SmartDrain^{TM} for Enhanced Biofiltration Controls

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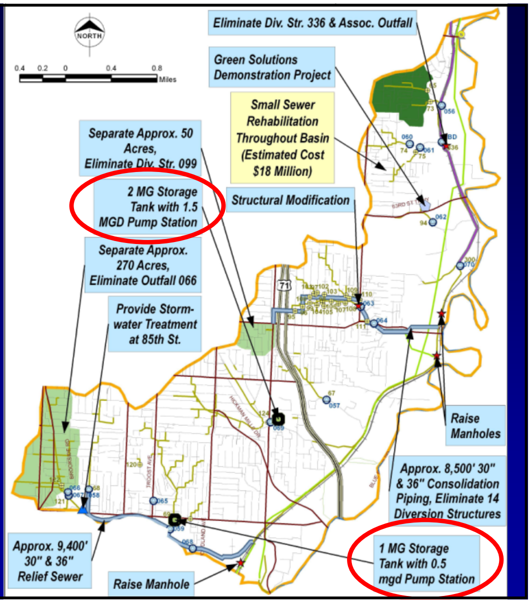
Outline of Presentation Topics

- Green Infrastructure case study for CSO control relying on biofiltration systems in Kansas City, MO
- Biofiltration media tests to optimize toxicant control for Southern California industrial site having numeric stormwater limits
- Residence time issues in biofiltration device designs
- The use of the SmartDrain^{TM} as a biofilter outlet control having slow drainage rates to enhance residence time and contaminant removal.

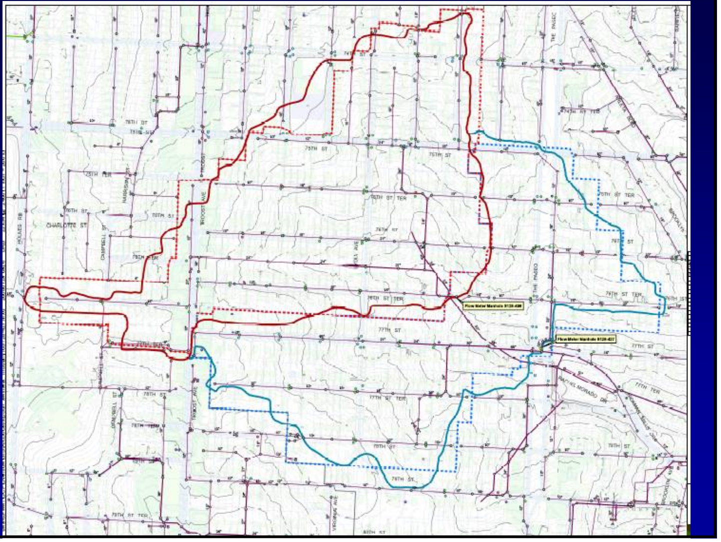
Kansas City's CSO Challenge

- Combined sewer area: 58 mi^2
- Fully developed
- Rainfall: 37 in./yr
- 36 sewer overflows/yr by rain > 0.6 in; reduce frequency by 65%.
- 6.4 billion gal overflow/yr, reduce to 1.4 billion gal/yr
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality

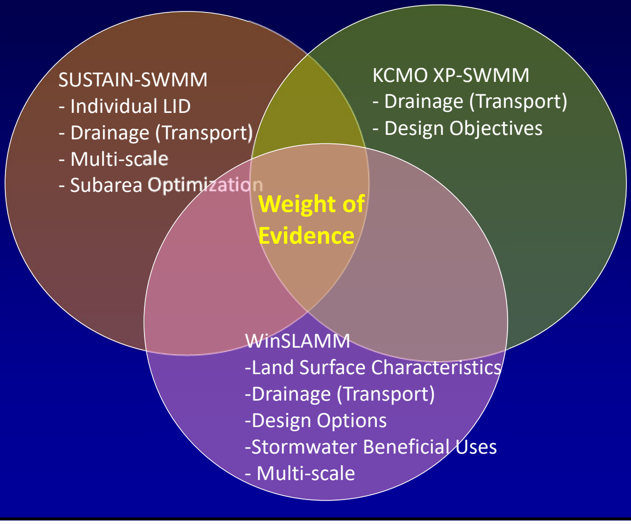
Kansas City's Original Middle Blue River Plan with CSO Storage Tanks



Adjacent Test and Control Watersheds



KC's Modeling Connections

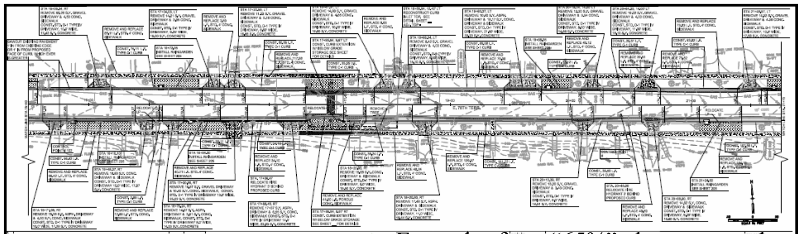


SUSTAIN-SWMM
- Individual LID
- Drainage (Transport)
- Multi-scale
- Subarea Optimization

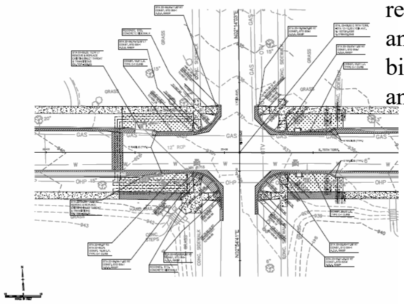
KCMO XP-SWMM
- Drainage (Transport)
- Design Objectives

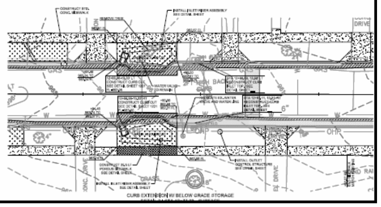
Weight of Evidence

WinSLAMM
- Land Surface Characteristics
- Drainage (Transport)
- Design Options
- Stormwater Beneficial Uses
- Multi-scale

