# Examining the Clogging Potential of Underdrain Material for Stormwater Biofilter

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## ABSTRACT

The drainage rates in biofiltration devices are usually controlled using an underdrain that is restricted with a small orifice or other flow-moderating component. These frequently fail, as effective orifices that are used for flow control are usually very small (< 10 mm) and are prone to clogging over time. The main goal of this study is to evaluate the performance of a foundation drain material (SmartDrain™) under a variety of challenging conditions. SmartDrains™ work by capillary action, requiring very little head to initiate flow through the use of a siphon. This paper will present the results from a series of tests conducted to determine the flow capacity and clogging potential of the SmartDrain™ material during biofouling experiments under controlled pilot-scale biofilter conditions. A pilot-scale biofilter that consists of a tall Formica-lined plywood box, 0.90 m by 0.85 m in cross sectional area and 1.20 m tall was used for the tests. The tests were conducted using two different species of green algal that were encouraged to grow in the biofilter device for several weeks before draining. The results indicated that the biofouling had only a small effect on the discharge rates, even though the algal growth was extensive. Prior tests evaluated the SmartDrain™ performance after excessive loadings by fine ground silica particulates (Sileshi et al., 2010b) and also for a range of length and slopes using clean water (Sileshi et al., 2010a ).

## INTRODUCTION

Biofilters (a bioretention device having an underdrain) are widely used in urban areas to reduce runoff volume, peak flows and stormwater pollutants impact on receiving waters. Biofiltration systems have the advantage of being able to be easily integrated into urban areas, as the small-scale devices can be retrofitted into densely built areas and large basins can be located at the outlet of separate stormwater system (LeCoustumer, et al. in press). One of the main factors that reduce the performance of stormwater biofilter devices is clogging of the filter media which in turn can decrease the life span of the device. Sediment deposition is considered to be the main cause of clogging of infiltration devices (Bouwer 2002) and can occur at the surface of the system with the creation of a clogged layer or at some depth where the soil is denser or finer, and where they form a thin subsurface clogging layer. Care also needs to be taken to prevent clogging at the underdrain also; effluent with a high pH value can cause vegetative kill around

the drain opening and causes clogging of the drain screens such as described by Wukasch and Siddiqui (1996 ) as part of the extensive research to examine the reuse of waste materials in construction and repair of highways conducted by Purdue University , Joint Highway Research Project In Cooperation with the Indiana Department of Transportation and the U.S. Department of Transportation Federal Highway Administration.
Several studies have demonstrated the pollutant removal efficiency of stormwater biofilters (City of Austin 1988; Clark and Pitt 1999; Clark 2000; Winer 2000). Water pretreatment techniques such as reducing suspended solids, nutrients, and organic carbon can minimize clogging. However Baveye, et al. (1998) described that even though suspended solids, nutrients, and organic carbon can be mostly removed from the water, clogging can still occur because of microbiological growth on the infiltrating surface (biofouling). A small orifice allows slow release of captured stormwater, but can easily clog due to its size (Hunt 2006). A clogged orifice can affect plant communities inside the facility.

