Biofiltration and Stormwater Management

Performance Expectations and Preliminary Design

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Steps in Sizing a Stormwater Bioretention Facility (from previous workshop presentations, supplemented with current workshop information)

1) Characterize the stormwater to be treated (critical pollutants needing removal along with constituents that affect maintenance), along with the expected runoff volume and flow rates for the drainage area.

2) Determine the required removals of the constituents of concern (concentrations and masses).

3) Identify the chemically active media to target these constituents (including necessary contact times and other factors affecting performance, such as anaerobic conditions and degradation of the media and leaching of constituents from the media).

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Steps in Sizing a Stormwater Bioretention Facility (cont.)

4) Inventory other site characteristics potentially affecting bioretention facility (maximum area available, depth to groundwater and seasonal changes to the water table, underlying natural soil characteristics, snowmelt SAR problems, etc.).

5) Prepare preliminary designs addressing these factors (size of facility, selection of media, outlet controls/underdrains, and maintenance interval).

6) Evaluate alternative designs using long-term continuous stormwater quality model and evaluate life-cycle costs and other decision support factors.

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Benefits of Bioinfiltration Controls

- Runoff volume and pollutant discharge reductions

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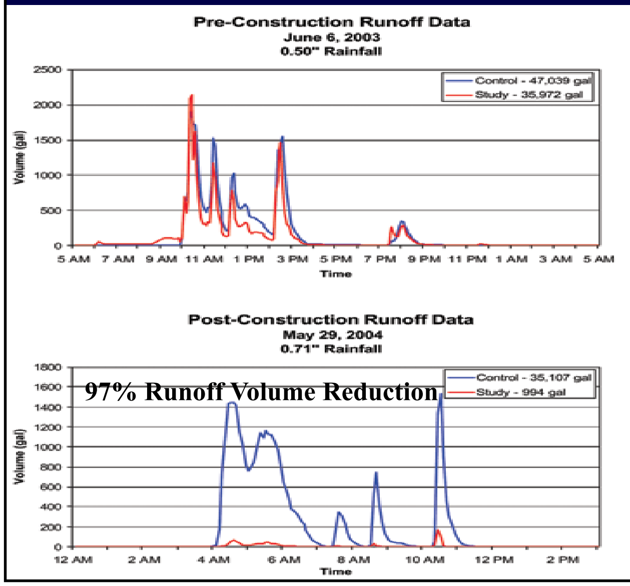

Neighborhood in Minnesota, showing almost complete elimination of runoff for moderate rain with extensive use of rain gardens.

Land and Water, Sept/Oct. 2004

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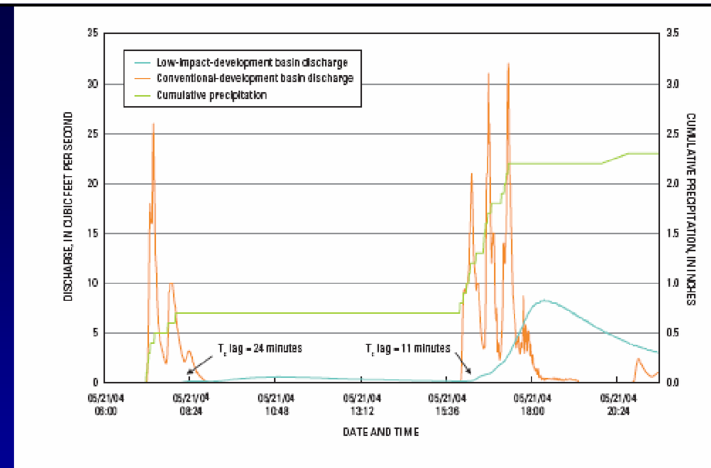

Figure 10. Hydrologic response of low-impact-development (LID) and conventional-development basins to two consecutive precipitation events, Cross Plains, Wis. [T_c, time of concentration]

Conservation design residential area in Wisconsin showing major runoff changes in large area.

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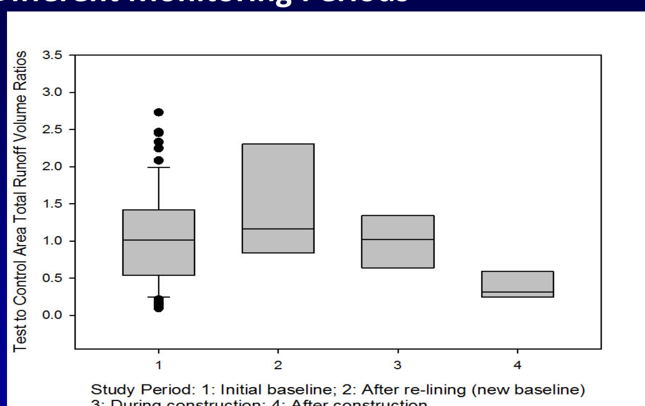
Test to Control Area Runoff Flow Ratios during Different Monitoring Periods