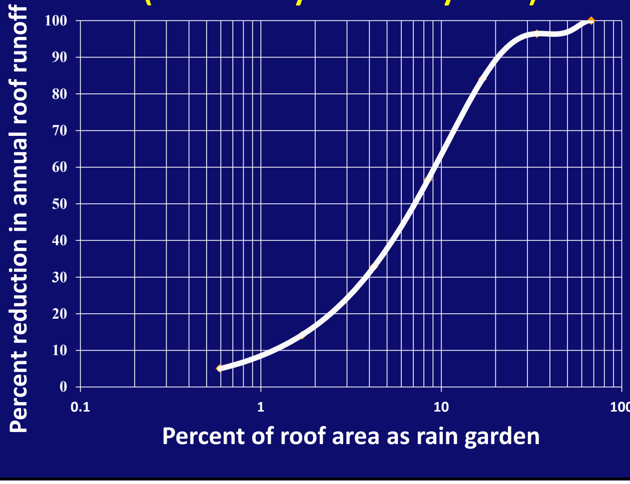


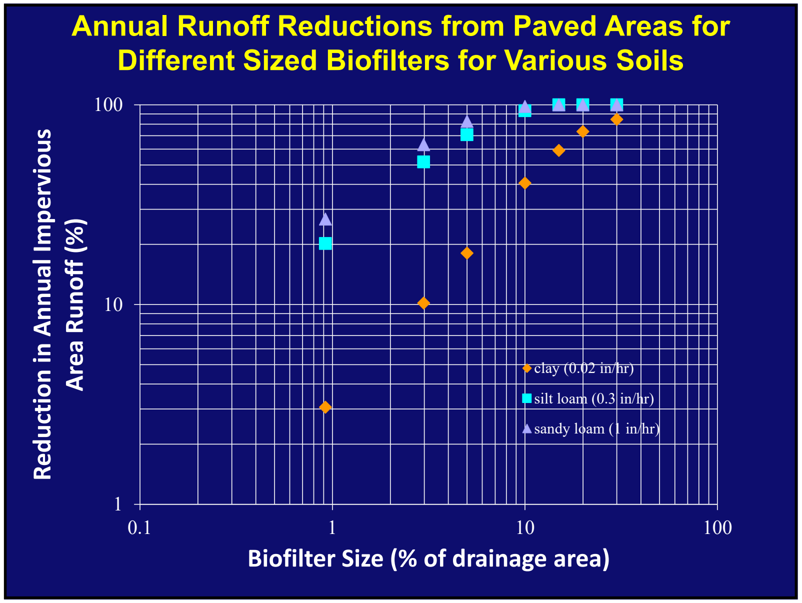
Examples from "65%" plans prepared by URS for project streets. Plans reviewed and modeled by project team, and construction of several hundred biofilter systems will occur in spring and summer of 2011.





Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Gardens (Kansas City CSO Study Area)





Annual Runoff Reductions from Paved Areas for Different Sized Biofilters for Various Soils

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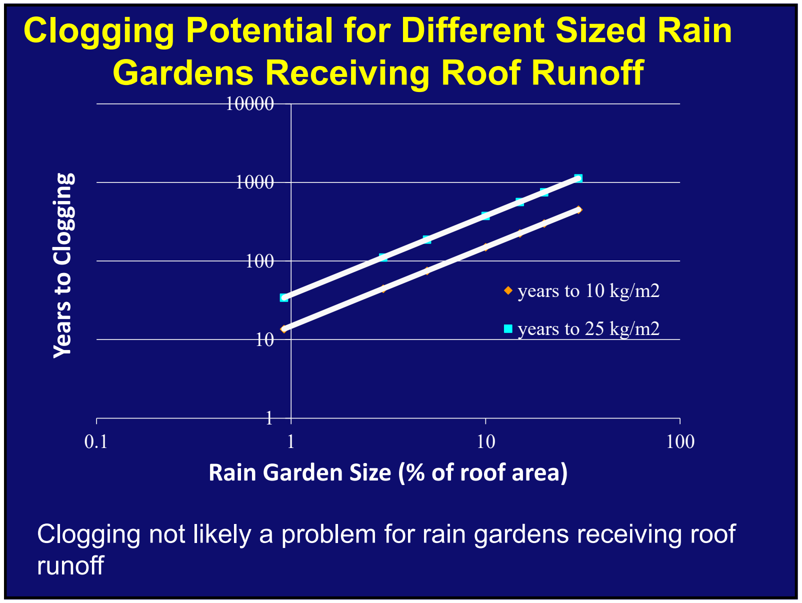

Clogging Potential for Different Sized Rain Gardens Receiving Roof Runoff

Clogging not likely a problem for rain gardens receiving roof runoff

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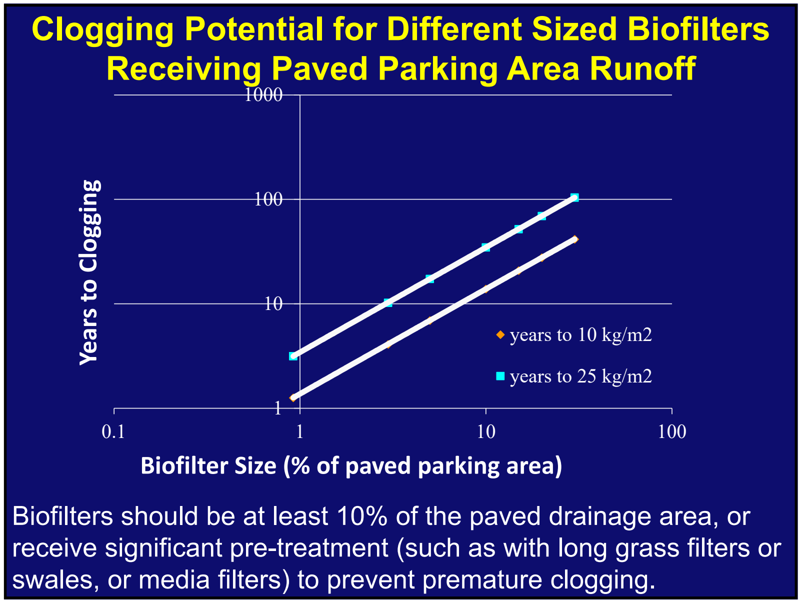

Clogging Potential for Different Sized Biofilters Receiving Paved Parking Area Runoff

Biofilters should be at least 10% of the paved drainage area, or receive significant pre-treatment (such as with long grass filters or swales, or media filters) to prevent premature clogging.

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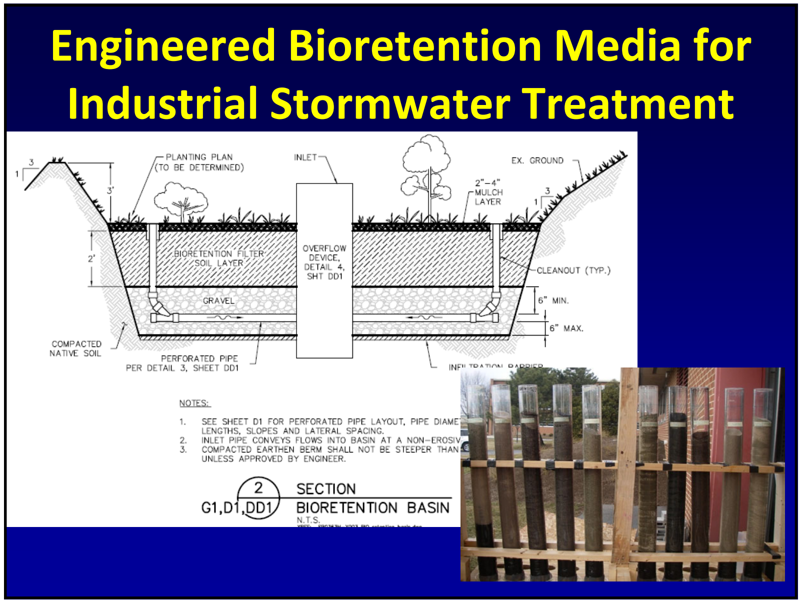

Engineered Bioretention Media for Industrial Stormwater Treatment

NOTES:

1. SEE SHEET D1 FOR PERFORATED PIPE LAYOUT, PIPE DIAME LENGTHS, SLOPES AND LATERAL SPACING.
2. INLET PIPE CONVEYS FLOWS INTO BASIN AT A NON–EROSIV
3. COMPACTED EARTHEN BERM SHALL NOT BE STEEPER THAN UNLESS APPROVED BY ENGINEER.

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Media Testing

- Goals:
  - To provide information for design (e.g., optimal media components, depths, and contact times)
  - To maximize the likelihood that filtration-based treatment controls will achieve desired level of performance in the most cost effective manner

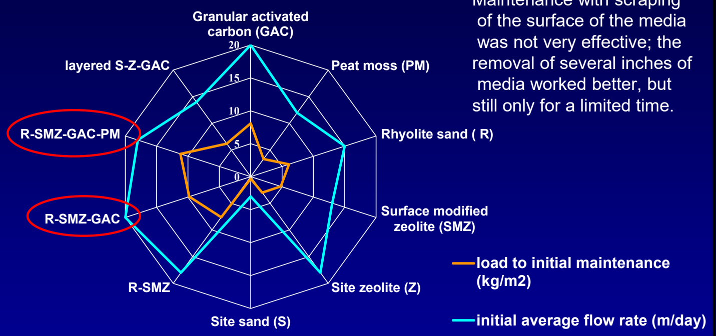
Media (from left to right): GAC, Rhyolite Sand, Site Zeolite, Surface Modified Zeolite, Sphagnum Peat Moss

These tests were conducted in conjunction with Dr. Shirley Clark at Penn State – Harrisburg and Geosystec, and sponsored by The Boeing Co.

