Tests for Biofilter Flow and Infiltration Rates, Media Amendment Options, Underdrain Options, and Particle Retention

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Presentation Topics

- Introduction
- Investigation of poorly performing biofilter
- Laboratory column and *in-situ* infiltration tests
- Rapid soil surveys in area of rapid rebuilding after severe storms
- Underdrain effects on biofilter performance
- Particle retention in biofilter media
- Conclusions

Note: much of this material is from the Ph.D. dissertation of Dr. Redahegn Sileshi, *Soil Physical Characteristics Related to Failure of Stormwater Biofiltration Devices*. http://unix.eng.ua.edu/~rpitt/Publications/11_Theses_and_Dissertations/Redi_dissertation.pdf

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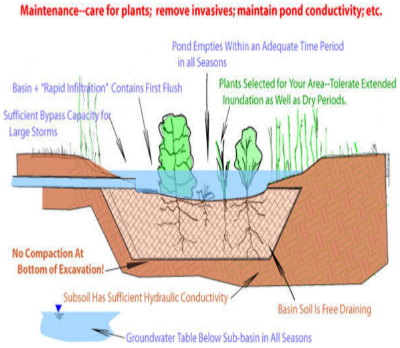
Introduction

- Biofilters (a bioretention device having an underdrain) are widely used in urban areas to reduce runoff volume, peak flows and stormwater discharges and impacts to receiving waters.
- However, the performance of these devices is reduced by clogging of the filter media, which in turn can decrease the life span of the device.
- Knowing the likely effects of soil compaction on urban hydrological conditions is critical for designing stormwater control practices. Restoring the infiltration capacity of a soil lining a biofilter or media is also possible and can provide significant benefits in stormwater management.

- Biofilters are designed with an underdrain connected to a stormwater collection system, while bioretention (bioinfiltration) devices do not have underdrains and discharge runoff into a permeable soil profile, while providing groundwater recharge (Prince George County 2002).



Cross-Section of a Bioinfiltration Stormwater Treatment Device (Source: VUSP). A biofilter would have an underdrain to capture much of the stormwater filtered through the media and return it to the surface flow regime

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- There is a need to develop and test alternatives that result in greater flexibility and efficiency in the design of biofiltration and bioretention devices
  - Alternative underdrain system to encourage infiltration
  - Effects of compaction and restoration of media
  - Better flow and particulate trapping information for different types of media

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- The underlying soil’s infiltration rate is usually the main factor that determines if an underdrain is required or not. In cases where existing soils have poor infiltration capacities, underdrains are typically used to discharge the filtered water back to the surface flows.
- Media selection is one of the critical factors affecting biofilter performance, as the media affects the amount of runoff that is treated and the level of treatment that can be obtained.

- Few quantitative guidelines are available for the design of biofilters and bioinfiltration devices for specific treatment goals while minimizing operational problems. A common restrictive example:
  - The natural soils beneath bioinfiltration systems should have infiltration rates greater than 0.5 in/hr (12 mm/hr) if underdrains are not to be used; however, when underdrains are not incorporated into the bioretention design, there is an increased risk of generating overflows during a storm event (Jones and Hunt 2009).

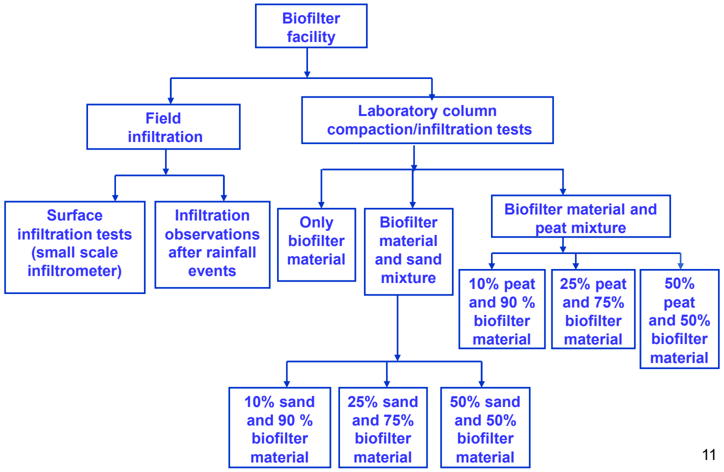
This suggestion is not true for many cases, as biofilters can be established in areas having marginal soil. Most underdrains severely handicap the amount of water infiltrated through short-circuiting. Restrictive underdrains can be a good solution however.

Investigation of Poorly Performing Biofilter

Field Testing of Existing Poorly Functioning Biofilter

- This poorly functioning biofilter is located in Shelby Park, adjacent to The Univ. of Alabama rental car parking lot from which it receives flow.
- It had standing water for extended periods and poor vegetation
- The biofilter is about 100 m long and 10 m wide (0.085 ha) and is about 11% of the paved and roofed source area.

Field and Lab Infiltration Study of Existing Biofilter



Biofilter facility

Field infiltration
- Surface infiltration tests (small scale infiltrometer)
- Infiltration observations after rainfall events

Laboratory column compaction/infiltration tests
- Only biofilter material
- Biofilter material and sand mixture
  - 10% sand and 90 % biofilter material
  - 25% sand and 75% biofilter material
  - 50% sand and 50% biofilter material
- Biofilter material and peat mixture
  - 10% peat and 90 % biofilter material
  - 25% peat and 75% biofilter material
  - 50% peat and 50% biofilter material

Field Infiltration Tests

- Four clusters of three infiltrometer tests were conducted to examine variations along the biofilter length.
- The infiltrometers were gently driven into the surface of the biofilter soil until the “saturn” ring was against the soil surface.
- Relatively flat areas were selected in the biofilter to install the Turf-Tec infiltrometers.

Very little “bio” in this biofilter, indicating compacted media having adverse affects on plant growth. This biofilter also had long periods of standing water.

- After the soil was inspected and sealed around each ring to make sure that it was even and smooth, clean water was poured into the inner ring and allowed to overflow and fill up the outer ring.
- The rate of decline in the water level was measured by starting the timer immediately when the pointer reached the beginning of the depth scale.
- The tests were conducted for a period of 1-2.5 hr, until the infiltration rate become relatively constant.

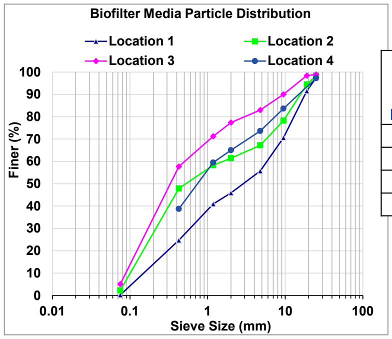
A Close Up of Turf-Tec Infiltrometer (Turf-Tec International)

Infiltration after Rainfall Events

- Extended periods of surface ponding of water on the biofilter was often observed following heavy rainfall events.
- Infiltration rate measurements were manually recorded from biofilter ponded areas after five rainfall events.
- Depth indicator rules were placed at 3 to 5 different locations along the biofilter at surface ponding areas.
- The decrease in the depth of water was measured every 30 min at the beginning of the observations and less frequently as the test progressed, until the water completely infiltrated.