Large-scale demonstration project in Kansas City showing large runoff reductions

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Calculated Benefits of Various Roof Runoff Controls (compared to typical directly connected residential pitched roofs)

Annual roof runoff volume reductions	Birmingham, Alabama (55.5 in.)	Seattle, Wash. (33.4 in.)	Phoenix, Arizona (9.6 in.)
Flat roofs instead of pitched roofs	13	21	25%
Cistern for reuse of runoff for toilet flushing and irrigation (10 ft. diameter x 5 ft. high)	66	67	88%
Planted green roof (but will need to irrigate during dry periods)	75	77	84%
Disconnect roof drains to loam soils	84	87	91%
Rain garden with amended soils (10 ft. x 6.5 ft.)	87	100	96%

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Disconnection of Roof Drains

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Problems Associated with Biofiltration Facilities

- Compacted soils and media and restoration of compacted soils with amendments and mechanical decompaction
- Sodium adsorption ratio (SAR) problems associated with high sodium in runoff (snowmelt with deicing salts for example) and clays and organic matter interference
- Groundwater mounding
- Groundwater contamination potential
- Scour and unstable designs

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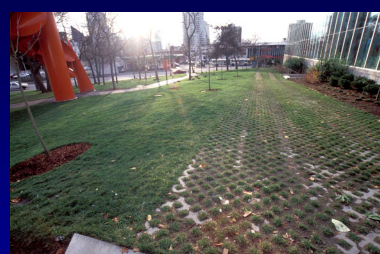
Temporary parking or access roads supported by geogrids, turf meshes, or paver blocks to minimize soil compaction and enhance infiltration



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Disturbed Urban Soils during Land Development

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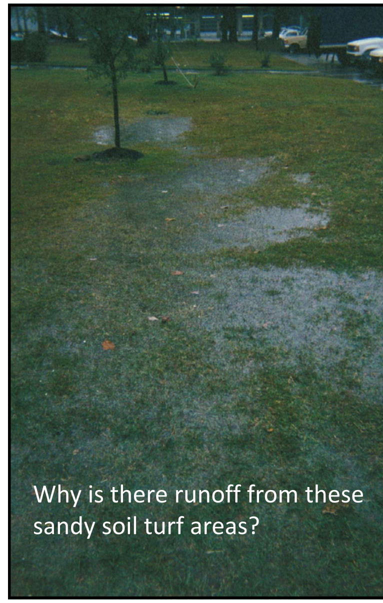
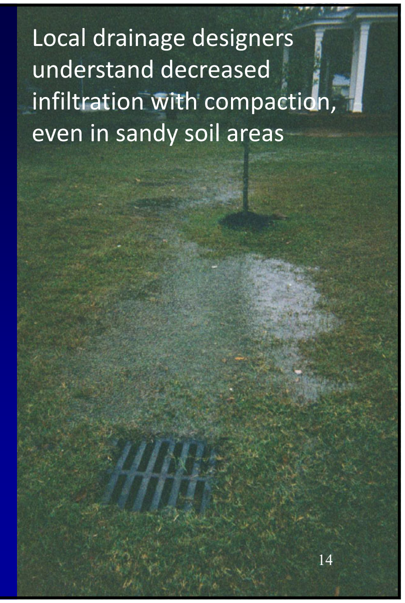

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Double-ring infiltration tests conducted in many urban areas to determine effects of compaction and soil characteristics.

This is a conventional ASTM double-ring setup that is difficult to use (hard to set the rings in the compacted soils and uses large volumes of water). Now we mostly use smaller Turf-Tec infiltrometers for surface soil infiltration rate measurements.

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Field Infiltration Tests using Clusters of Turf-Tech Infiltrometers

- We use clusters of Turf-Tech infiltrometers (spaced about a meter apart) to measure variations in surface infiltration rates in an area. Water is poured into the inner ring and allowed to overflow and fill up the outer ring.
- The rate of decrease in the water level was measured at many intervals, starting the timer immediately and reading the water levels on the pointer on the depth scale.
- The tests were usually conducted for a period of 1 to 2.5 hr, until the infiltration rate become constant.