Media Tests (cont'd)

- Long-Term Column tests using actual stormwater:
  - Clogging, breakthrough, and removal
  - Effects of contact time and media depth on removal
- Batch tests:
  - Media uptake capacity and removal kinetics
  - Aerobic and anaerobic effects on pollutant mass e

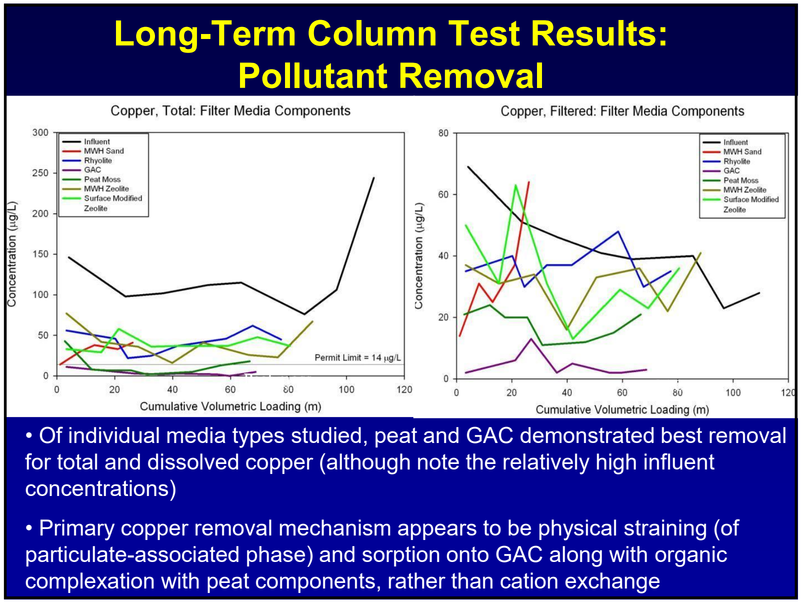
Column test results: Hydraulics and Clogging



Maintenance with scraping of the surface of the media was not very effective; the removal of several inches of media worked better, but still only for a limited time.

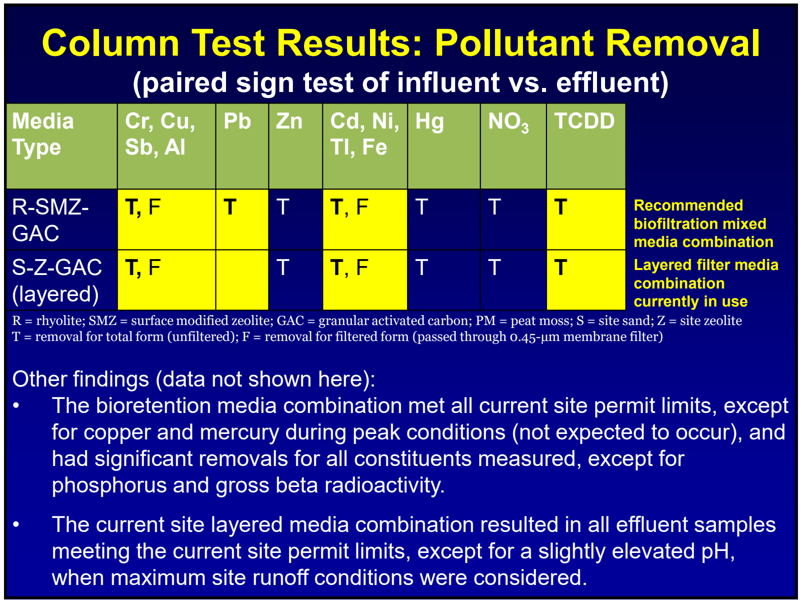
1. Site sand clogged first and had the lowest flow rate
2. Site zeolite and peat alone were next to clog
3. Biofiltration mixed media combination performed better than current site layered media combination

Pitt and Clark 2010



Long-Term Column Test Results: Pollutant Removal

- Of individual media types studied, peat and GAC demonstrated best removal for total and dissolved copper (although note the relatively high influent concentrations)
- Primary copper removal mechanism appears to be physical straining (of particulate-associated phase) and sorption onto GAC along with organic complexation with peat components, rather than cation exchange



Column Test Results: Pollutant Removal

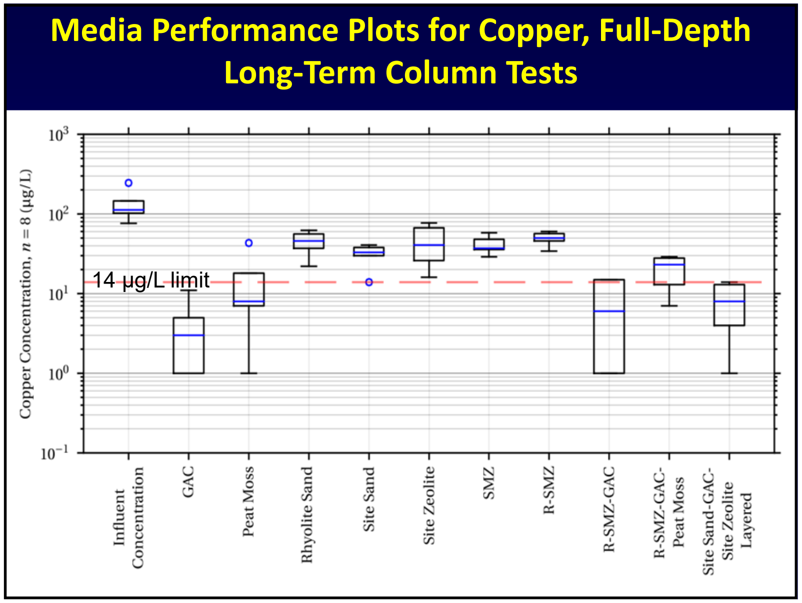
(paired sign test of influent vs. effluent)

Media Type	Cr, Cu, Sb, Al	Pb	Zn	Cd, Ni, Tl, Fe	Hg	NO_3	TCDD	
R-SMZ-GAC	**T**, F	**T**	T	**T**, F	T	T	**T**	**Recommended biofiltration mixed media combination**
S-Z-GAC (layered)	**T**, F		T	**T**, F	T	T	**T**	**Layered filter media combination currently in use**