The Vegetation Cover Is Very Poor Indicating Likely Serious Compaction).

Biofilter Media Characteristics



Test locations	median size D_{50} (mm)	uniformity coefficient (C_u)	dry density (g/cm³)	moisture content (%)
1	3.0	38	2.18	9.2
2	0.5	17	2.32	5.6
3	0.3	5.6	1.80	8.0
4	0.7	12.5	2.05	8.2

- Density and uniformity coefficients (D60/D10) are high.

Laboratory Column and *In-situ* Infiltration Tests to Identify Restoration Options for Poorly Operating Biofilter

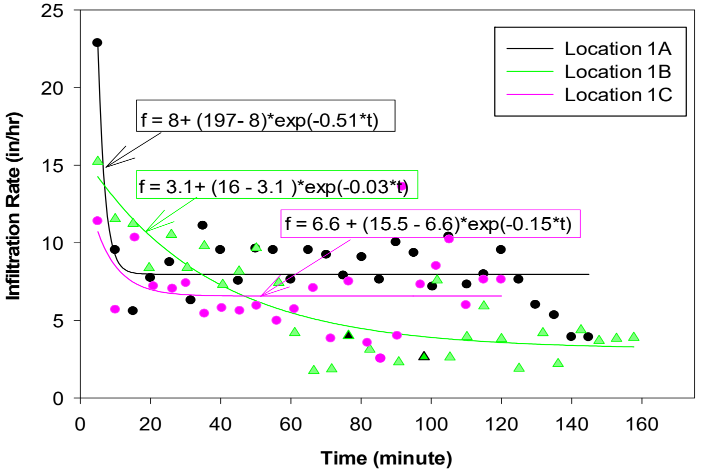
Lab Column Tests

- The effects of different compaction levels on the infiltration rates through the biofilter media in controlled laboratory column tests, along with benefits associated with adding sand, to the media mixture were examined.
- 100 mm diameter PVC pipes (Charlotte Pipe TrueFit 4 in. PVC Schedule 40 Foam-Core Pipe) 0.9 m long, were used for these test.
- The bottom of the columns had a fiberglass window screen secured to contain the media and were placed in funnels.

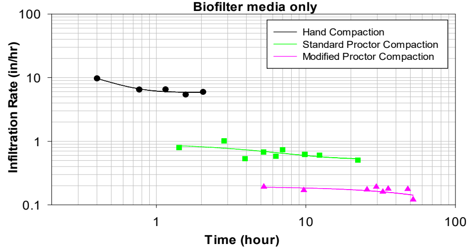
- To separate the gravel layer from the media layer, a permeable fiberglass screen was also placed over the gravel layer.
- The columns were then filled with the biofilter media imported from the biofilter, with varying amounts of added filter sand added mixed with the media. The media layer was about 0.5 m ft thick.
- The infiltration rates were measured in each column using clean tap water.
- The surface ponding depths in the columns ranged between 30 and 35 cm, similar to observed maximum ponding depths.

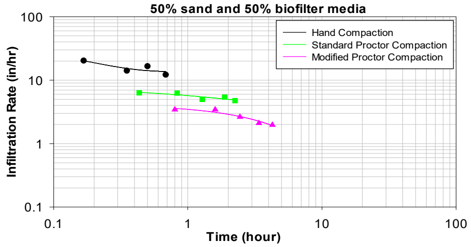
Data series	Compaction	percent (%) sand	percent (%) media
1	hand	0	100
2	standard proctor	0	100
3	modified proctor	0	100
4	hand	10	90
5	standard proctor	10	90
6	modified proctor	10	90
7	hand	25	75
8	standard proctor	25	75
9	modified proctor	25	75
10	hand	50	50
11	standard proctor	50	50
12	modified proctor	50	50

In Situ Biofilter Media Infiltration Using Turf-Tec Infiltrometers



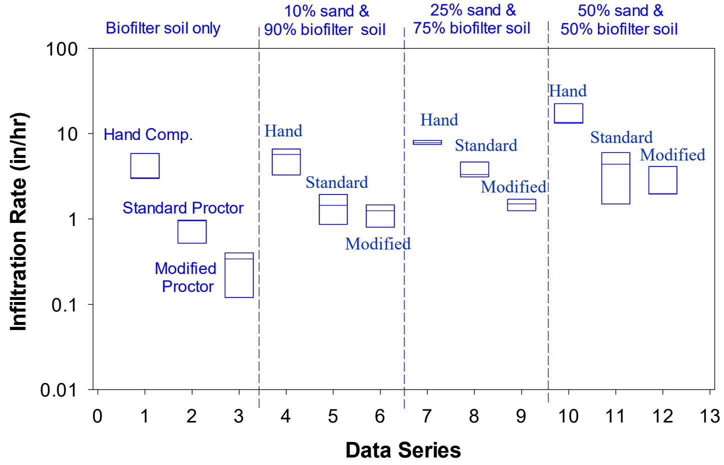
Biofilter Media Infiltration Characteristics using Lab Columns





Summary of Lab Biofilter Media Inf. Rate Comparing Different Compaction Conditions with Varying Amounts of Sand Amendments

***In-situ* observations after rains were similar to standard to modified compaction (infiltrometers over-estimated infiltration rates)**



Rapid Soil Infiltration Surveys in Area Subject to Rapid Rebuilding after being Destroyed by Tornado

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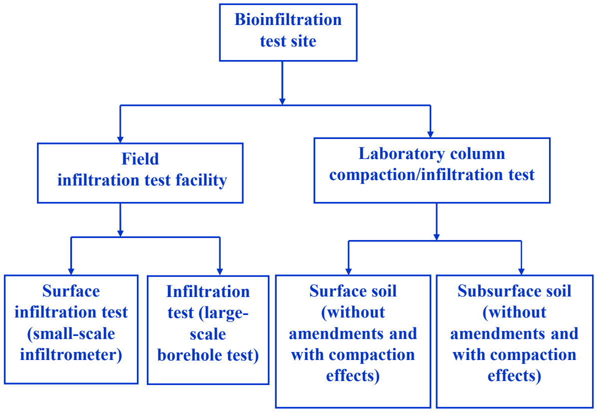
Soil Media Characteristics at Reconstruction Sites

- Laboratory and field-scale tests were conducted to provide data on the existing soil characteristics at candidate stormwater bioinfiltration sites.
- Surface and subsurface soil characteristic studies were conducted to assist in the design of new stormwater management practices in the city of Tuscaloosa, AL.
- The test sites are located in four areas which were destroyed by the April 27, 2011 tornado that devastated the city of Tuscaloosa and are undergoing reconstruction.

Field and Lab Infiltration Study of Stormwater Bioinfiltration Sites



Bioinfiltration test site

Field infiltration test facility

Laboratory column compaction/infiltration test

Surface infiltration test (small-scale infiltrometer)

Infiltration test (large-scale borehole test)

Surface soil (without amendments and with compaction effects)

Subsurface soil (without amendments and with compaction effects)

Stormwater Bioinfiltration Site Studies

- The test sites are all located adjacent to fire hydrants for easy access to large quantities of water and are located in the city's right-of way.
- A 1 m diameter auger was used to drill holes about 1 to 1.5 m deep.
- An approximate 2 m length of Sonotube was inserted in the bore holes to maintain structural integrity and had a several cm layer of coarse gravel placed on the bottom to protect the native soil.