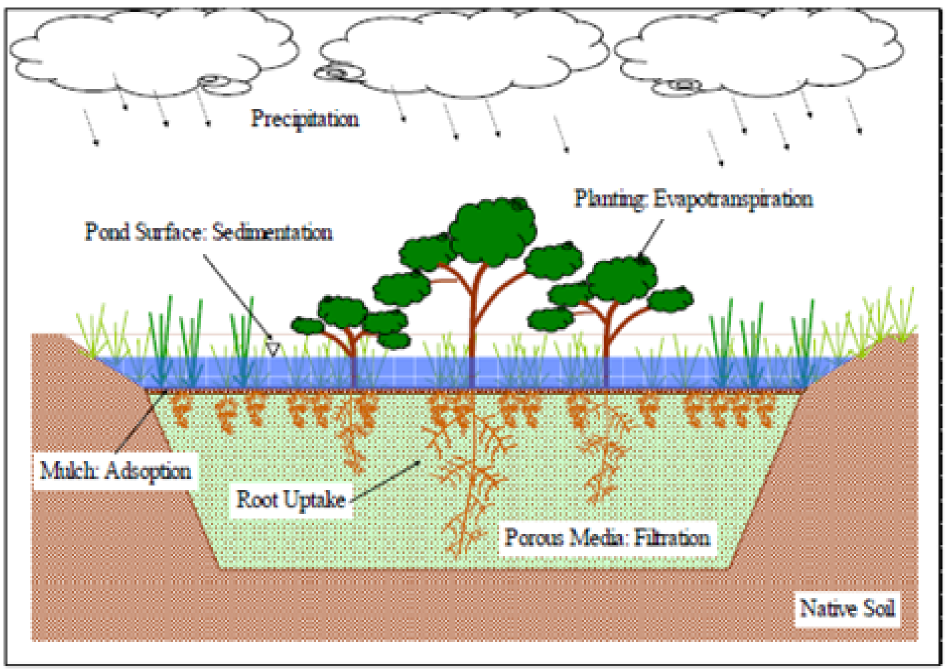


Figure 1, Cross-section of a bioinfiltration stormwater treatment device. bioinfiltration combines sedimentation, filtration, adsorption and biological processes to treat and infiltrate stormwater runoff (Ermilio 2005, figure used with permission ). A biofilter would have an underdrain to capture much of the stormwater filtered through the media and return it to the surface flow regime.

The appropriate choice of vegetation can be a key element in stormwater biofilter design (LeCoustumer et al. in press, Read et al. 2008). Plants play a significant role in limiting the clogging of the filter media, and therefore indirectly increasing the annual load treated limiting the volume of water bypassing the system. The plants also help incorporate the added sediment transported to the biofilter into the growing soil layer, breaking up a surface clogging layer, as long as the biofilter area is large enough. Accumulation of algae and bacterial flocs in the water, on the infiltrating surface; and growth of micro-organisms on and in the soil to form biofilms and biomass can reduce the infiltration capacity of the filter media, as described by Bouwer (2002).

Perforated pipe underdrains in biofilter devices short-circuit infiltration into the underlying soil, resulting in decreased performance and increased surface flows. Orifice outlet controls that allow long residence times (needed to enhance pollutant removal in the biofilter media) usually are very small and clog easily. This paper presents a study conducted on a foundation drain material (SmartDrain$^{TM}$) that can be used in biofiltration devices and provides another option for outlet control. 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, easily meeting typical 72 hr maximum ponded water drainage times usually specified for mosquito control. This is a substantial residence time in the media and also provides significant retention of stormwater before being discharged to a combined sewer system in green infrastructure projects for CSO control. In addition, this slow drainage time will allow infiltration into the native underlying soil, with minimal shortcircuiting to the underdrain. Even sandy-silt loam soils frequently used in bioretention devices may result in extended surface ponding, requiring an underdrain. Conventional underdrains (perforated pipe) reduce ponding, but also decrease infiltration opportunities. SmartDrain$^{TM}$ also reduces the ponding time but does not allow as much short-circuiting of the infiltration water. SmartDrain$^{TM}$ operates under laminar flow conditions (Reynolds number of 100 to 600). The SmartDrain$^{TM}$ has a low sediment carrying capacity due to the low Reynolds numbers and therefore has a reduced clogging potential by the fines that are in the stormwater. It has 132 micro channels about 1 mm in diameters that are connected to the bottom of the 200 mm wide strip with smaller slots. This arrangement results in very small discharge rates (Figure 2).