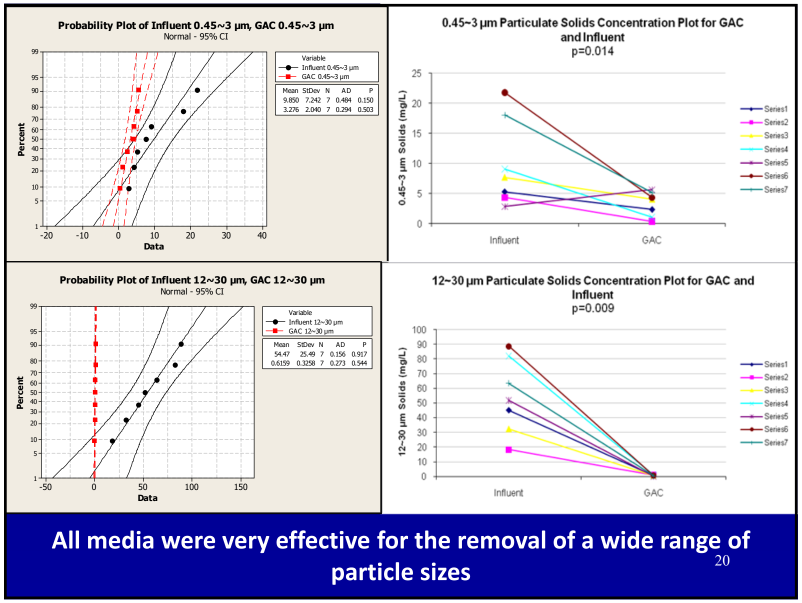
R = rhyolite; SMZ = surface modified zeolite; GAC = granular activated carbon; PM = peat moss; S = site sand; Z = site zeolite
T = removal for total form (unfiltered); F = removal for filtered form (passed through 0.45-µm membrane filter)

Other findings (data not shown here):

- The bioretention media combination met all current site permit limits, except for copper and mercury during peak conditions (not expected to occur), and had significant removals for all constituents measured, except for phosphorus and gross beta radioactivity.
- The current site layered media combination resulted in all effluent samples meeting the current site permit limits, except for a slightly elevated pH, when maximum site runoff conditions were considered.



Media Performance Plots for Copper, Full-Depth Long-Term Column Tests

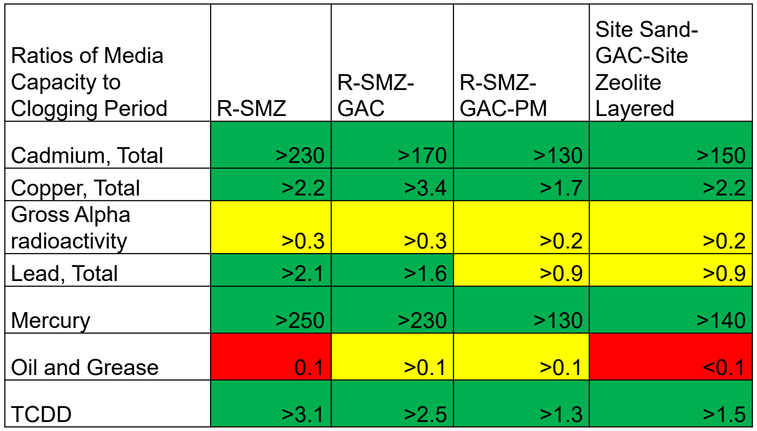


Mean	StDev	N	AD	P
9.850	7.242	7	0.484	0.150
3.276	2.040	7	0.294	0.503

Mean	StDev	N	AD	P
54.47	25.49	7	0.156	0.917
0.6159	0.3258	7	0.273	0.544

All media were very effective for the removal of a wide range of particle sizes

Breakthrough Capacity Compared to Clogging Period



Ratios of Media Capacity to Clogging Period	R-SMZ	R-SMZ-GAC	R-SMZ-GAC-PM	Site Sand-GAC-Site Zeolite Layered
Cadmium, Total	🟩 >230	🟩 >170	🟩 >130	🟩 >150
Copper, Total	🟩 >2.2	🟩 >3.4	🟩 >1.7	🟩 >2.2
Gross Alpha radioactivity	🟨 >0.3	🟨 >0.3	🟨 >0.2	🟨 >0.2
Lead, Total	🟩 >2.1	🟩 >1.6	🟨 >0.9	🟨 >0.9
Mercury	🟩 >250	🟩 >230	🟩 >130	🟩 >140
Oil and Grease	🟥 0.1	🟨 >0.1	🟨 >0.1	🟥 <0.1
TCDD	🟩 >3.1	🟩 >2.5	🟩 >1.3	🟩 >1.5

Green: will clog before breakthrough
Red: breakthrough before clogging

Cumulative Particulate Loading to Failure and Expected Years of Operation for Largest Sedimentation-Biofiltration Treatment Trains on Project Site

	R-SMZ	R-SMZ-GAC	R-SMZ-GAC-PM	Site Sand-GAC-Site Zeolite Layered
Load to clogging (kg/m^2)	7.5 - 38	11 - 53	11 - 55	6.5 - 33
Years to replacement	12 - 58	16 - 81	17 - 84	10 - 50

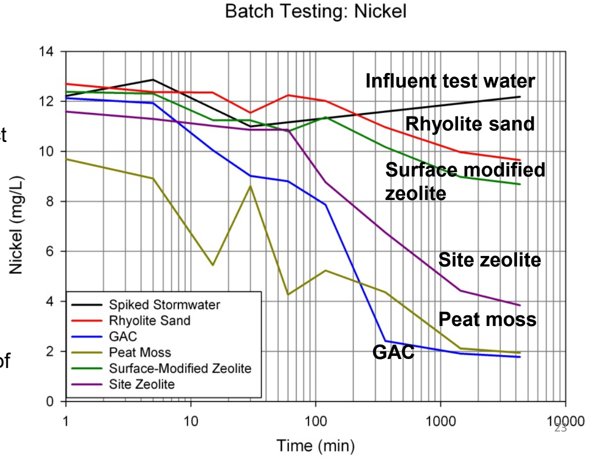
- Seven of the site biofilters were evaluated for clogging potential and chemical removal capacity. The biofilters were from about 1 to 10% of the drainage areas in size and had sedimentation pre-treatment.
- All of the media combinations would likely have an operational life of at least 10 years for the constituents of greatest concern, with the exception of oil and grease for the layered media.

Batch Testing Results: Contact Time

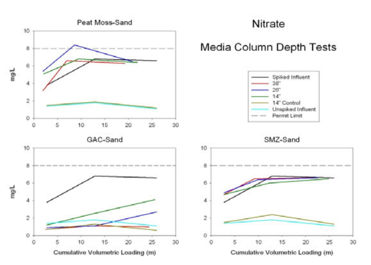
Minimal filtered metal removal observed for all media except peat when contact time <10 minutes.

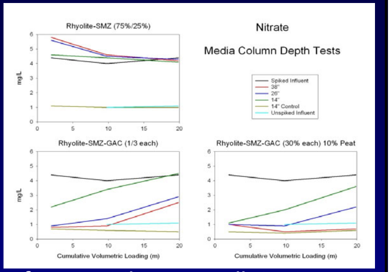
The optimal contact times for filtered metals removal ranged from 10 to 1,000 minutes (17 hrs), depending on the metal and the media type.

However too long of a contact time increased leaching losses from some media.