Bore Hole Drilling, Double-ring and Bore Hole Infiltration Measurement Installations (Intersection of 21st Ave. E. and University Blvd E).

Field Tests for Stormwater Bioinfiltration Construction Sites

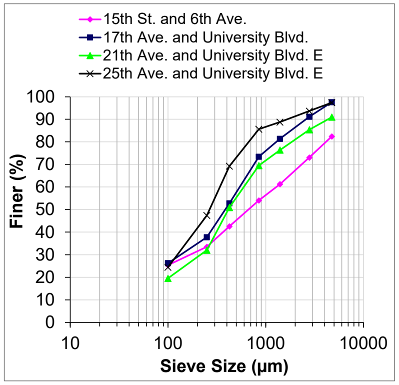
- During the tests, these bore holes were filled with water from the fire hydrants and the water elevations were manually measured with time until the infiltration rates reached an approximate steady rate.
- The effects of different compaction levels on the infiltration rates through the soil (obtained at the surface and subsurface locations at the test sites) was examined during laboratory column experiments.

Bore Hole Drilling, Double-ring and Bore Hole Infiltration Measurement Installations (Intersection of 21st Ave. E. and University Blvd E).

- Aerial Photograph of Bioinfiltration Site and Double-ring Infiltration Measurement Installation on 17th Ave. E. and University Blvd. E. (Tuscaloosa Physical Therapy).

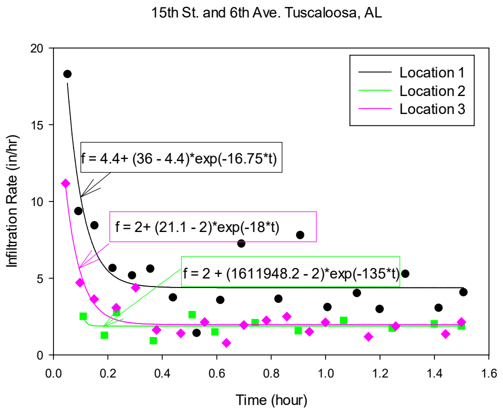
Bioinfiltration Site Soil Media Characteristics

test locations	median size D_{50} (mm)	uniformity coefficient (C_u)	dry bulk density (g/cm³)	moisture content (%)
1	0.7	75	1.88	17.3
2	0.4	37	1.66	19.8
3	0.4	12	1.61	12.3
4	0.3	6	1.66	14.2



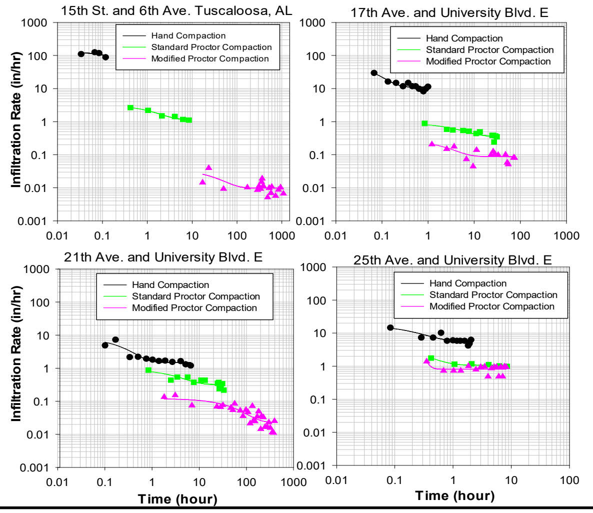
Uniformity values were high, but compaction was moderate

Example of Surface Infiltration Measurements Fitted with Horton Equation

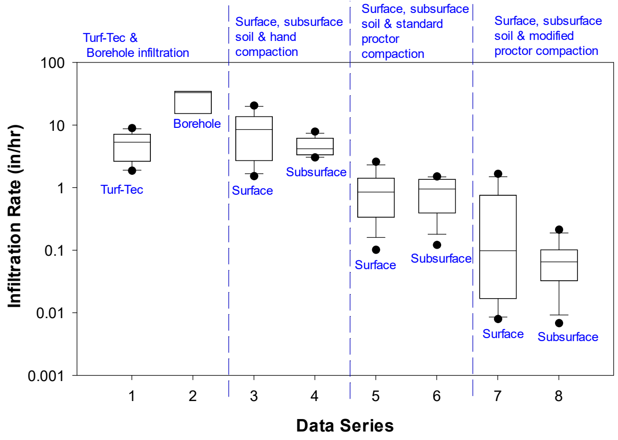


Surface Soil Infiltration Characteristics using Lab Columns

(Site measurements indicated “hand” to standard compaction)



Summary of Surface, Subsurface, and Laboratory Infiltration Data for Bioinfiltration Sites



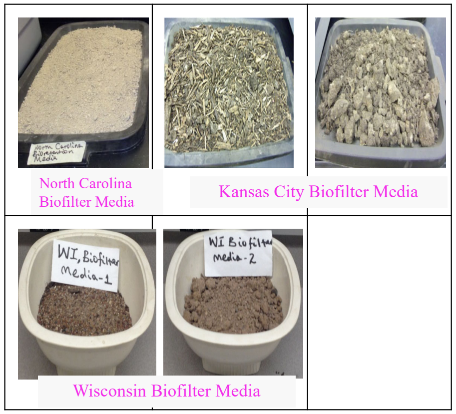
Lab Column Tests for Predicting Changes in Flow with Changes in Various Biofilter Mixtures

- Appropriate hydraulic characteristics of biofilter media, including flow rate and water contact time, along with pollutant removal, are important characteristics when selecting the media and associated subsurface drainage system.
- A series of controlled laboratory column tests conducted using various media to predict changes in flow with changes in the mixture, focusing on media density associated with compaction, particle size distribution (and uniformity), and amount of organic material.

- The results of these tests will enable the biofilter designer to better estimate the flow rates and filter residence times for various mixtures of common biofilter media components.
- The laboratory columns used in the tests have various mixtures of sand and peat. The results of the predicted performance of these mixtures were also verified using column tests (for different compaction conditions) of surface and subsurface soil samples obtained from Tuscaloosa, AL, infiltration test areas, along with biofilter media obtained from actual Kansas City biofilters, standard samples of North Carolina media, and Wisconsin biofilter media.

Actual Biofilter Media

The effects of different compaction levels on the infiltration rates through the soil media obtained from Kansas City biofiltration monitoring test sites, North Carolina and Wisconsin media samples, were examined during laboratory column testing in The University of Alabama Environmental Engineering Laboratory.



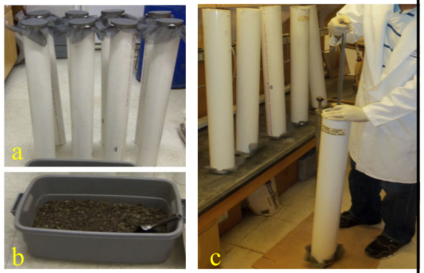
North Carolina Biofilter Media

Kansas City Biofilter Media

Wisconsin Biofilter Media

Lab Column Tests

- Three levels of compaction were used to modify the density of the media layer during the tests: hand compaction, standard proctor compaction, and modified proctor compaction.
- 100 mm diameter PVC pipes 0.9 m long, were used for these tests
- The densities were directly determined by measuring the weights and volume of the media material added to each column.