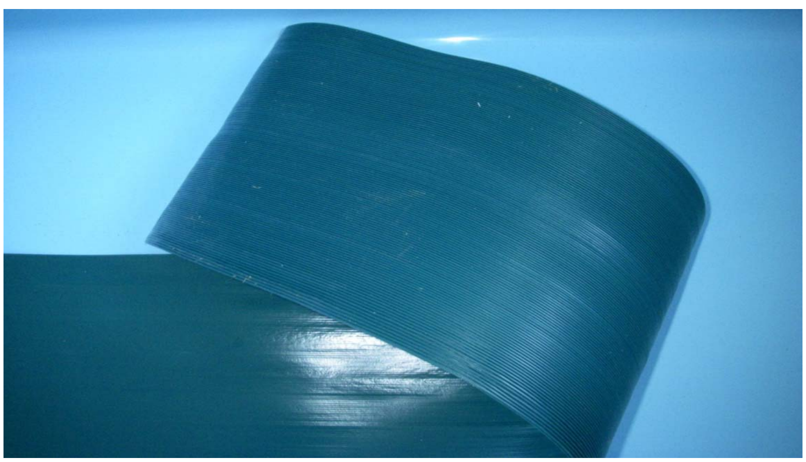

Figure 2. SmartDrain$^{TM}$ material showing the microchannels on the underside of the 200 mm wide strip.

Sand typically used as a filter media at water treatment plants was purchased from a local supplier in Tuscaloosa, Alabama and was used as the bedding material during these tests. The filter sand has a median particle size (*D*50) of about 700 µm and a uniformity coefficient (*Cu*) of 3.3. The particle size distribution of the sand filter media (along with the Sil-Co-Sil material used for the clogging challenge tests) is shown in (Figure 3).

## MATERIALS and METHODS

A pilot-scale biofilter that consists of a tall Formica-lined plywood box, 0.90 m by 0.85 m in cross sectional area and 1.20 m tall (Figure 4a) , was used for both the clogging tests using US Silica Sil-Co-Sil250 ground silica materials as a challenge solution to the test water and biofouling tests to verify the stage-discharge relationships. The outlet end of the SmartDrain™ was inserted into a slit cut in the PVC collection pipe and secured with screws and silica sealant. SmartDrain™ material 0.84m in length was installed with the microchannels on the underside of the strip. The SmartDrain™ directs the collected water into the PVC pipe, with a several inch drop to enhance a siphoning action. The SmartDrain™ was installed on top of a 100 mm layer of the drainage sand, and another 100 mm layer of the sand was placed on top of the SmartDrain™ . The PVC pipe is 50 mm in diameter and is placed at the bottom of the tank. The pipe outlet is located so the flows can be measured and water samples collected for analyses. Detailed SmartDrain ™ installation procedures in a fiberglass trough were described in a separate paper (Sileshi et al., 2010a).