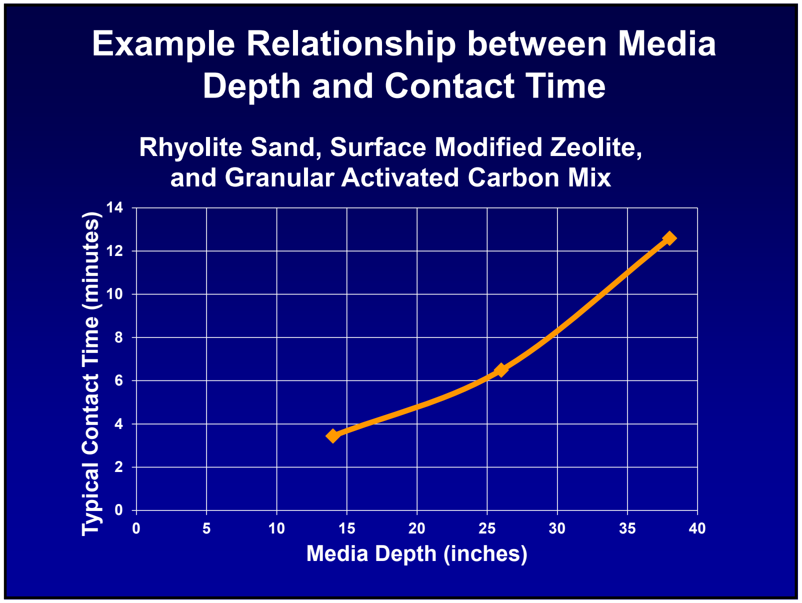


Varying Depth Column Test Results



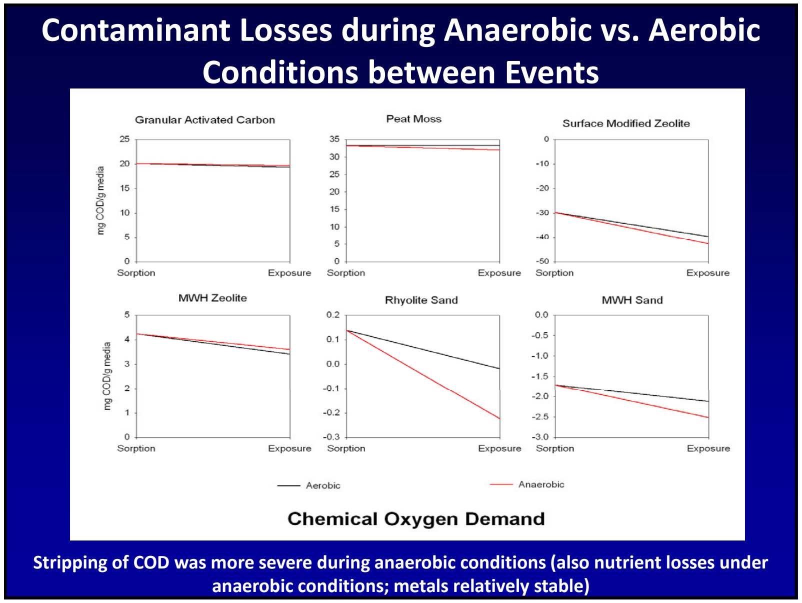


- These tests determined the effect of contact time on pollutant removal. Longer contact times should enhance pollutant removals because the likelihood of making a favorable contact with the media increases.
- Only the GAC showed good removals of nitrate, with the removal ability being best with the deepest column. GAC therefore has a limited capacity for nitrate and increasing the amount of GAC in contact with the passing influent water increases the length of time that excellent removals occur.



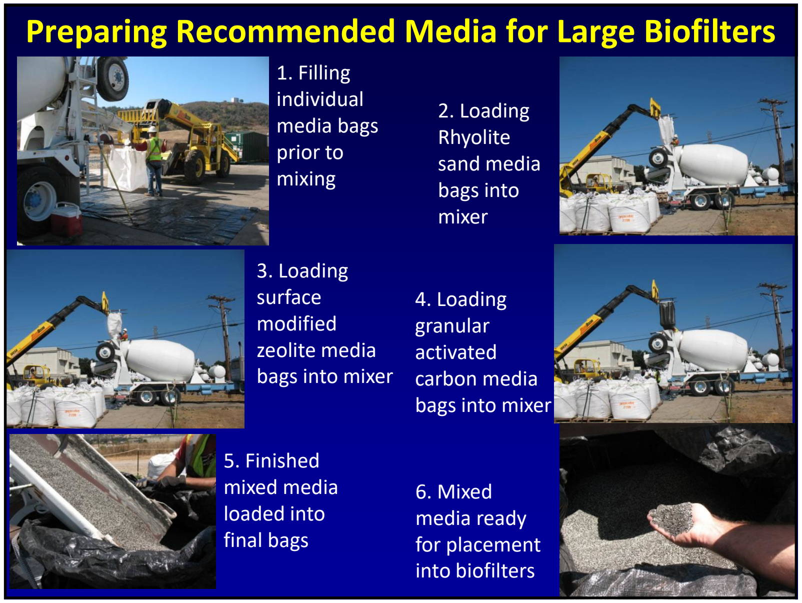
Example Relationship between Media Depth and Contact Time

Rhyolite Sand, Surface Modified Zeolite, and Granular Activated Carbon Mix



Contaminant Losses during Anaerobic vs. Aerobic Conditions between Events

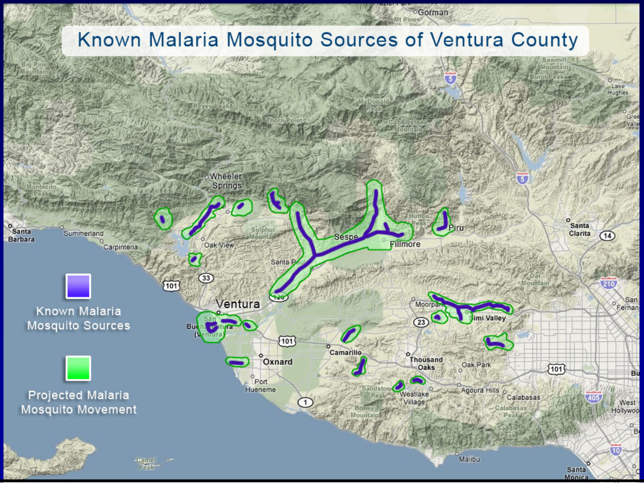
Stripping of COD was more severe during anaerobic conditions (also nutrient losses under anaerobic conditions; metals relatively stable)

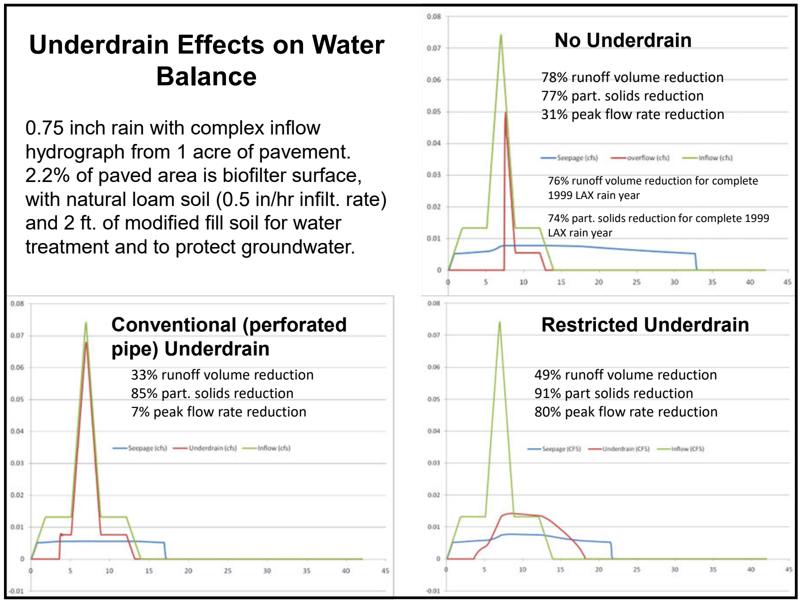


Preparing Recommended Media for Large Biofilters

1. Filling individual media bags prior to mixing
2. Loading Rhyolite sand media bags into mixer
3. Loading surface modified zeolite media bags into mixer
4. Loading granular activated carbon media bags into mixer
5. Finished mixed media loaded into final bags
6. Mixed media ready for placement into biofilters

Many Areas Require Biofilter Drainage within 72 hours to Prevent Mosquito Infestation





Underdrain Effects on Water Balance

0.75 inch rain with complex inflow hydrograph from 1 acre of pavement. 2.2% of paved area is biofilter surface, with natural loam soil (0.5 in/hr infilt. rate) and 2 ft. 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

- 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.