Lab column construction for flow test using bioretention media: a) bottom of the columns secured with a fiberglass window screen, b) bioretention media, and c) compaction

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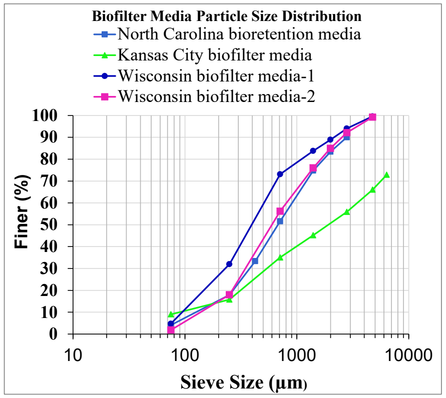
Lab Measurements of Porosity of Soil Media

- The pore volumes of the soil media were determined from the volume of water needed to saturate the media in the columns.
- To keep water from coming out from the soil columns during the porosity measurements, plastic sheeting sealed with tape on the inside and wet mat secured using screw-type radiator hose clamps on the outside and bottom of the columns to form a seal.
- The bottoms of the columns were placed in buckets so that when the seals were lift up the water flowed into the buckets.
- The volume of the void in 5 cm pea gravel placed in the bottom of each column was subtracted from the total void volume of a water-saturated, soil and gravel layer in the columns to get the void in soil media alone.

- Three levels of compaction were used to modify the density of the column media samples during the tests: hand compaction, standard proctor compaction, and modified proctor compaction. Both standard and modified proctor compactions follow ASTM standard (D 1140-54).
- The media layer was about 0.5 m thick.
- The infiltration rates were measured in each column using clean tap water and were replicated three times.
- The surface ponding depths in the columns ranged between 28 cm and 36 cm to correspond to the approximate maximum ponding depths at biofilters.

Actual Biofilter Media Particle Size Distribution

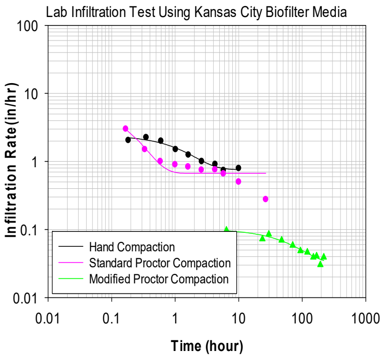
- Samples of the sand-peat mixture and bioretention media were also analyzed by Auburn University's Soil Testing Laboratory, where soil texture, organic matter, and general nutrients were also analyzed.

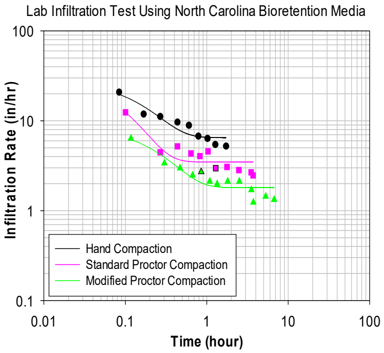


The particle distribution graph indicate that the material is relatively coarse, but the KC media has larger uniformity coefficient.

Lab Infiltration Data Fitted to Horton's Equation

- Infiltration data for different test trials were fitted to Horton's equation to estimate f_c (final infiltration) based on the observed data

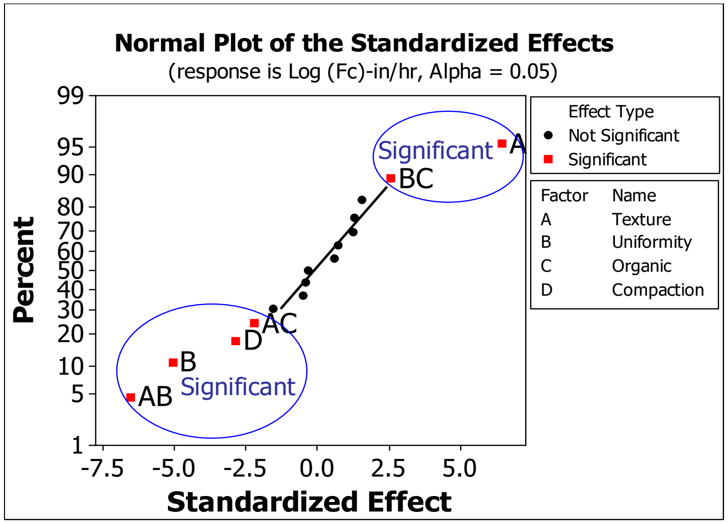




Full 2^4 Factorial Design

Case	Texture	Uniformity	Organic content	Compaction	Average Fc for test conditions (in/hr)
1	+	+	+	+	3.6
2	+	+	+	-	8.2
3	+	+	-	+	1.6
4	+	+	-	-	4.4
5	+	-	+	+	43.2
6	+	-	+	-	92.3
7	+	-	-	+	394.0
8	+	-	-	-	404.7
9	-	+	+	+	2.7
10	-	+	+	-	18.3
11	-	+	-	+	0.7
12	-	+	-	-	7.8
13	-	-	+	+	4.2
14	-	-	+	-	22.3
15	-	-	-	+	3.0
16	-	-	-	-	7.5

Normal Plot of the Standardized Effects

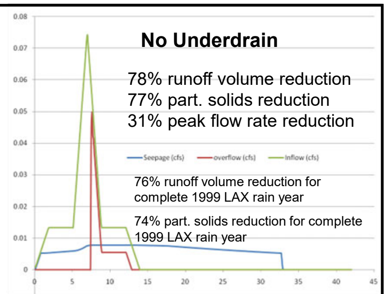


Underdrain Effects on Biofilter Performance

- Perforated pipe underdrains short-circuit natural infiltration, resulting in decreased performance.
- Restricted outlet control can be more consistent in providing desired resident time for pollutant control.
- However, most outlet controls (underdrains) are difficult to size to obtain long residence times.
- Orifice outlet controls that allow long residence times usually are very small and clog easily.
- We studied a foundation drain material (SmartDrain^{TM}) that can be applied to biofiltration devices and provide another option for outlet control.

Underdrain Effects on Water Balance

19 mm rain with complex inflow hydrograph from 0.4 ha of pavement. 2.2% of paved area is biofilter surface, with natural loam soil (12 mm/hr infilt. rate) and 0.65 m of modified fill soil for water treatment and to protect groundwater.

