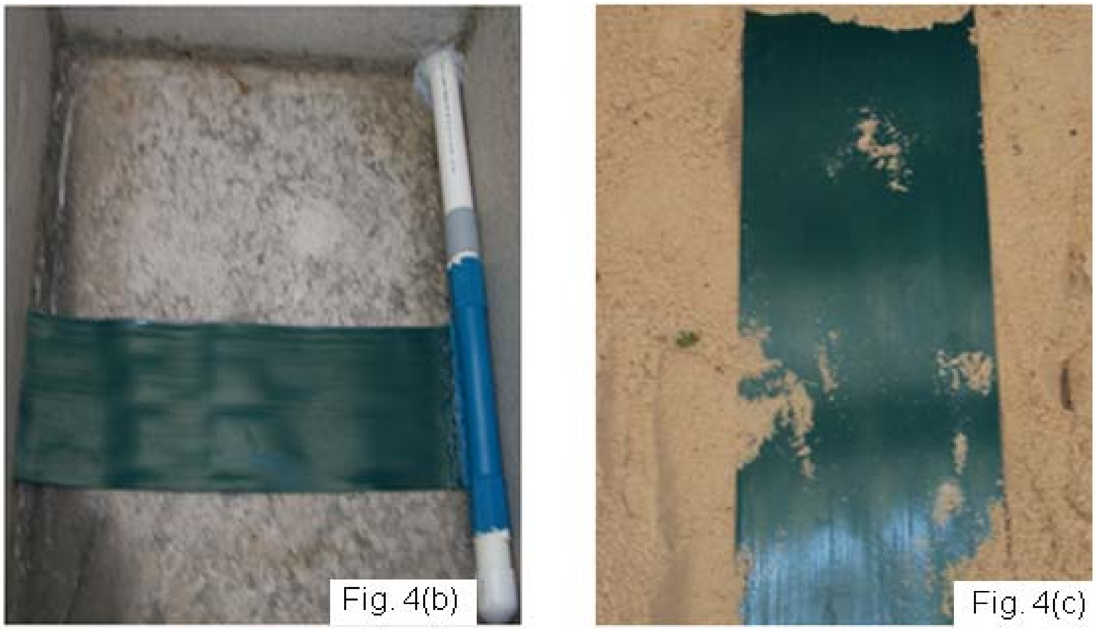


Figure 4, SmartDrain^{TM} installation for the clogging test in the tall box.

Results and Discussions

Effect of Slope on the drainage characteristics of the filter media

Five replicates for each of the five different lengths of the SmartDrain^{TM} (9.4ft (2.87m), 7.1ft (2.2m), 5.1ft (1.56m), 3.1ft (0.95m) and 1.1ft (0.34m)) were conducted to study the variables affecting the drainage characteristics of the material as a function of length, slope, and hydraulic head. Two different lengths of the SmartDrain^{TM} (9.4ft and 7.1ft) were tested for five different slopes (0%, 3%, 6%, 9%, and 12%) and the remaining three lengths of the SmartDrain^{TM} (5.1ft, 3.1ft and 1.1ft) were tested for three different slopes (0%, 3%, and 12%). Flowrate measurements are manually taken from the effluent of the biofilter at 25 to 30 minute intervals until the water is completely drained from the trough. The flows were measured by timing how long it took to fill a 0.5 L graduated cylinder. Stage-discharge relationship plots (Fig. 5) are shown for different length of SmartDrain^{TM} material. Linear regression analyses were used to determine the intercept and slope terms of the head vs. discharge relationships. The p-values of the estimated coefficients were used to determine if the coefficients were significant ($p < 0.05$). All of the five lengths tested for the given slopes showed that slope coefficients were statistically significant ($p < 0.05$), while many of the intercept terms were not found to be significant (Table 1).

Stage-discharge relationship plots (Fig. 5) (The data) shows that slope of the SmartDrain^{TM} has no significant effect. on the stage-discharge relationship.