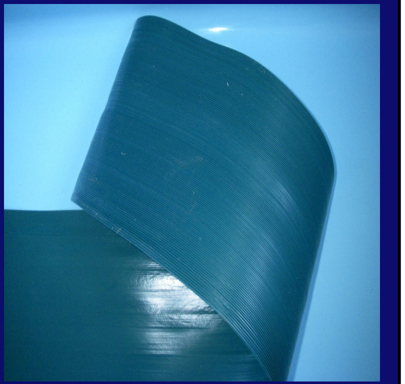
- Perforated pipe underdrains short-circuit natural infiltration, resulting in decreased performance.

- Orifice outlet controls that allow long residence times usually are very small and clog easily.

- We are studying a foundation drain material (SmartDrain^{TM}) that can be applied to biofiltration devices and provide another option for outlet control.

SmartDrain^{TM} (http://www.smartdrain.com/)

- SmartDrain^{TM} operates under laminar flow conditions (Reynolds number of 100 to 600); low sediment carrying capacity and reduced clogging potential.
- SmartDrain^{TM} has132 micro channels in an 8 inch wide strip; results in very small discharge rates.



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

Variables affecting the drainage characteristics of the underdrain material

A pilot-scale biofilter was used to test the variables affecting the drainage characteristics of the underdrain material:

- Length
- Slope
- Hydraulic head
- Type of sand media

A fiberglass trough 10 ft long and 2 x 2ft in cross section used as the pilot-scale biofilter

Experimental procedure

- The SmartDrain^{TM} was installed on top of a 4" layer of the drainage sand, and another 4" layer of the sand was placed on top of the SmartDrain^{TM}.
- 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.

SmartDrain^{TM} installation In the drainage sand (it was unrolled before placement of the cover sand).

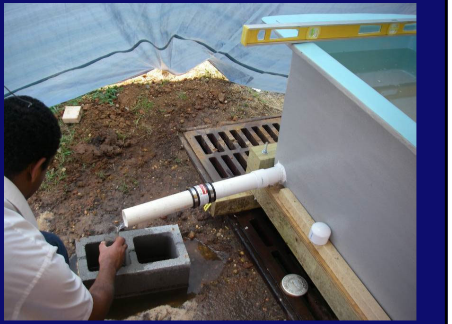
Experimental procedure Cont.

- During the tests, the trough was initially filled with water to a maximum head of 22 inches above the center of the pipe and then allowed to drain, resulting in head vs. discharge data.
- A hydraulic jack and blocks were used to change the slope of the tank.

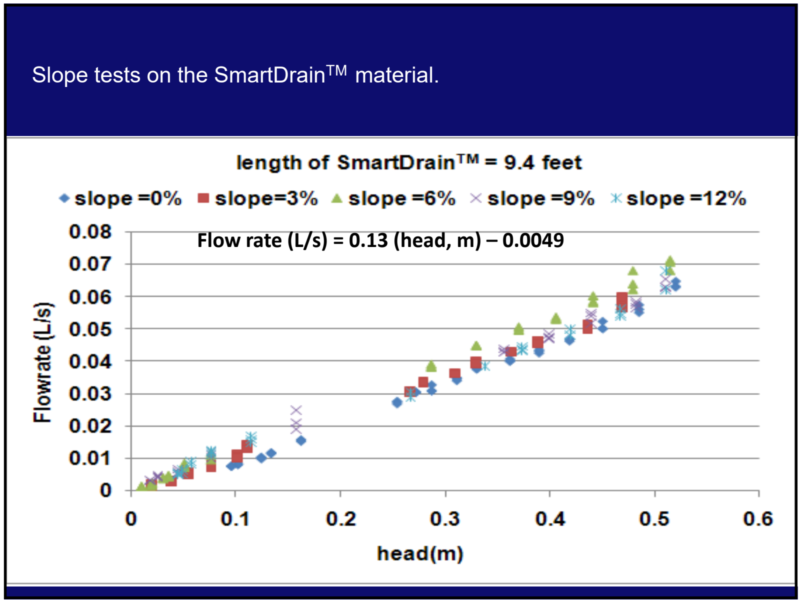
test for effect of length and slope on the drainage characteristics of SmartDrain^{TM} material

Experimental procedure Cont.

- 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^{TM} (9.4ft, 7.1ft, 5.1ft, 3.1ft, and 1.1ft) and three to five slopes were examined to study the variables affecting the drainage characteristics of the material.



Flow rate measurement from effluent of the biofilter



Slope tests on the SmartDrain^{TM} material.

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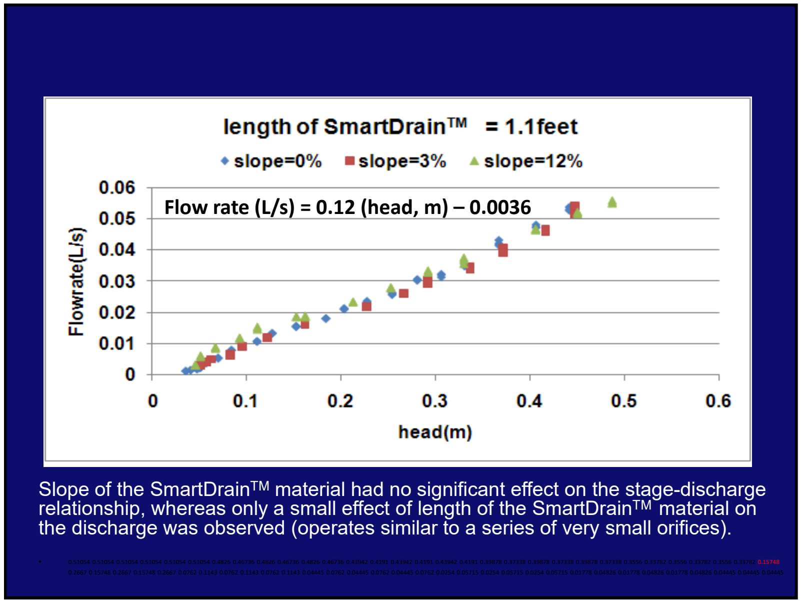

Slope of the SmartDrain^{TM} material had no significant effect on the stage-discharge relationship, whereas only a small effect of length of the SmartDrain^{TM} material on the discharge was observed (operates similar to a series of very small orifices).

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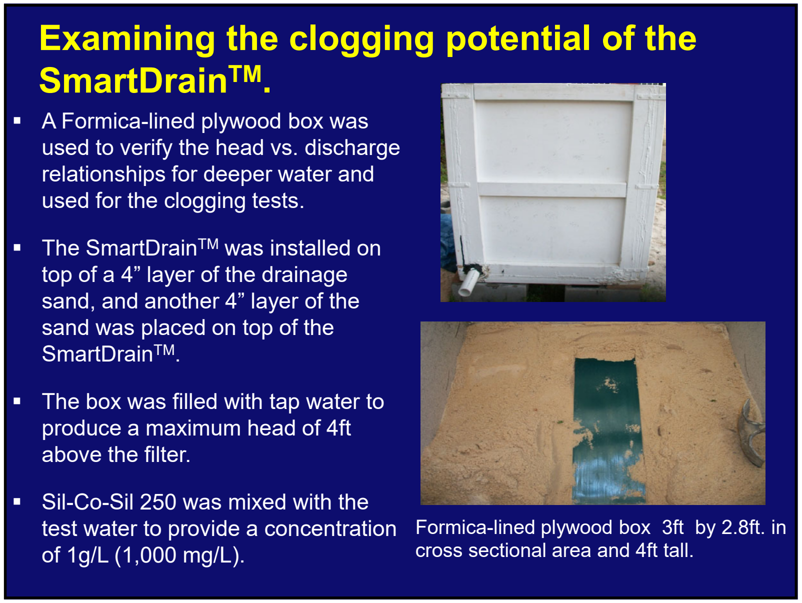

Examining the clogging potential of the SmartDrain^{TM}.