Turf-Tec Infiltrometer (Turf-Tec International)

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For subsurface infiltration tests (needed at bottom of new biofiltration facility), we use larger bore hole setup and greater amounts of water (to saturate surrounding soils)

- A tractor-mounter auger (about 0.75m diameter) was used to drill holes about 1 to 2 m deep in test areas (to depth of bottom of future infiltration facility). A large cardboard concrete form tube was inserted in the bore hole and several cm of gravel was placed in the bottom of the tube to protect the soil.
- The bore holes were filled with water from fire hydrants (or could use water trucks) and the water elevations were manually measured with time until the infiltration rates reached an approximate steady rate.

Double-ring and Bore Hole Infiltration Measurement Installations (Intersection of 21st Ave. E. and University Blvd E, Tuscaloosa, AL, in area destroyed by massive tornado). 17

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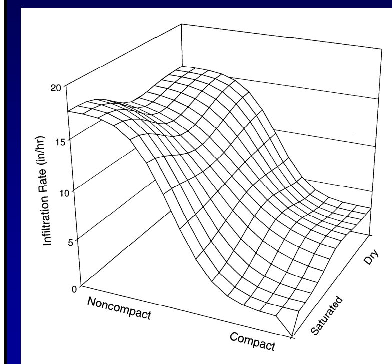
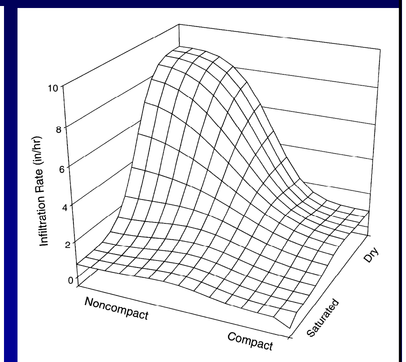
Infiltration Rates in Disturbed Urban Soils
from our early Turf-Tec double-ring tests in areas having varying soil textures and compaction (Pitt, *et al.* 1999)



Sandy Soils



Clayey Soils

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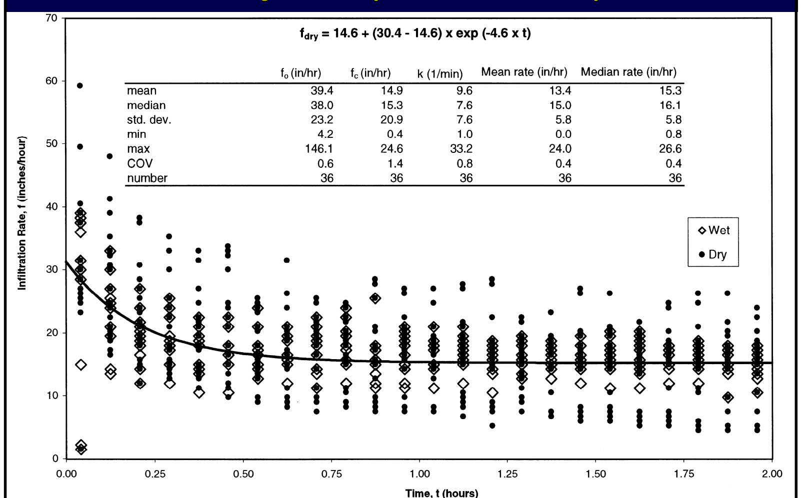
Infiltration Measurements for Noncompacted, Sandy Soils (Pitt, *et al.* 1999)



	f_o (in/hr)	f_c (in/hr)	k (1/min)	Mean rate (in/hr)	Median rate (in/hr)
mean	39.4	14.9	9.6	13.4	15.3
median	38.0	15.3	7.6	15.0	16.1
std. dev.	23.2	20.9	7.6	5.8	5.8
min	4.2	0.4	1.0	0.0	0.8
max	146.1	24.6	33.2	24.0	26.6
COV	0.6	1.4	0.8	0.4	0.4
number	36	36	36	36	36

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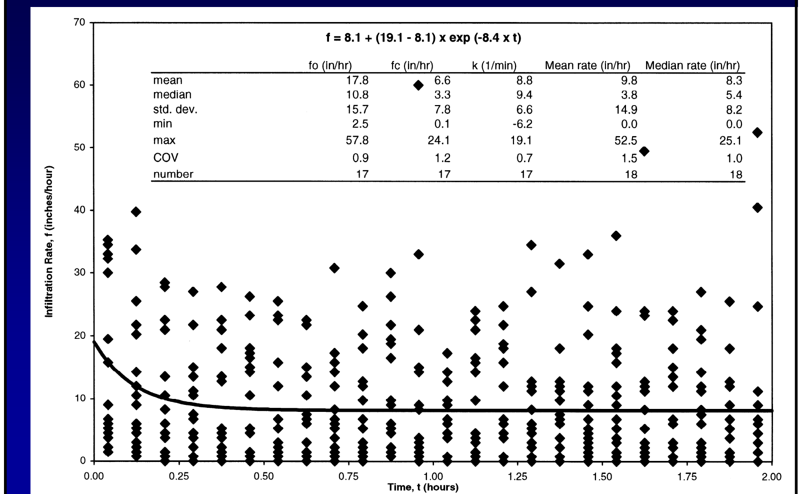
Infiltration Measurements for Dry-Noncompacted, Clayey Soils (Pitt, *et al.* 1999)