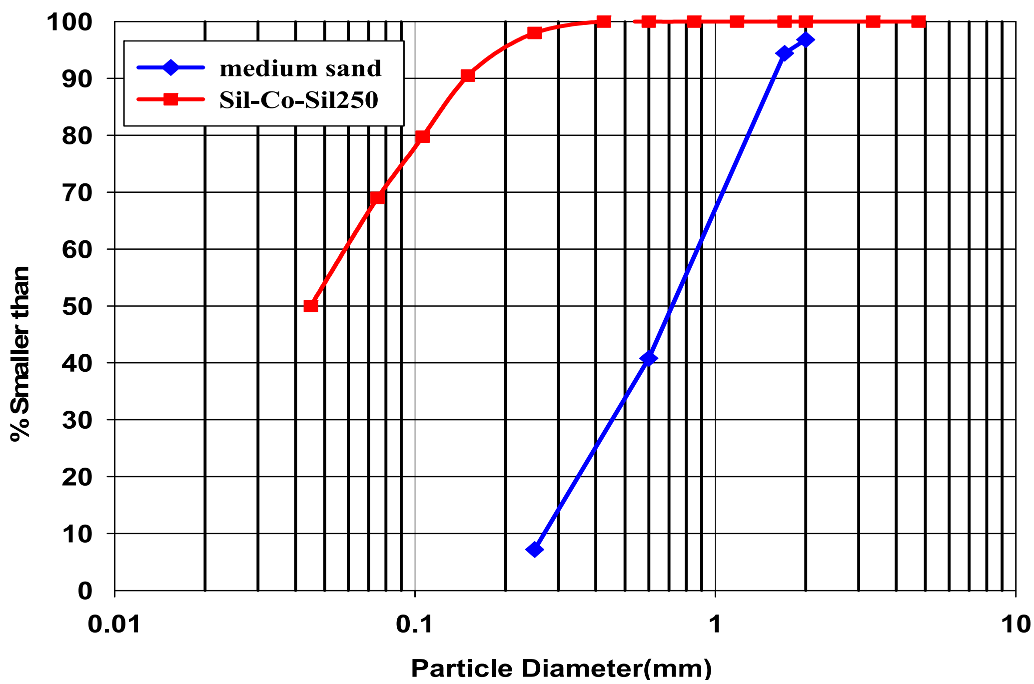


Figure 3. Particle size distributions of the sand filter media material (coarse material on graph) and the U.S Sil-Co-Sil 250 (fine material on graph) used for the clogging test.

To supplement the earlier flow and clogging tests, biofouling tests were conducted from mid June to mid October 2010. The average daily temperature during the test period ranged between 65 and 85 degree Fahrenheit (°F) (http://www.accuweather.com/us/al/tuscaloosa/35401/forecast-month.asp?mnyr=6-01-2010&view=table). Seven biofouling trials were conducted at various algal growth stages in the device, each test lasting several weeks (Table.1). During these tests, the tank was filled with tap water to produce a maximum head of 1.2 m above the center of the pipe. The tank was left open to the sun for several weeks to promote the growth of the algae.

Two different species of algal collected from a pond located at the University of Alabama campus and from the Black Warrior River in Tuscaloosa, AL were added to the test water. Miracle-Gro 12-4-8 all purpose liquid fertilizer (http://www.stancoe.org/scoe/busserv/safety/msds/uploaded/plant%20food,%20all%20purpose-miracle%20gro.pdf) having primary components nitrogen, phosphate and potassium, manufactured by the Scott Miracle-Gro Company, a capful of the fertilizer was added to the test water for the first three trials to increase the growth rate of the algae in the biofilter device (Figure 4a-4f). The depth of the test water in the tank for the first five trials was 1.2m above the center of the pipe, and was reduced to 0.41 m for the last two trails. However, the water depth was noted decreased by a few centimeters with time during the tests because of evaporation. The test water was then allowed to drain at the end of the exposure period, resulting in seven stage-discharge relationships. Regression analyses were conducted to obtain equation coefficients for these different conditions.