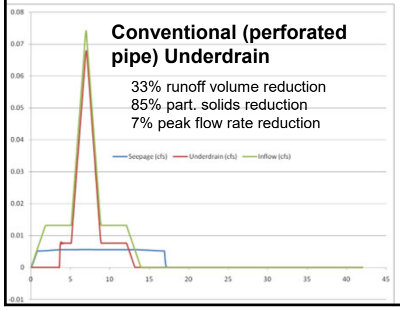


No Underdrain

78% runoff volume reduction
77% part. solids reduction
31% peak flow rate reduction

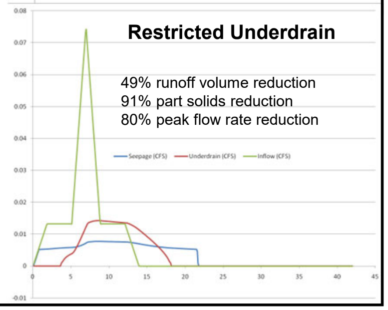
76% runoff volume reduction for complete 1999 LAX rain year

74% part. solids reduction for complete 1999 LAX rain year



Conventional (perforated pipe) Underdrain

33% runoff volume reduction
85% part. solids reduction
7% peak flow rate reduction

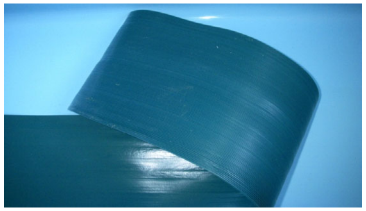


Restricted Underdrain

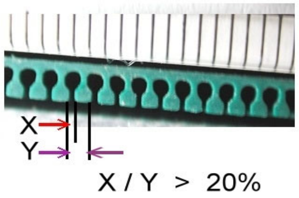
49% runoff volume reduction
91% part solids reduction
80% peak flow rate reduction

Study on Underdrain (SmartDrain ™) Material

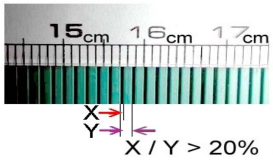
- The drainage characteristics of the SmartDrain™ material (such as length, slope, hydraulic head, and type of sand media) under a range of typical biofilter conditions were examined using a pilot-scale biofilter device.



Close-up photograph of SmartDrain™ material showing the microchannels on the underside of the 200 mm wide strip. It has132 micro channels.



Y: Pitch spacing 1.5mm



X: Water inlet opening 0.3mm

SmartDrain™ (http://www.smartdrain.com/)

- SmartDrain™ operates under laminar flow conditions (Reynolds number of 100 to 700); low sediment carrying capacity and reduced clogging potential.

Drainage Characteristics of the SmartDrain™ Material

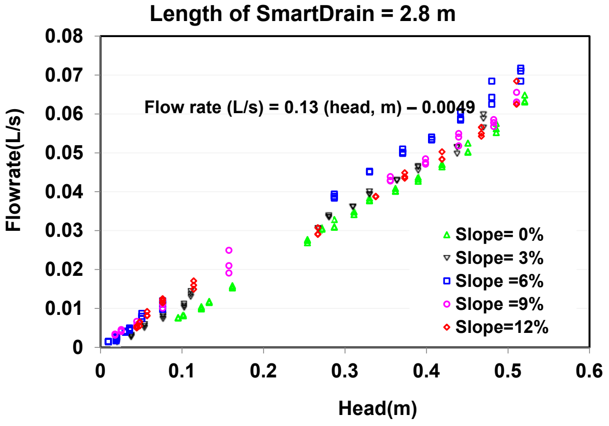
- A pilot-scale biofilter was used to test the variables affecting the drainage characteristics of the underdrain material (Length, Slope, Hydraulic head, and type of sand media).
- The SmartDrain™ was installed on top of a 100 mm layer of the drainage sand, and another 100 mm layer of the sand was placed on top of the SmartDrain™.
- During the tests, the trough was initially filled with water to a maximum head of 56 cm above the center of the pipe and then allowed to drain, resulting in head vs. discharge data.

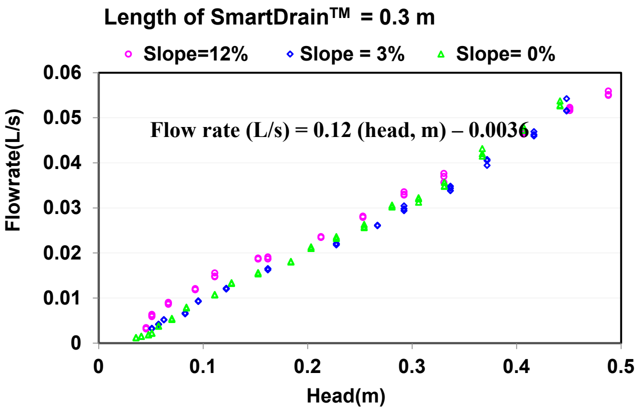
A fiberglass trough 3 m long and 0.6 m X 0.6 m in cross section used as the pilot-scale biofilter

- The flows were measured by timing how long it took to fill a 0.5 L graduated cylinder.
- Five replicates for each of five different lengths of the SmartDrain™ ranging between 0.3 m and 2.8 m and three to five slopes were examined to study the variables affecting the drainage characteristics of the material.
- Flow rate measurements were manually taken from the effluent of the biofilter at 25 to 30 minute intervals until the water was completely drained from the trough.
- A hydraulic jack and blocks were used to change the slope of the tank.

Test for effect of length and slope on the drainage characteristics of SmartDrain™ material

Slope Tests on the SmartDrain^{TM} Material





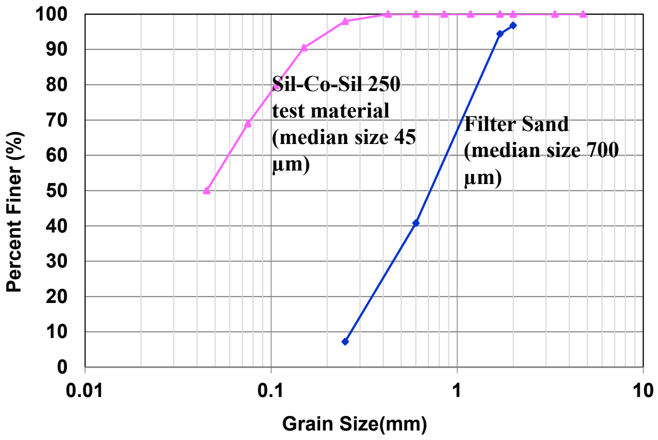
Slope of the SmartDrain^{TM} material had no significant effect on the stage-discharge relationship, whereas only a small effect of length of the SmartDrain^{TM} material on the discharge was observed (operates similar to a series of very small orifices).

Examining the Clogging Potential of the SmartDrain^{TM}.

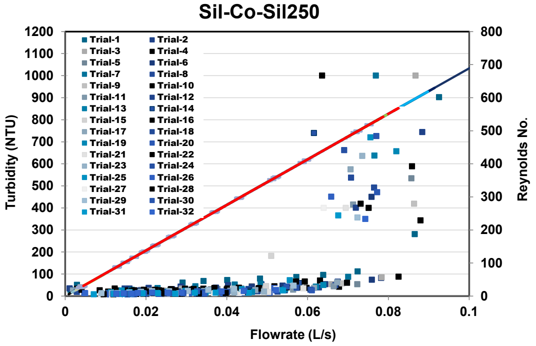
- A Formica-lined plywood box was used to verify the head vs. discharge relationships for deeper water and used for the clogging tests.
- The SmartDrain^{TM} was installed on top of a 10 mm layer of the drainage sand, and another 10 mm layer of the sand was placed on top of the SmartDrain^{TM}.
- The box was filled with tap water to produce a maximum head of 1.2 m above the filter.
- Sil-Co-Sil 250 was mixed with the test water to provide a concentration of 1,000 mg/L.