	fo (in/hr)	fc (in/hr)	k (1/min)	Mean rate (in/hr)	Median rate (in/hr)
mean	17.8	6.6	8.8	9.8	8.3
median	10.8	3.3	9.4	3.8	5.4
std. dev.	15.7	7.8	6.6	14.9	8.2
min	2.5	0.1	-6.2	0.0	0.0
max	57.8	24.1	19.1	52.5	25.1
COV	0.9	1.2	0.7	1.5	1.0
number	17	17	17	18	18

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Results of Infiltration Tests in Disturbed Urban Soils

- Four general categories were found to be unique:
  - Noncompacted sandy soils
  - Compacted sandy soils
  - Dry, noncompacted clayey soils
  - All other clayey soils (compacted and dry, plus all saturated conditions)

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Infiltration Rates during Tests of Disturbed Urban Soils

	Number of tests	Average infiltration rate (in/hr)	COV
Noncompacted sandy soils	36	13	0.4
Compacted sandy soils	39	1.4	1.3
Noncompacted and dry clayey soils	18	9.8	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	0.2	2.4

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In-situ soil density sampling and measurements:
1) Small hole is excavated and soil brought to lab for moisture and dry weight analyses (and usually texture measurements also)
2) The hole is backfilled with a known amount of free-flowing sand to measure the volume of the excavation
3) The soil density is then directly calculated (infiltration rates are also simultaneously measured in the same area)

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Mechanical Lawn Aeration Not Effective to Restore Compacted Soils

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Natural processes much more effective to restore compacted soils (deeper penetration), although most folks would not like fire ants aerating their soils! 25

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Effects of Compost-Amendments on Runoff Properties

- Another portion of the EPA-funded research was conducted by Dr. Rob Harrison, of the University of Washington
- They examined the benefits of adding large amounts of compost to glacial till soils at the time of land development

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Infiltration test areas (sealed) constructed at the University of Washington examining compost-amended soils (composts derived from yard wastes and from biosolids from the wastewater treatment facility). Surface runoff and subsurface flows were continuously measured during many rains.

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Water Quality and Quantity Effects of Amending Urban Soils with Compost

- Surface runoff rates and volumes decreased by five to ten times after amending the soils with compost, compared to unamended sites.
- Unfortunately, the concentrations of many pollutants increased in surface runoff from amended soils, especially nutrients which were leached from the fresh compost.
- However, the several year old test sites had less, but still elevated concentrations, compared to unamended soil only test plots.

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Amended Soil Compared to Un-amended Soil

Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09	0.29
Phosphate	0.62	3.0
Ammonia	0.56	4.4
Nitrate	0.28	1.5
Copper	0.33	1.2
Zinc	0.061	0.18

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Sodium Adsorption Ratio (SAR)

- Excessive amounts of sodium in relation to calcium and magnesium causes the dispersion of clays in a soil, severely restricting infiltration capacity.
- Problem when deicing salts and snowmelt entering infiltration devices that have even small amounts of clay in the soil or media mixture.
- Not much of an issue for roof runoff rain gardens (as long as heavily salted walks or driveways do not drain towards them).
- Acceptable media and soil mixtures should prohibit clays, focusing on sandy material with stable organic amendments (peat recommended; compost can be a problem).

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Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio can radically affect the performance of an infiltration device. Soils with an excess of sodium ions, compared to calcium and magnesium ions, remain in a dispersed condition, almost impermeable to rain or applied water.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+2} + Mg^{+2})}{2}}}$$

An SAR value of 15, or greater, indicates that an excess of sodium will be adsorbed by the soil clay particles. This can cause the soil to be hard and cloddy when dry, to crust badly, and to take water very slowly. SAR values near 5 can also cause problems, depending on the type of clay present.

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A new infiltration pond after first winter; receives snowmelt from adjacent salted parking areas (plus sediment from area construction); lost almost all of the infiltration capacity and is rapidly becoming a (poorly designed) wet pond. Was restored and less salt is used in area currently.