Figure4a

Figure 4b

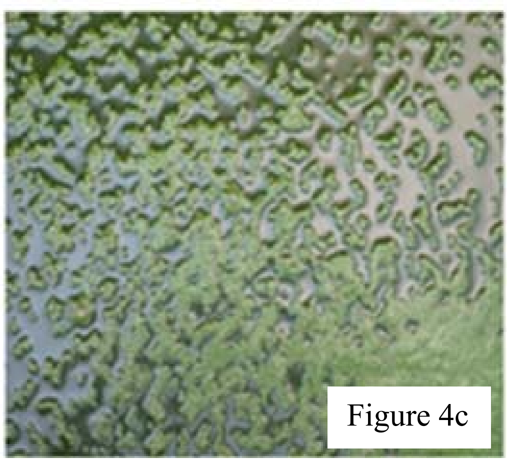

Figure 4c

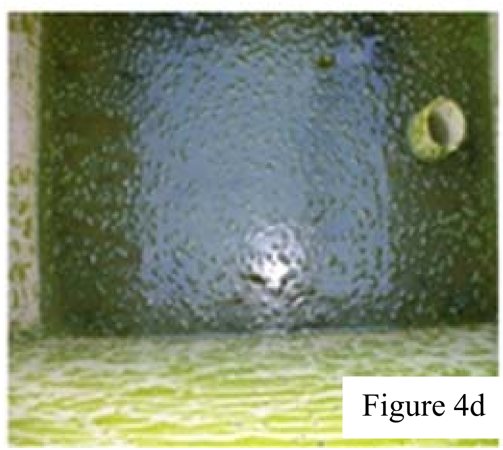

Figure 4d

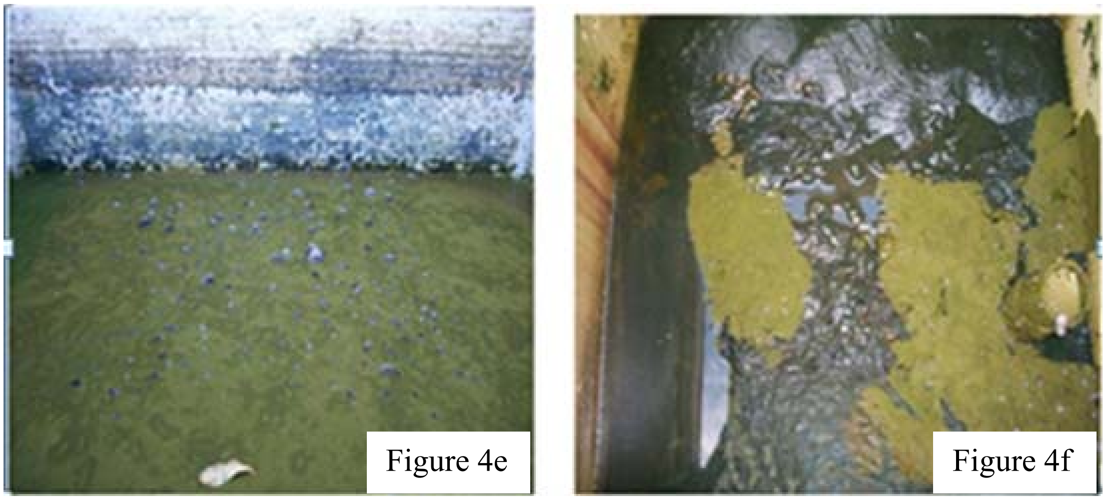


Figure 4. Formica-lined plywood box that was used to measure the head vs. discharge relationships during the biofouling tests and a close look up of algae floating in the tank and trapped on top of the filter sand after the water was completely drained from the tank.

Table-1. Drainage date and exposure period for the algae in the biofilter device

| Trial No. | Drainage date | algae exposure period(days) |
|---|---|---|
| 1 | 17-Jun-10 | 14 |
| 2 | 8-Jul-10 | 35 |
| 3 | 25-Jul-10 | 52 |
| 4 | 12-Aug-10 | 70 |
| 5 | 3-Sep-10 | 92 |
| 6 | 27-Sep-10 | 116 |
| 7 | 11-Oct-10 | 130 |

**DISCUSSIONS**

Flow rate and turbidity measurements were made for the test mixture inside the biofilter box and for the effluent of the device at 25-30 minute intervals until the water completely drained from the tank during the biofouling tests. The flows were measured by timing how long it took to fill a 0.5 L graduated cylinder. Stage-discharge relationship plots (Figure 5) are shown for the seven different trials. Linear regression analyses were used to determine the intercept and slope terms of the resulting equations. The p-values of the estimated coefficients were used to determine if the coefficients were significant ($p < 0.05$). All of the seven trials tested for the biofouling experiment at various growth stages of algae in the tank showed that all slope coefficients were statistically significant ($p < 0.05$), while one of the intercept terms were not found to be significant on the stage-discharge relationship (Table 2).