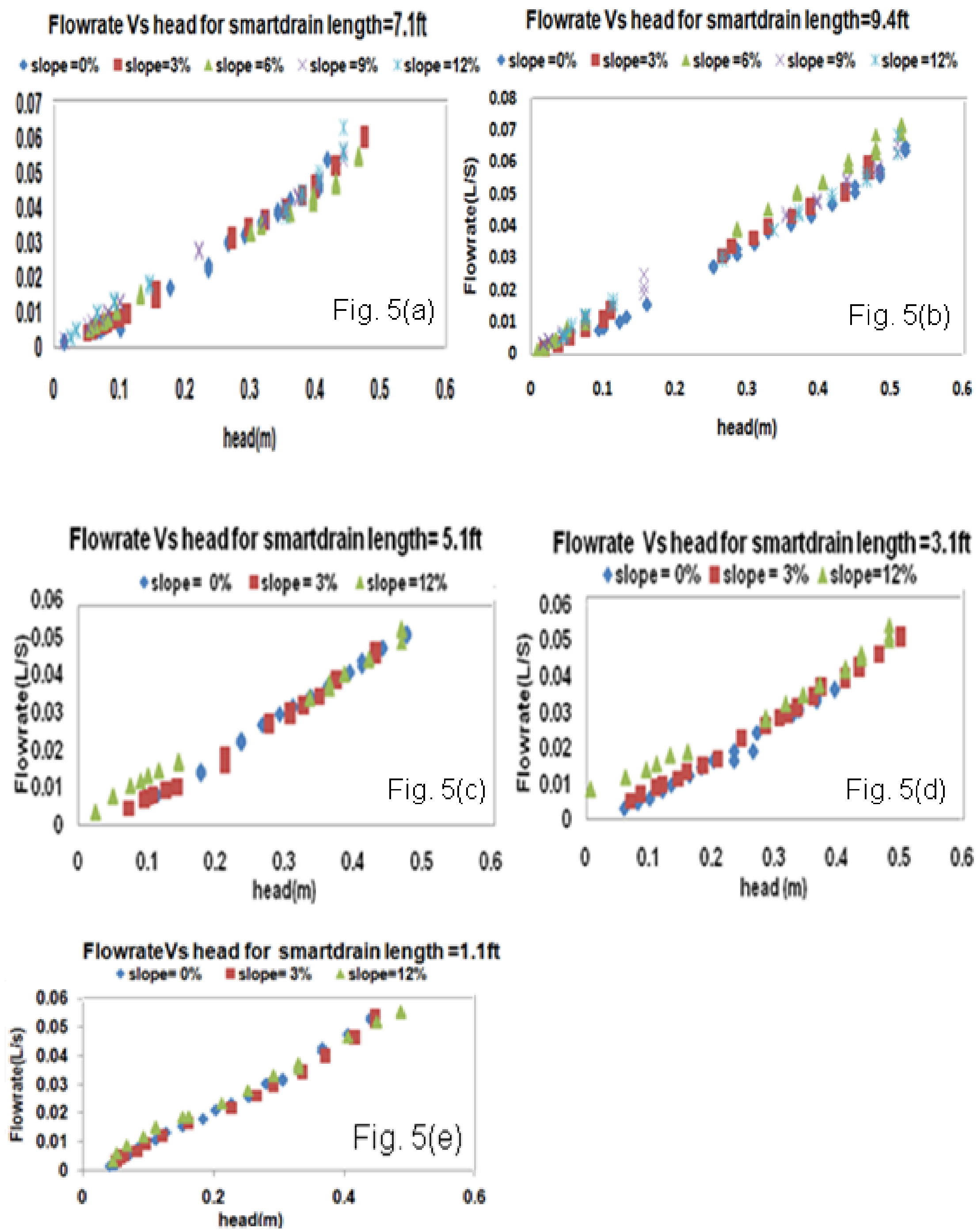


Figure 5, plots of flowrate versus head for five different SmartDrain^{TM} length (a to e) tested for five different slopes.

Clogging

Flowrate measurements are taken from the effluent of the device at (25-30) minute intervals until the water completely drained from the tank. Reductions in the outflow rate relationships of the filter media have not yet been observed during the first nine clogging tests (having a total load of about 9 kg/m^2 onto the filter area). We would normally expect "complete" clogging (to less than about 1m/day flow rates) after many repeated tests on the same media when a resulting total surface loading of about 20 kg/m^2 of sediment has been loaded to the filter area. The solids loading required to induce clogging will be compared between different sand-based media having different particle sizes in experiments planned for the winter and spring of 2010. In addition, algal fouling will be tested during the spring months by allowing nutrient loaded test water to stagnate in the test tank for extended periods and then conducting flow rate measurements.