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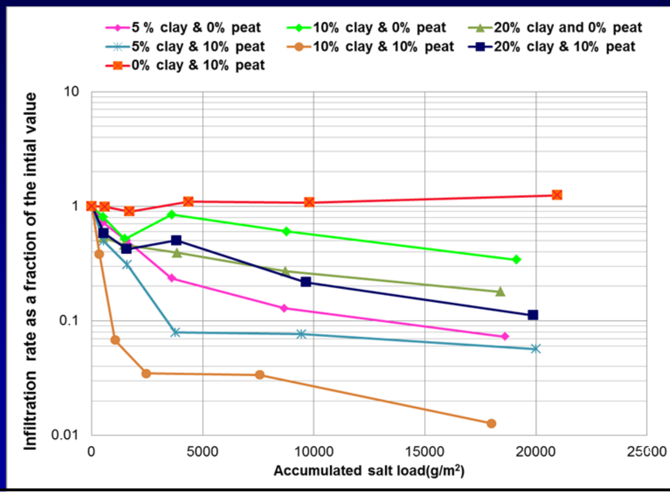
Salt Addition Tests to Biofilter Media Showing Lost Infiltration Rates with Clay (above 5%) and with Organic Supplements (peat in this example)



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Cation Exchange Capacity (CEC)

- CEC is commonly used as a measure of potential removal of soluble stormwater pollutants using chemically-active biofilter media. It is a measure of the ion exchange capacity of the material (but not the sorption capacity that may be more important).
- Sands have low CEC values, typically ranging from about 1 to 3 meq/100g of material. As the organic content of the soil increases, so does its' CEC. Compost, for example, can have a CEC of between 15 and 20 meq/100 grams, while clays can have CEC values of 5 and 60 meq/100 grams. Natural soils can therefore vary widely in CEC depending on their components. Silt loam soils can have CEC between 10 and 30 meq per 100 gram for example. Soil amendments (usually organic material, such as compost) can greatly increase the CEC of a soil that is naturally low in organic material, or clays.

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- Problem: Determine the approximate "life" of the CEC of a media in an infiltration device having the following characteristics:

- the media in the infiltration device has a CEC of 200 meq/L (averaged for 0.5 m in depth and the media has a dry density of 1.6 g/cm³),
- receives runoff from a paved area 30 times the area of the infiltration device,
- 1 m of rainfall a year, and paved area Rv is 0.85, and
- the total cation content of the runoff water is 1.0 meq/L

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- Solution:

- total CEC content of media (per m² of biofilter):

$$0.5\,m^3 \times \frac{1.6\,g}{cm^3} \times \frac{(100\,cm)^3}{m^3} \times \frac{200\,meq}{100\,g} = 1{,}600{,}000\,meq$$

- total cation content of a years worth of runoff (per 30 m² of watershed area):

$$30\,m^2 \times \frac{0.85\,m}{year} \times \frac{(1000\,L)}{m^3} \times \frac{1\,meq}{L} = \frac{25{,}500\,meq}{year}$$

- therefore, the unit's CEC would be able to remove cations for about 60 years, a suitable design period. However, if the media CEC was only 5 meq/100 grams, then the facility would only remove cations for about 3 years. In this case, either the infiltration device should be made larger, the contributing paved area made smaller, the media needs to be amended with organics, or the media will have to be replaced every several years.

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Ground Water Mounding beneath Infiltration Devices

- Mounding (interaction of subsurface water with the saturated infiltration device) reduces the infiltration rate to saturated permeability of soil, often 2 to 3 orders of magnitude lower than infiltration rate.
- Long narrow system (i.e. trenches) don't mound as much as broad, square/round systems

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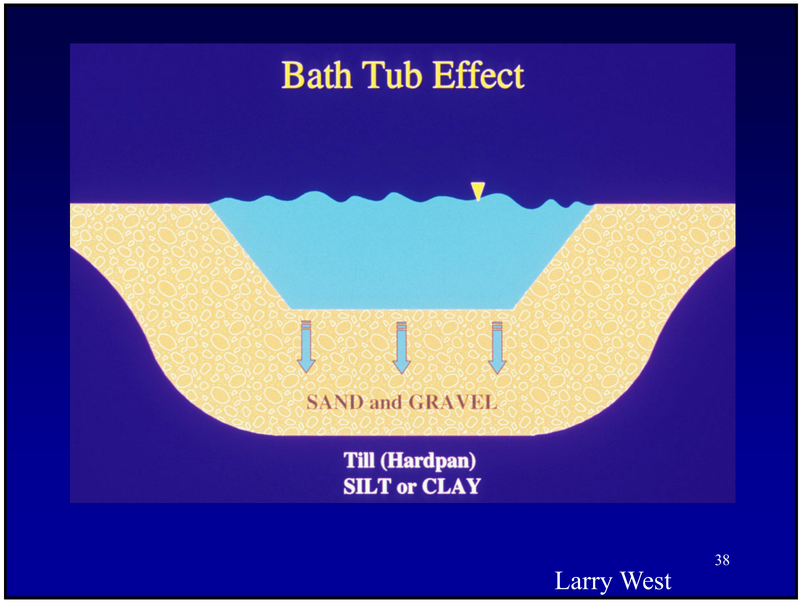