As noted during the earlier tests (Sileshi et al.(2010a), the physical slope of the SmartDrain™ material (beyond the small drop for the siphon at the header pipe) had no significant effect on the stage discharge relationships, while length had a small, but still significant effect under a range of typical biofilter conditions.

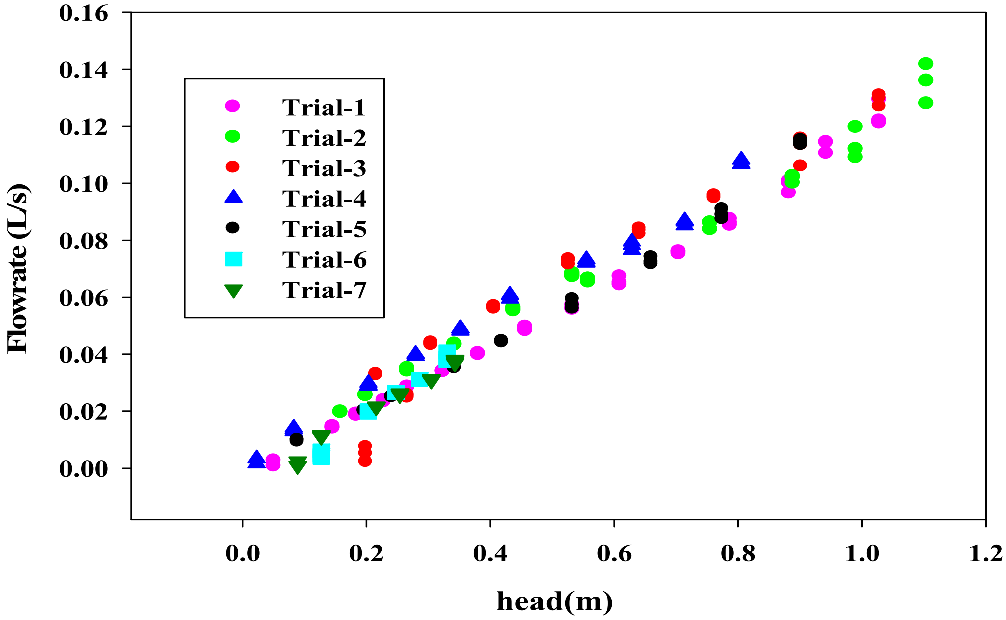


Figure 5. The stage-discharge relationship plots for the biofouling tests and 0.84 m length of SmartDrain™ . These discharge rates are higher than the discharge rates observed during the clogging tests using US silica SIL-CO-SIL® 250

Turbidity values in the tank ranged from 4 to 88 NTU, while the effluent values ranged from 1 to 27 NTU during these biofouling tests. The prior tests conducted to examine the clogging potential of the SmartDrain™ material using the ground silica (SIL-CO-SIL® 250) mixed with the test water had a concentration of about 1,000 mg/L as a challenge solution reported (Sileshi et al. 2010b). The effluent turbidity tests during the clogging tests indicated that the turbidity (NTUs) measurements rapidly decreased with the head of water in the tank (and effluent flow rate) (Figure 7). During the biofouling tests, the influent turbidity (NTU) values in the tank increased with the drop in water level for most of the trials since the algae partially accumulated at the bottom of the device (Figure 6), whereas insignificant differences were observed in the effluent turbidity (NTU) values.