Turbidity measurements of the effluent are also being taken at 25 to 30 minute intervals at the same time as the flowrate measurements until the water completely drains from the tank. We have observed that turbidity (NTUs) measurement decrease with the head of water in the tank (and effluent flow rate). The initial turbidity levels are about 1,000 NTU in the tank at the beginning of the test (and with similar effluent water turbidity at the beginning of the tests), but with significantly decreasing effluent turbidity values as the test progresses and the flow rates decrease (Fig. 7).

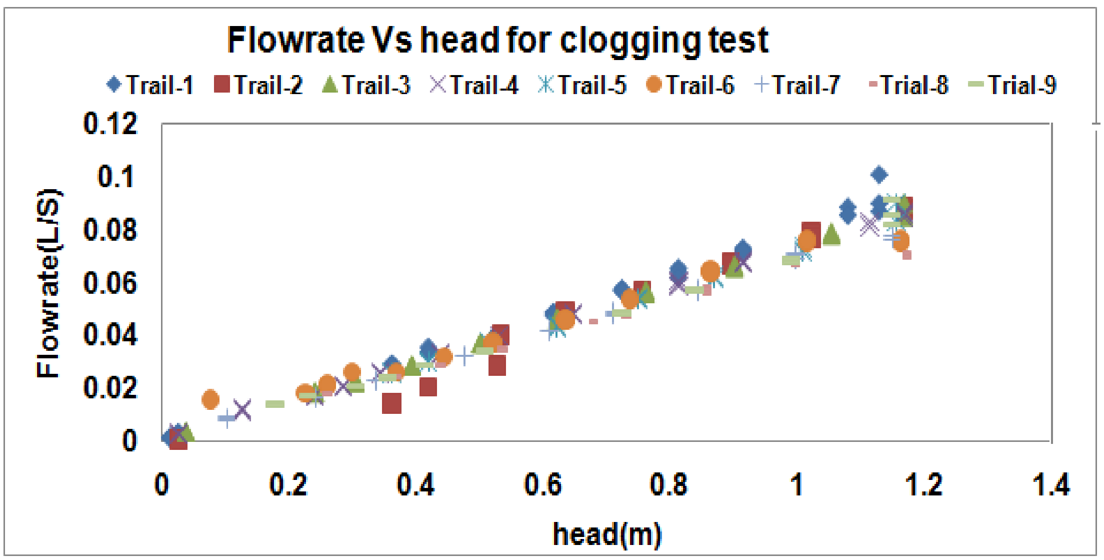


Figure 6, flowrate plotted as a function of head of water in the tank with an influent concentration increase from trial-1 to trail-9.