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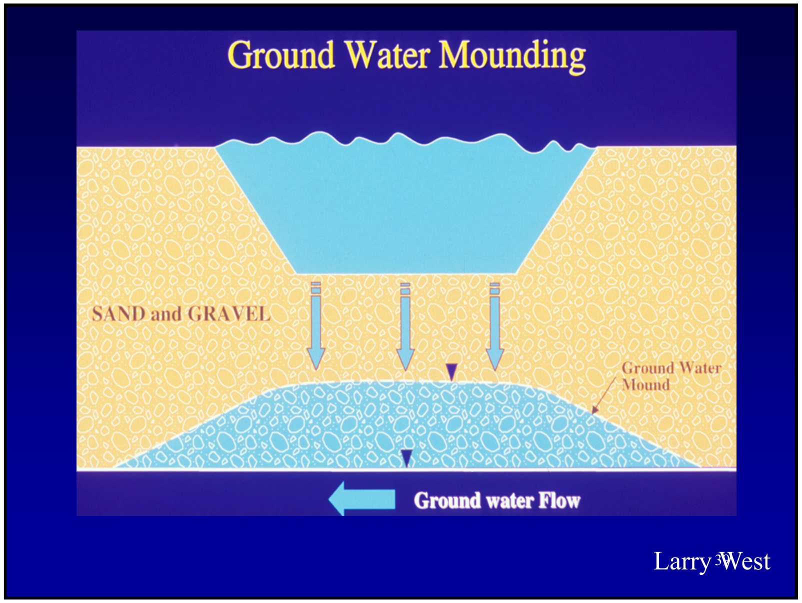

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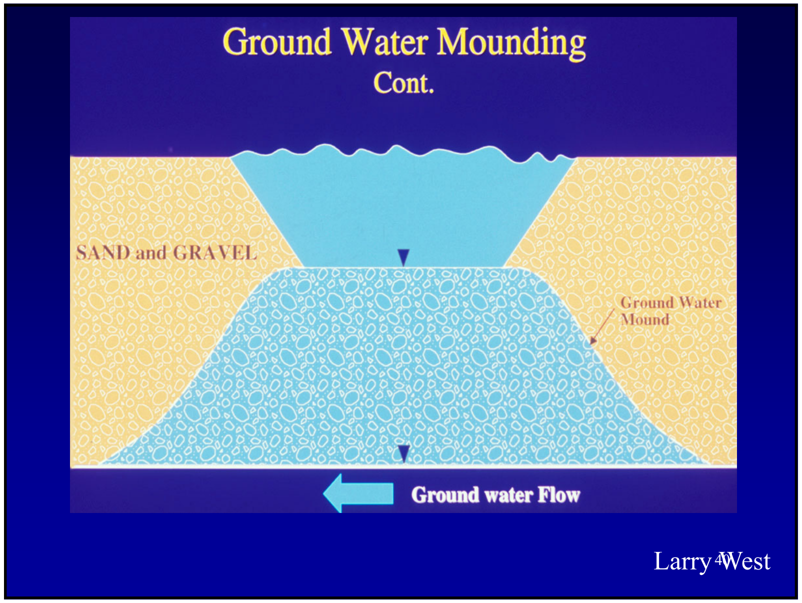

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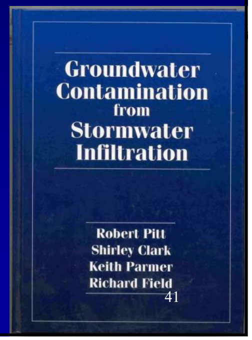
Groundwater Contamination Potential with Stormwater Infiltration

- Enhanced infiltration increases water movement to groundwater compared to conventional development.
- Care must also be taken to minimize groundwater contamination potential.

Pitt, et al. book published by Ann Arbor Press/CRC, 219 pages. 1996, based on EPA research and NRC committee work.