- 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 4" layer of the drainage sand, and another 4" 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 4ft above the filter.
- Sil-Co-Sil 250 was mixed with the test water to provide a concentration of 1g/L (1,000 mg/L).

Formica-lined plywood box 3ft by 2.8ft. in cross sectional area and 4ft tall.

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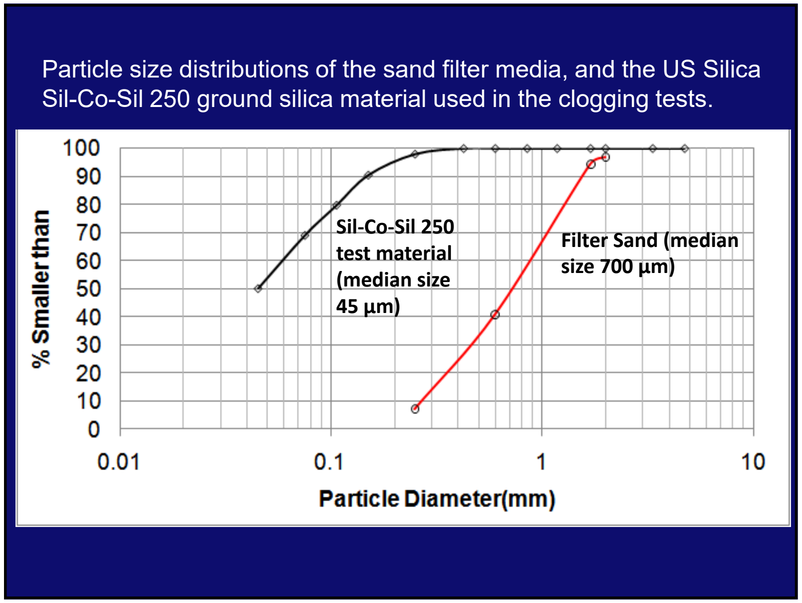

Particle size distributions of the sand filter media, and the US Silica Sil-Co-Sil 250 ground silica material used in the clogging tests.

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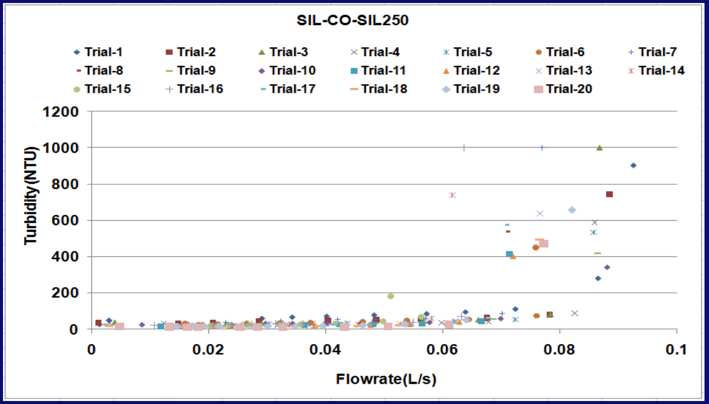
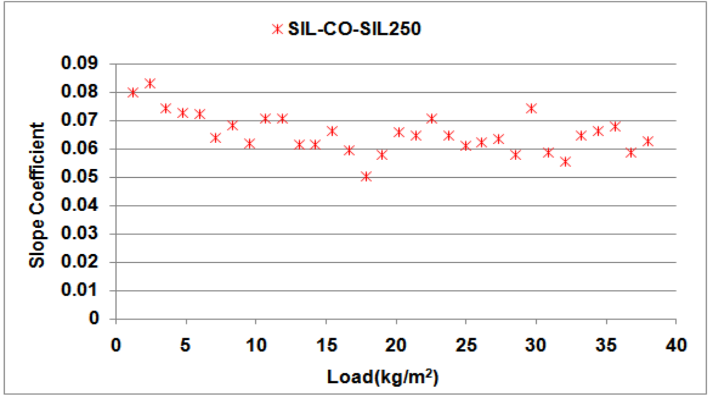
Turbidity measurements taken from the effluent of the device during the clogging tests.



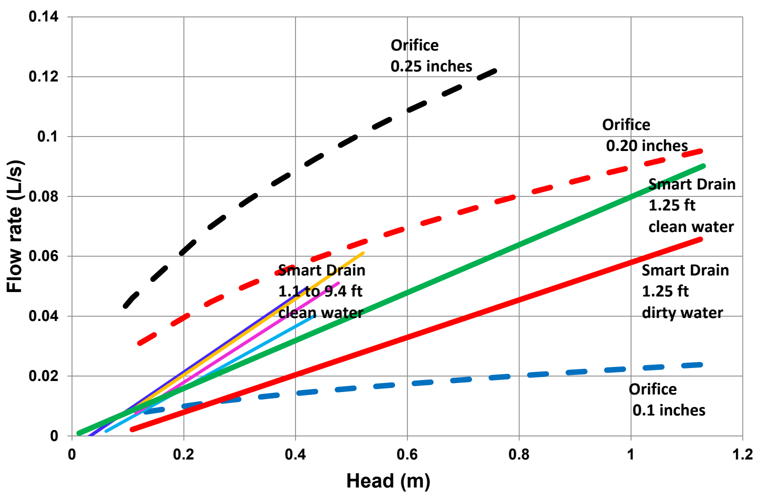
The initial turbidity values in the tank were about 1,000 NTU, similar to the initial turbidity values in the treated water. However, these effluent values decreased significantly and rapidly during the drainage period, with most of the sediment remaining trapped in the tank on top of the filter sand.

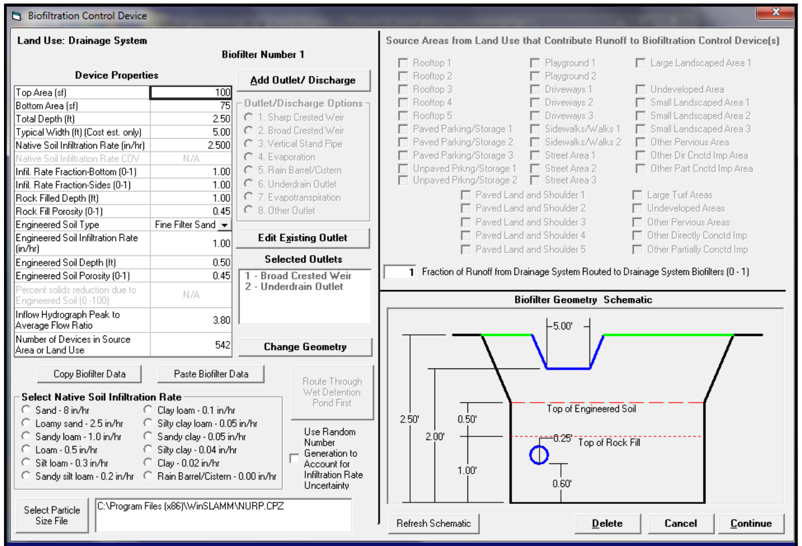
Plot showing Sil-Co-Sil250 load(kg/m^2) vs. slope coefficients for the clogging tests.