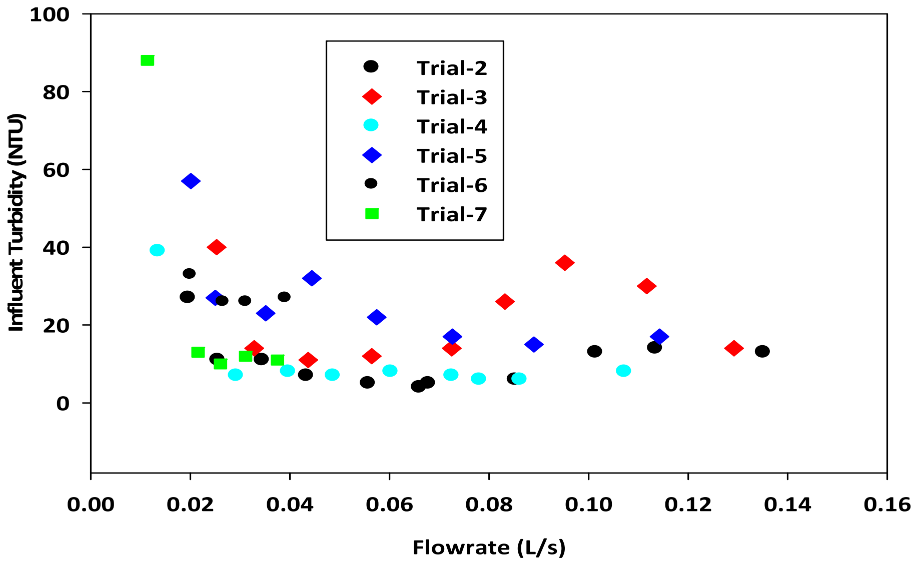


Figure 6. Influent Turbidity (NTU) Vs Flowrate for the biofouling tests. the influent turbidity (NTU) values in the tank increased as the water levels dropped for most of the trials .

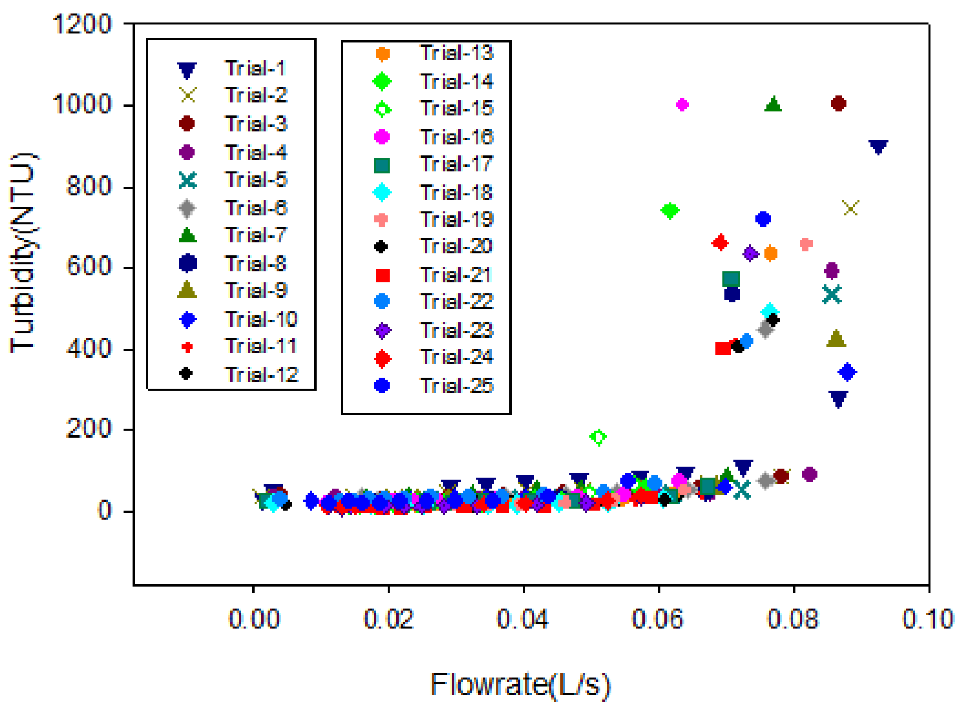


Figure 7. Turbidity measurements taken from the effluent of the device during the clogging tests using ground silica (SIL-CO-SIL® 250) material mixed with the test water. The initial turbidity values in the tank were about 1,000 NTU, similar to the initial turbidity values in the treated water. However, these effluent values decreased significantly and rapidly during the drainage period, with most of the sediment remaining trapped in the tank on top of the filter sand.