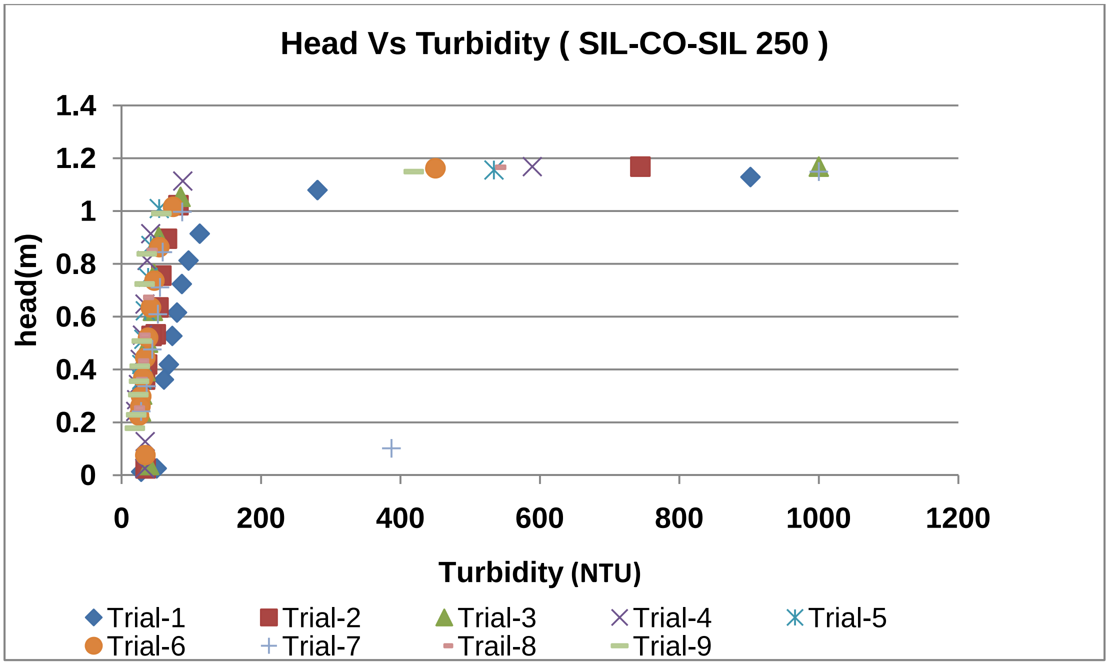


Figure 7, Turbidity as a function of head for the high purity silica (SIL-**CO-SIL®** 250) with increase in influent concentration at each trial.

Table-1 linear regression analysis results for the given SmartDrain™ length and trail slopes

	SmartDrain™ length = 9.4ft		SmartDrain™ length = 7.1ft	
	Slope = 0%		Slope = 0%	
Equation Coefficients	*Coefficient values*	*P-value*	*Coefficient values*	*P-value*
Intercept	-0.005	$p < 0.05$	-0.004	$p < 0.05$
Slope	0.127	$p < 0.05$	0.127	$p < 0.05$
	Slope = 3%		Slope = 3%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	-0.001	$p < 0.05$	-0.003	$p < 0.05$
Slope	0.123	$p < 0.05$	0.126	$p < 0.05$
	Slope = 6%		Slope = 6%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0	#N/A	0	#N/A
Slope	0.135	$p < 0.05$	0.11	$p < 0.05$

	Slope = 9%		Slope = 9%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0.001	$p < 0.05$	0	#N/A
Slope	0.119	$p < 0.05$	0.118	$p < 0.05$

	Slope = 12%		Slope = 12%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0	#N/A	0	#N/A
Slope	0.12	$p < 0.05$	0.121	$p < 0.05$

SmartDrain^{TM} length = 5.1ft

	Slope = 0%		Slope = 3%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	-0.006	$p < 0.05$	-0.005	$p < 0.05$
Slope	0.12	$p < 0.05$	0.114	$p < 0.05$

	Slope = 12%	
	Coefficients	*P-value*
Intercept	0.002	$p < 0.05$
Slope	0.1	$p < 0.05$

L= 3.1ft | L = 1.1ft

	Slope = 0%		Slope = 0%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	-0.005	$p < 0.05$	-0.004	$p < 0.05$
Slope	0.103	$p < 0.05$	0.123	$p < 0.05$

	Slope = 3%		Slope = 3%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	-0.003	$p < 0.05$	-0.003	$p < 0.05$
Slope	0.105	$p < 0.05$	0.116	$p < 0.05$

	Slope = 12%		Slope = 12%	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0.006	$p < 0.05$	0	#N/A
Slope	0.088	$p < 0.05$	0.114	$p < 0.05$

Table-2 linear regression analysis result for clogging tests

	Trial-1		Trial-6	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0	#N/A	0.006	$p < 0.05$
Slope	0.080	$p < 0.05$	0.064	$p < 0.05$
	Trial-2		Trial-7	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	-0.008	$p < 0.05$	0	#N/A
Slope	0.083	$p < 0.05$	0.068	$p < 0.05$
	Trial-3		Trial-8	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0	#N/A	0.0026	$p < 0.05$
Slope	0.0741	$p < 0.05$	0.0620	$p < 0.05$
	Trial-4		Trial-9	
	Coefficients	*P-value*	*Coefficients*	*P-value*
Intercept	0.001	$p < 0.05$	0	#N/A
Slope	0.073	$p < 0.05$	0.071	$p < 0.05$
	Trial-5			
	Coefficients	*P-value*		
Intercept	0	#N/A		
Slope	0.072	$p < 0.05$		

Conclusions

The results from the experiments conducted to test the variables affecting the drainage characteristics of the filter media indicate that slope of the SmartDrain^{TM} material had no significant effect on the stage-discharge relationship whereas effect of length of the SmartDrain^{TM} material on the discharge is observed with decrease in length. Research is ongoing to investigate the clogging potential of the. Research is ongoing to investigate the clogging potential of the SmartDrain^{TM} material. Reductions in the outflow rate relationships of the filter media have not yet been observed during the first nine clogging tests (having a total load of about 9 kg/m^2 onto the filter area), although only about half of the critical loading has been applied to date.