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)

Smart Drain Flow Rates Compared to Very Small Orifices





Land Use: Drainage System

Biofilter Number 1

Device Properties

Top Area (sf)	100
Bottom Area (sf)	75
Total Depth (ft)	2.50
Typical Width (ft) (Cost est. only)	5.00
Native Soil Infiltration Rate (in/hr)	2.500
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	1.00
Rock Fill Porosity (0-1)	0.45
Engineered Soil Type	Fine Filter Sand
Engineered Soil Infiltration Rate (in/hr)	1.00
Engineered Soil Depth (ft)	0.50
Engineered Soil Porosity (0-1)	0.45
Percent solids reduction due to Engineered Soil (0 -100)	N/A
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	542

Outlet/Discharge Options
- ○ 1. Sharp Crested Weir
- ○ 2. Broad Crested Weir
- ○ 3. Vertical Stand Pipe
- ○ 4. Evaporation
- ○ 5. Rain Barrel/Cistern
- ○ 6. Underdrain Outlet
- ○ 7. Evapotranspiration
- ○ 8. Other Outlet

Selected Outlets

1 - Broad Crested Weir
2 - Underdrain Outlet

Select Native Soil Infiltration Rate
- ○ Sand - 8 in/hr
- ○ Loamy sand - 2.5 in/hr
- ○ Sandy loam - 1.0 in/hr
- ○ Loam - 0.5 in/hr
- ○ Silt loam - 0.3 in/hr
- ○ Sandy silt loam - 0.2 in/hr
- ○ Clay loam - 0.1 in/hr
- ○ Silty clay loam - 0.05 in/hr
- ○ Sandy clay - 0.05 in/hr
- ○ Silty clay - 0.04 in/hr
- ○ Clay - 0.02 in/hr
- ○ Rain Barrel/Cistern - 0.00 in/hr

☐ Use Random Number Generation to Account for Infiltration Rate Uncertainty

C:\Program Files (x86)\WinSLAMM\NURP.CPZ

Source Areas from Land Use that Contribute Runoff to Biofiltration Control Device(s)

- ☐ Rooftop 1
- ☐ Rooftop 2
- ☐ Rooftop 3
- ☐ Rooftop 4
- ☐ Rooftop 5
- ☐ Paved Parking/Storage 1
- ☐ Paved Parking/Storage 2
- ☐ Paved Parking/Storage 3
- ☐ Unpaved Prkng/Storage 1
- ☐ Unpaved Prkng/Storage 2
- ☐ Playground 1
- ☐ Playground 2
- ☐ Driveways 1
- ☐ Driveways 2
- ☐ Driveways 3
- ☐ Sidewalks/Walks 1
- ☐ Sidewalks/Walks 2
- ☐ Street Area 1
- ☐ Street Area 2
- ☐ Street Area 3
- ☐ Large Landscaped Area 1
- ☐ Undeveloped Area
- ☐ Small Landscaped Area 1
- ☐ Small Landscaped Area 2
- ☐ Small Landscaped Area 3
- ☐ Other Pervious Area
- ☐ Other Dir Cnctd Imp Area
- ☐ Other Part Cnctd Imp Area
- ☐ Paved Land and Shoulder 1
- ☐ Paved Land and Shoulder 2
- ☐ Paved Land and Shoulder 3
- ☐ Paved Land and Shoulder 4
- ☐ Paved Land and Shoulder 5
- ☐ Large Turf Areas
- ☐ Undeveloped Areas
- ☐ Other Pervious Areas
- ☐ Other Directly Conctd Imp
- ☐ Other Partially Conctd Imp

1 Fraction of Runoff from Drainage System Routed to Drainage System Biofilters (0 - 1)

Typical biofilter as modeled in WinSLAMM for an area having poor soils.

Biofilter Underdrain Options and Water Balance

- The sandy-silt loam soil results in extended surface ponding, requiring an underdrain (736 hours of rain per year; 44,500 ft^3/acre discharged to biofilters per year).
- Conventional underdrain (3 inch perforated pipe) reduces ponding, but also decreases infiltration opportunities and decreases contact time with media.
- SmartDrain^{TM} also reduces ponding time, while providing additional infiltration and increased media contact time.

Annual runoff (ft^3/acre/year) and percentage fate:

	Surface ponding (hrs/year)	Infiltration volume	Surface discharge	Subsurface (filtered) discharge	Surface discharge reduction (%)
No underdrain	1,480	31,700 (72%)	12,800 (28%)	0 (0%)	72%
Typical 3 inch underdrain	530	17,200 (39%)	4,400 (10%)	22,900 (51%)	38%
SmartDrain^{TM}	1,080	26,300 (59%)	10,500 (23%)	7,800 (18%)	58%

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 4" layer of the drainage sand, and another 4" 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.

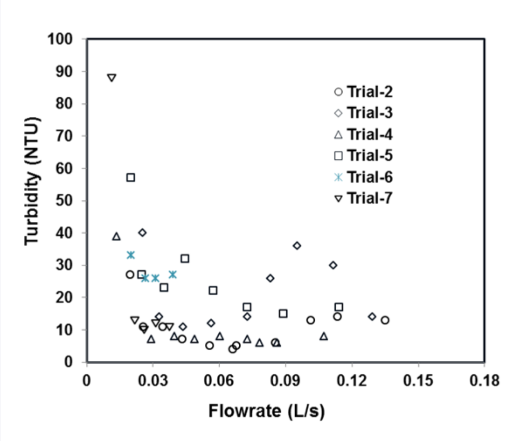
	Drainage	algae exposure
Trial No.	date	period(days)
1	17-Jun-10	14
2	8-Jul-10	35
3	25-Jul-10	52
4	12-Aug-10	70
5	3-Sep-10	92
6	27-Sep-10	116
7	11-Oct-10	130

growth of algae in the biofilter device

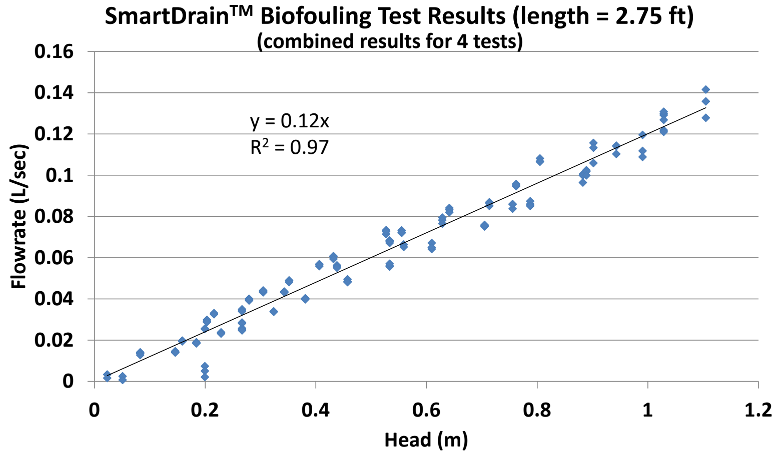
Biofouling Tests of SmartDrain^{TM} Material

Turbidity values in the tank after several weeks ranged from 6 to 39 NTU, whereas effluent values were reduced to 4 to 7 NTU during the drainage tests.

Turbidity (NTU) vs. Flowrate for the biofouling tests



Stage-discharge relationships for the biofouling tests were very similar to the Sil-Co-Sil clogging test results.



Conclusions

- The slope of the SmartDrain™ material had no significant effect on the stage-discharge relationship, while the length had only a small effect on the discharge rate.
- Effluent turbidity (NTU) measurements decreased rapidly with time, indicating significant retention of silt in the test biofilter.
- Clogging and biofouling of the SmartDrain™ material was minimal during extended tests.
- Our tests indicate that the SmartDrain™ material provides an additional option for biofilters, having minimal clogging potential while also providing very low discharge rates which encourage infiltration and allow extended media contact periods, compared to typical underdrains.

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- Many University of Alabama and Penn State – Harrisburg graduate students assisted in conducting these tests.