Formica-lined plywood box 1 m by 0.85 m in cross sectional area and 1.2 m tall.

Particle size distributions of the sand filter media, and the US Silica Sil-Co-Sil 250 ground silica material used in the clogging tests.

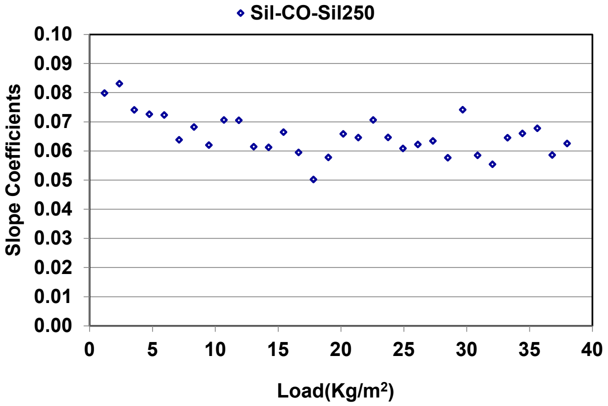


Reynolds No. vs. Flowrate relationships for all test trials superimposed on Turbidity measurements plots taken from the effluent of the device during the clogging tests. Reynolds No. vs. Flowrate relationships are represented by the first order linear equation.



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.

Plot showing Sil-Co-Sil 250 load(kg/m^2) vs. slope coefficients for the clogging tests.



Very little reduction in flow rates observed with time, even after 40 kg/m^2 load on the biofilter (2 to 4 times the typical clogging load)

Biofouling Testing of SmartDrain^{TM} Material

- The Formica-lined plywood box was also used to verify the head vs. discharge relationships for the biofouling tests.
- The SmartDrain^{TM} 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^{TM}.
- The box was filled with tap water and left open to the sun for several weeks to promote the growth of algae. Two different species of algal and liquid fertilizer were added to the test water.

	Drainage	algae exposure
Trial No.	date	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

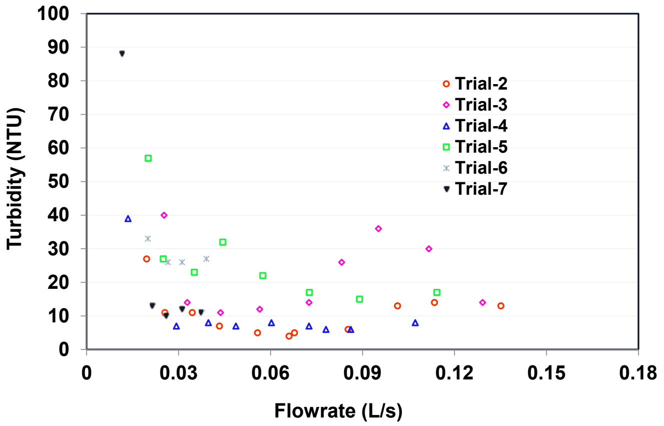
growth of algae in the biofilter device

- Turbidity measurements were taken from the influent and effluent of the device at 25 to 30 minute intervals until the water was completely drained from the tank

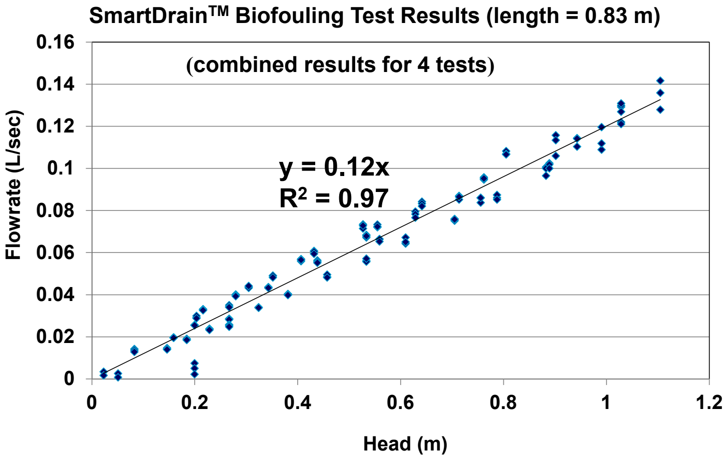
A close-up photograph of algae floating in the tank and trapped on top of the filter sand after the water was completely drained from the tank.

- Influent turbidity values in the tank after about four month ranged from (11 to 88 NTU) whereas effluent values (1 to 27 NTU) during the drainage period.

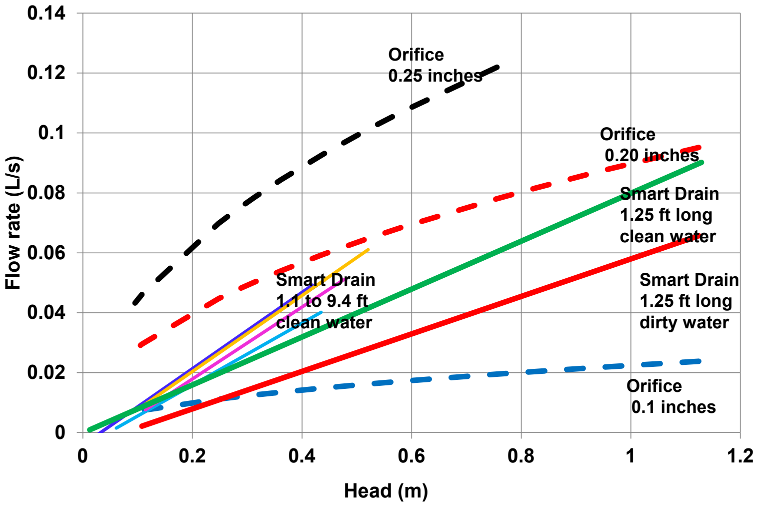
Turbidity (NTU) vs. Flowrate for the biofouling tests



Stage-discharge relationships for the biofouling tests were very similar to the pilot scale test using clean water.



SmartDrain^{TM} Flowrates Compared to Very Small Orifices



Biofilter Underdrain Options and Water Balance

- The sandy-silt loam soil results in extended surface ponding, requiring an underdrain.
- Conventional underdrain (perforated pipe) reduces ponding, but also decreases infiltration opportunities.
- SmartDrain^{TM} also reduces ponding time, while providing additional infiltration.