Table-2. Linear regression analysis result for the biofouling tests after two different species of algal were added to the test water and allowed to grow in the biofilter device for several weeks

| | | *Coefficients* | | P-value | |
|---|---|---|---|---|---|
| Trial no. | Date | Intercept | slope | Intercept | slope |
| 1 | 17-Jun-10 | -0.005 | 0.120 | < 0.05 | < 0.05 |
| 2 | 8-Jul-10 | 0.003 | 0.114 | < 0.05 | < 0.05 |
| 3 | 25-Jul-10 | 0 | 0.126 | #N/A | < 0.05 |
| 4 | 12-Aug-10 | 0.004 | 0.124 | < 0.05 | < 0.05 |
| 5 | 3-Sep-10 | -0.0056 | 0.1246 | < 0.05 | < 0.05 |
| 6 | 27-Sep-10 | -0.0151 | 0.1649 | < 0.05 | < 0.05 |
| 7 | 11-Oct-10 | -0.0070 | 0.1291 | < 0.05 | < 0.05 |

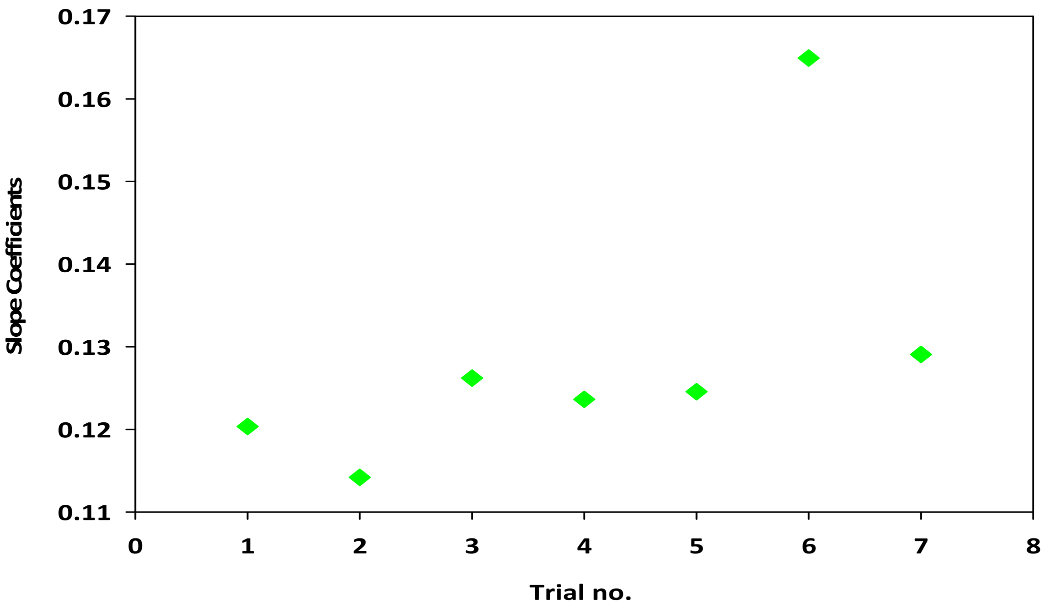


Figure 8. Equation slope coefficients Vs number of trials for the biofouling tests.

## CONCLUSION

The results from the biofouling tests conducted to examine the clogging potential of the SmartDrain$^{TM}$ material indicated that the growth and accumulation of algae in the biofilter device had no significant or obvious effect on the discharge rates. Turbidity (NTU) values in the biofilter tank increased as the test progressed as water level dropped, condensing more algae in the water as it began to settle and accumulate on the surface of the media. These tests indicate that the SmartDrain$^{TM}$ material provides an additional option for biofilters, having minimal clogging potential while also providing very low discharge rates. We expect to continue these tests using different filter media.

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