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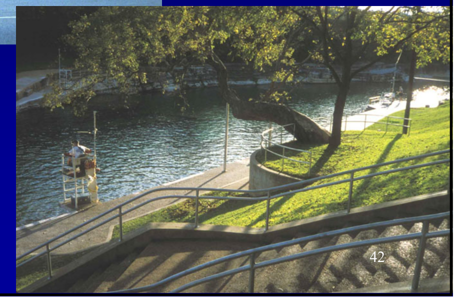
Edward's Aquifer Contamination Potential, Austin, TX

Karst geology showing direct piping of surface flows to groundwater, which rapidly flows to natural springs (Barton's Springs)

Barton's Springs



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Groundwater Contamination Potential of Stormwater Infiltration

- Our research on stormwater and groundwater interactions began during an EPA cooperative agreement to identify and control stormwater toxicants.
- Our first efforts were based on extensive literature reviews for reported groundwater data beneath urban areas and management options.
- Initial stormwater - groundwater impact report published by EPA (1994) and Lewis Publishers, CRC Press (1996).
- Have since continued to investigate pollutant fates in amended and natural soils and filtration media.

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Potential Problem Pollutants were Identified Based on a Weak-Link Model Having the Following Components:

- Their abundance in stormwater,
- Their mobility through the unsaturated zone above the groundwater, and
- Their treatability restrictions before discharge.

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Links Depend on Infiltration Method
(contamination potential is the lowest rating of the influencing factors)

- Subsurface injection with minimal pretreatment (infiltration trench in parking lot or dry well)
  - **Abundance** most critical
- Surface infiltration with no pretreatment (pavement or roof disconnections to pervious areas, use of porous pavement or rain gardens, etc.)
  - **Mobility and abundance** most critical
- Surface infiltration with sedimentation pretreatment (grass filters, treatment train such as percolation pond after wet detention pond or MCTT)
  - **Mobility, abundance, and treatability** all important

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Example Weak-Link Model Influencing Factors

Constituent	Abundance in Stormwater	Mobility (sandy/low organic soils)	Treatability Problems (filterable fraction)
Nitrates	low/moderate	mobile	high
Chlordane	moderate	intermediate	very low
Anthracene	low	intermediate	moderate
Pyrene	high	intermediate	high
Lead	moderate	very low	very low

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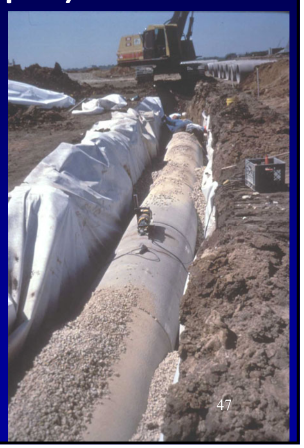
Minimal Pre-treatment before Infiltration Needed to Reduce Groundwater Contamination Potential (lacking in these examples)



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Additional Objectives of Bioinfiltration Facilities

- Maintain time of concentration
- Enhance aesthetics of neighborhood

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Landscaped swale in Alabama
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Portland, OR, biofiltration around parking areas
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Portland, OR, infiltration around parking area
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Rain garden (during rain) in a highly landscaped commercial site along Route 1.
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Larry Coffman, Prince George's County

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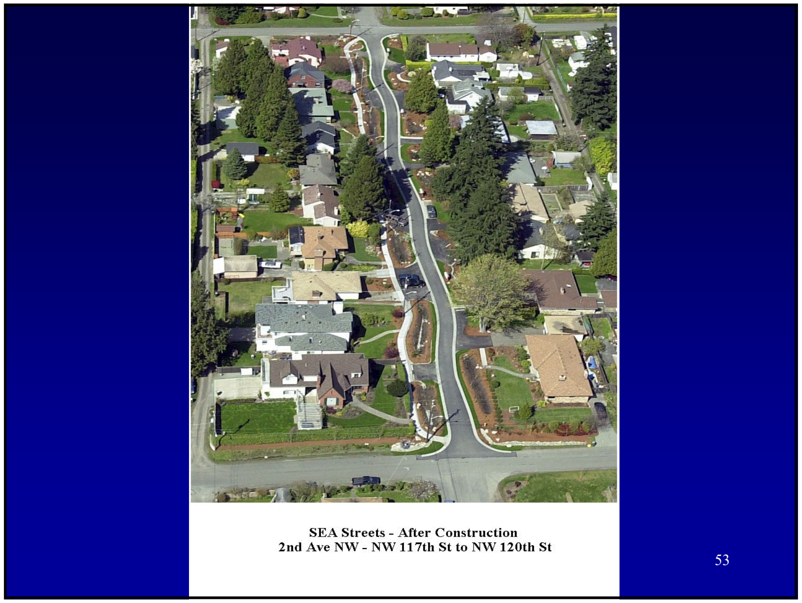
SEA Streets - After Construction
2nd Ave NW - NW 117th St to NW 120th St
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Seattle SEA street draining stormwater away from street to vegetated area
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Madison, WI, Rain Garden Designed for Complete Infiltration of Roof Runoff (monitored site)
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Portland, OR, Green (brown?) Roof