	Surface ponding (hrs)	Infiltration volume (ft³)	Surface discharge (ft³)	Subsurface (filtered) discharge (ft³)	Volume discharge reduction (%)
No underdrain	**56**	**115**	**126**	**0**	**48%**
Typical underdrain	**20**	**51**	**118**	**72**	**21%**
SmartDrain™	**25**	**80**	**118**	**43**	**33%**

Particle Retention in Biofilter Media

Particle Retention Tests

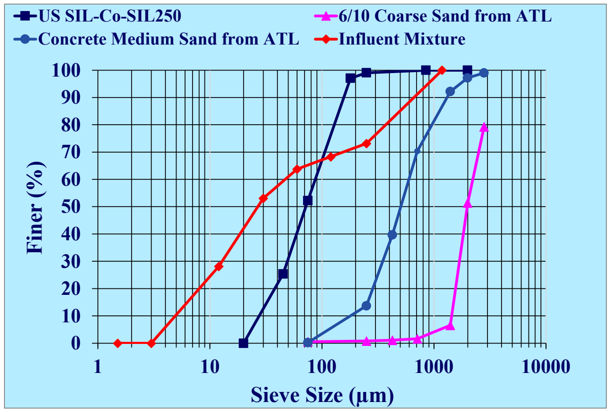
- Controlled lab column tests were conducted to determine flow and particle trapping capabilities of sand-peat media mixtures, along with Tuscaloosa surface and subsurface soils, using challenge water made up of a wide range of particle sizes.

Sand media

Surface (a) and subsurface soil (b) media from Tuscaloosa, AL USA

- The test sediment added to the Black Warrior River Water (coarse sand:medium sand:fine Sil-Co-Sil 250 = 10:15:75 by mass) resulted in a generally uniform particle size distribution.
- The resulting total concentrations of sediment in the influent challenge water were about 100 and 1,000 mg/L during the experiments.

Test Sediment Particle Distribution



Black Warrior River water was used as the test water to provide the smaller particles which are less than 20 µm in the challenge water mixture.

Particle Trapping Tests

- The influent dirty water samples were composited for analysis for each batch, while the column effluents were separated for suspended sediment concentration (SSC), total dissolved solids (TDS), particle size distribution (PSD), turbidity, and conductivity analyses.
- This influent solution was then split into ten 4 liter capacity containers for testing each of ten columns and were replicated three times.

Laboratory Column Tests

- Particle trapping tests were conducted in some of the sand- peat columns (selected to represent the overall range of conditions observed) and Tuscaloosa surface soil for hand and modified proctor compaction conditions.
- Both standard and modified proctor compactions follow ASTM standard (D 1140-54).
- 100 mm diameter PVC pipes 0.9 m long, were used for these tests

Lab column construction

Biofilter media characteristics

- The median size of the filter sand components used in the sand-peat mixtures ranged from 0.3 to 2 mm, and the uniformity coefficients ranged from 1.5 to 3.
- The median sizes of the biofilter media mixtures ranged from 0.4 to 2 mm and the uniformity coefficients ranged from 5.5 to 40.

Sand-peat mixture, Tuscaloosa soil, and standard biofilter media characteristics used during flow and particle trapping.

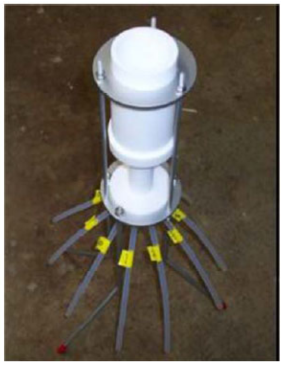
Components	D_{50} (um)	Uniformity
10% Peat and 90% sand	350 to 1875	1 to 22
25% Peat and 75% sand	300 to 1875	2 to 16
50% peat and 50% sand	300 to1625	2.5 to 20
Tuscaloosa surface soils	270	6
Tuscaloosa subsurface soils	1300	33
Standard biofilter media		
Kansas City	2000	40
North Carolina	700	6
Wisconsin (avg.)	500	5.5

- The media layer was about 0.5 m thick.
- Four liters of challenge water was poured into each lab column. Clean water was used for the flow test.
- The surface ponding depths in the columns ranged between 28 cm and 36 cm to correspond to the approximate maximum ponding depths at biofilters.

Effluent samples were collected from the bottom of the columns at the beginning, middle, and end of the drainage time and composted in clean 1 L bottles for the lab analyses.

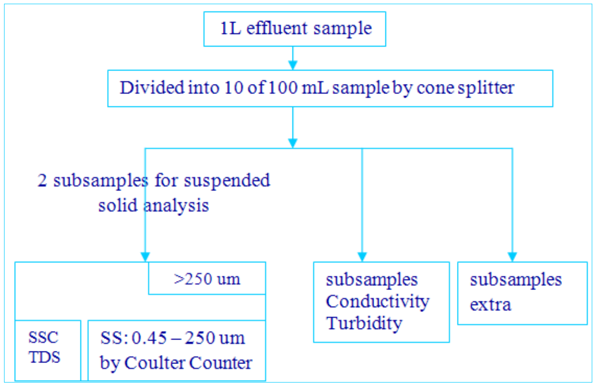
Laboratory Solids Analysis

- The constituents analyzed included:
  - SSC
  - TDS (< 0.45 um particles)
  - PSD (by sieves and Coulter Counter)
  - turbidity (continuous and for samples)
  - conductivity analyses (continuous and for samples).



USGS/Dekaport cone splitter.

Solids analysis flow sheet



1L effluent sample

Divided into 10 of 100 mL sample by cone splitter

2 subsamples for suspended solid analysis

>250 um

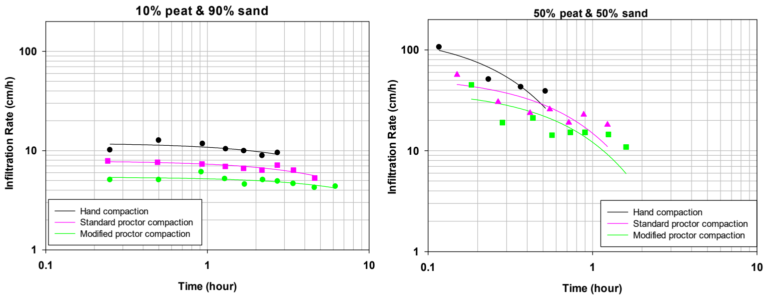
SSC
TDS

SS: 0.45 – 250 um
by Coulter Counter

subsamples
Conductivity
Turbidity

subsamples
extra

Example Infiltration Test Results

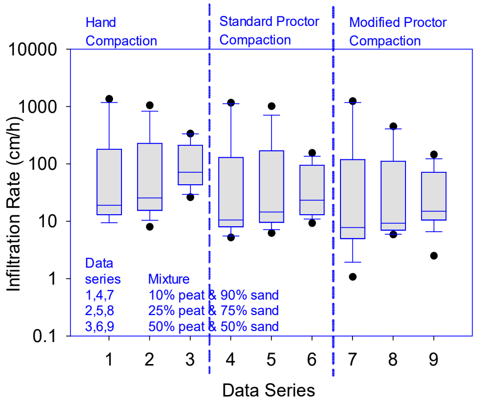


Example infiltration data for different test trials were fitted to Horton's equation to estimate f_c (final infiltration) based on the observed data

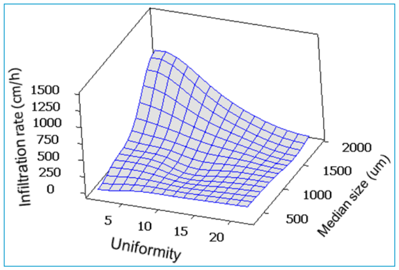
Infiltration Test Results

Box and Whisker plots of the different test conditions, comparing different compaction conditions with varying amounts of peat amendments.

The avg. infiltration rates of the saturated mixtures indicated that the average infiltration rates through the mixtures increased with increases in the percentage of peat.



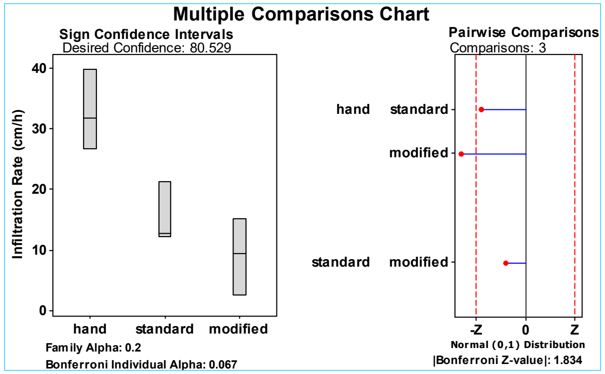
An example surface plot for uniformity and texture vs. final infiltration rate for low organic content conditions. Higher infiltration rate values were observed for a mixture having low uniformity and higher median size values, as expected.



The saturated soil infiltration rates for hand, standard proctor, and modified proctor compaction using North Carolina and Wisconsin media are greater than the saturated soil infiltration rates through the Kansas City biofilter material for the three levels of compaction.

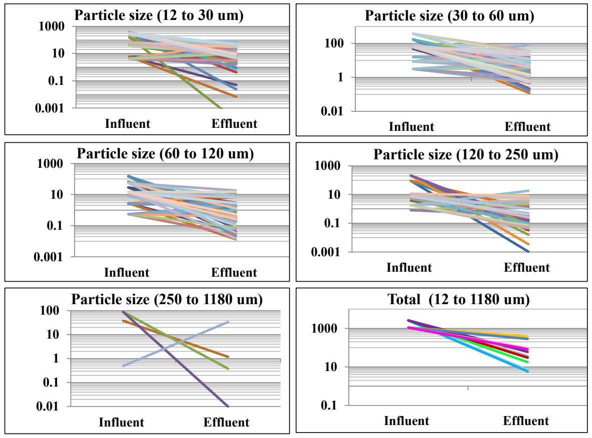
Compaction method	Test	Wisconsin media -1	Wisconsin media -2	North Carolina	Kansas City
		f_c (cm/hr)	f_c (cm/hr)	f_c (cm/hr)	f_c (cm/hr)
hand		density = 1.51 g/cc	density = 1.7 g/cc	density = 1.24 g/cc)	density = 1.36 g/cc
	1	70.4	6.5	32.1	1.3
	2	76.2	75.1	16.6	1.9
	3	44.4	74.9	7.1	0.9
	mean	63.6	52.1	18.6	1.4
	COV	0.3	0.76	0.7	0.36
standard	Test	density = 1.74 g/cc)	density = 1.8 g/cc	density = 1.34 g/cc	density = 1.36 g/cc
	1	13	80.3	14.2	2.2
	2	13.2	33.2	9	1.7
	3	19	47.4	6.6	0.9
	mean	15.1	53.6	10	1.6
	COV	0.2	0.45	0.4	0.41
modified	Test	density = 1.8 g/cc)	density = 1.81 g/cc	density = 1.36 g/cc	density = 1.36 g/cc
	1	8.5	75.1	5.7	0.84
	2	10.2	34.7	4.6	0.08
	3	13.4	31.2	4.1	0.1
	mean	10.7	47	4.8	0.34
	COV	0.2	0.52	0.17	1.27

Kruskal-Wallis multiple pairwise comparisons test of different levels of compaction using 50% peat and 50% sand mixture (mixture D_{50} = 1250 um and C_u = 19).



There are significant differences (p = 0.02) between the saturated infiltration rate values using hand vs. modified proctor compaction methods.

Particle Trapping Test Results



Example line performance plots for sand-peat media mixtures for different particle ranges. Reductions occurred for most of these lab column tests, with consistent reduced effluent concentrations.

Conclusions

- Compaction did not significantly affect the infiltration rates for the mixtures having large amounts of sand and little peat; however infiltration studies conducted previously indicated that compaction significantly affected typical soil infiltration rates having normal organic content, especially if high in fines content.

- The particle trapping experiments using sand-peat mixtures and Tuscaloosa surface soil samples indicated that significant reductions occurred for most lab columns, with relatively consistent effluent conditions.

- Controlled flow studies conducted previously, and analyzed using full factorial analyses, indicated that texture and uniformity of the media mixture have the greatest effect on the measured final infiltration rates of the media.

- The organic matter in the biofilter media did not have a significant effect by itself on the infiltration rates compared to the other factors (texture, uniformity, and compaction). However the organic matter serves as a reservoir of nutrients and water in the biofilter media and increases water infiltration into the media.

A restricted underdrain (such as the SmartDrain^{TM}) results in enhanced outlet control for bioinfiltration devices.

- The SmartDrain^{TM} material flow capacity and clogging potential tests, after excessive loadings by fine ground silica particulates, and biofouling experiments indicated that they have minimal clogging potential while also providing very low discharge rates (preferred to encourage natural infiltration and to increase contact time with the media).
- SmartDrains^{TM} also reduced the surface ponding time compared to no underdrains, while minimizing short-circuiting of the infiltration water. They also provide a substantial residence time in the media to optimize contaminant removal and also provide significant retention of stormwater.
- A complete two level and three factors (2^3, SmartDrain^{TM} length, slope, and head) factorial experiment and ANOVA tests conducted to examine the effects of those factors, plus their interactions on the SmartDrain^{TM} flowrate performances indicated that head, SmartDrain^{TM} length have significant effects on SmartDrain^{TM} flowrate performance whereas slope has negligible effect on SmartDrain^{TM} flowrate performance.

- Effluent turbidity (NTU) measurements decreased rapidly with time, indicating significant retention of silt in the test biofilter for the clogging tests using ground silica material. The high turbidity values were associated with Re > 500.
- Our pilot scale tests indicate that the SmartDrain^{TM} material provides an additional option for biofilters, having minimal clogging potential while also providing very low discharge rates.

Recommendations

- A common failure mechanism for biofilters is overly compacted media (especially with high uniformity coefficients and fine material), as reflected in a large installation in Tuscaloosa, therefore care needs to be taken during the construction of biofilter stormwater treatment facilities to reduce detrimental compaction effects.
- Small scale, rapid, tests are needed to quickly inventory soil conditions in areas undergoing planning following natural disasters, or to meet short schedules associated with accelerated construction goals.
- Small-scale infiltrometers work well if surface characteristics are of the greatest interest (such as infiltration thru surface landscaped soils, as in turf areas, grass swales or in grass filters). Large-scale (deep) infiltration tests would be appropriate when subsurface conditions are of importance (as in bioinfiltration systems and deep rain gardens).
- It is important that Stormwater practice designers determine the subsoil characteristics before designing stormwater treatment facilities and consider the use of added amendments (sand and peat) to the soils.

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