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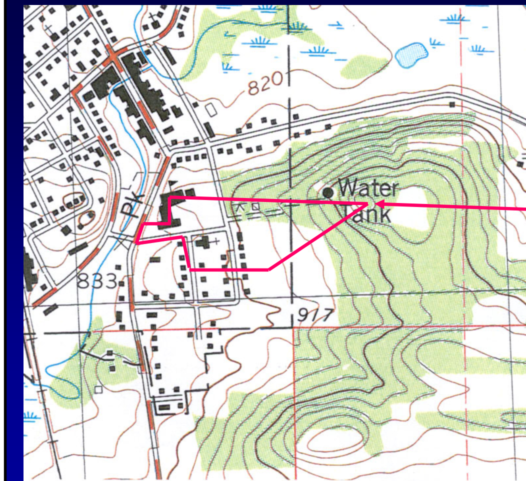
Lodi, WI, Transportation Area Infiltration Facility



Drainage Basin Area: 16 acres

Paved Area: 3.2 acres (20% of total area)

City of Lodi, Columbia County

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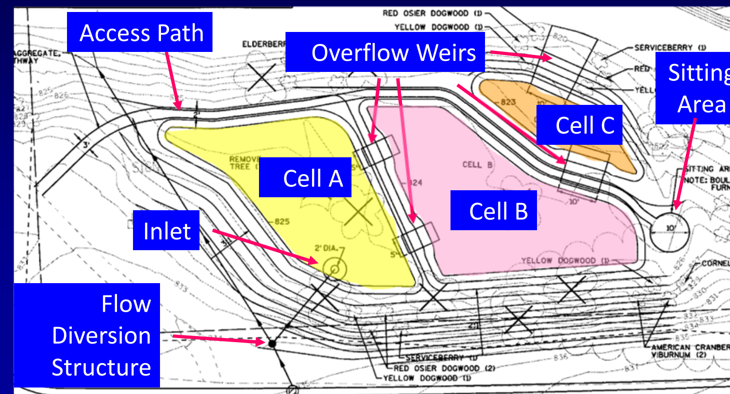
Infiltration Area Features



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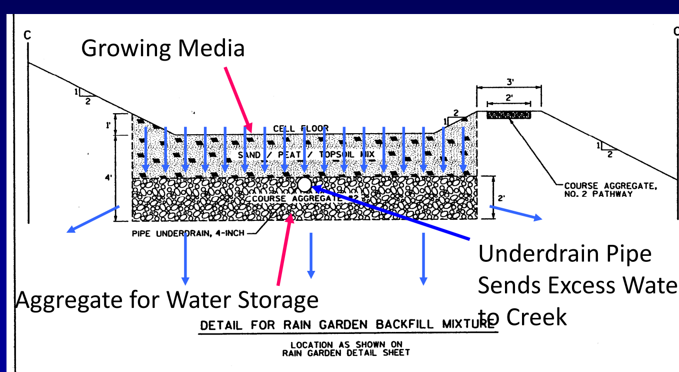
Infiltration Area Backfill Media Material and Underdrain



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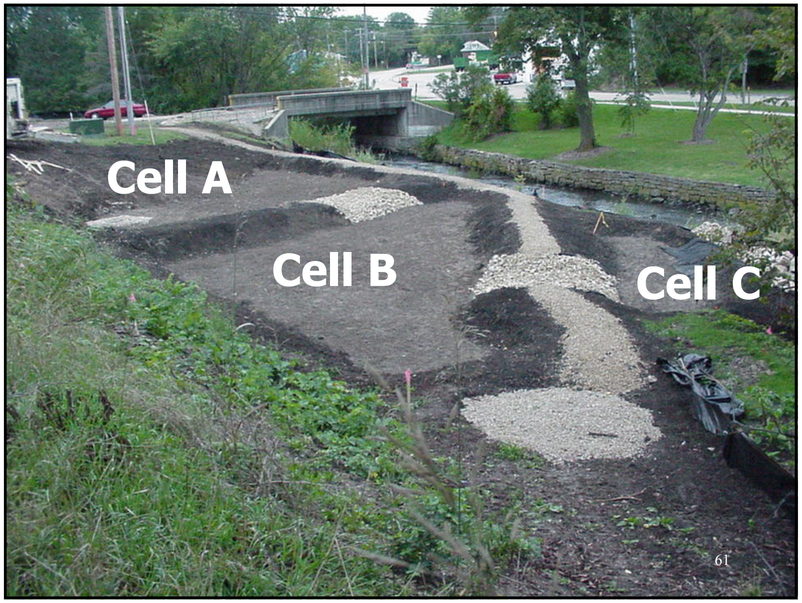

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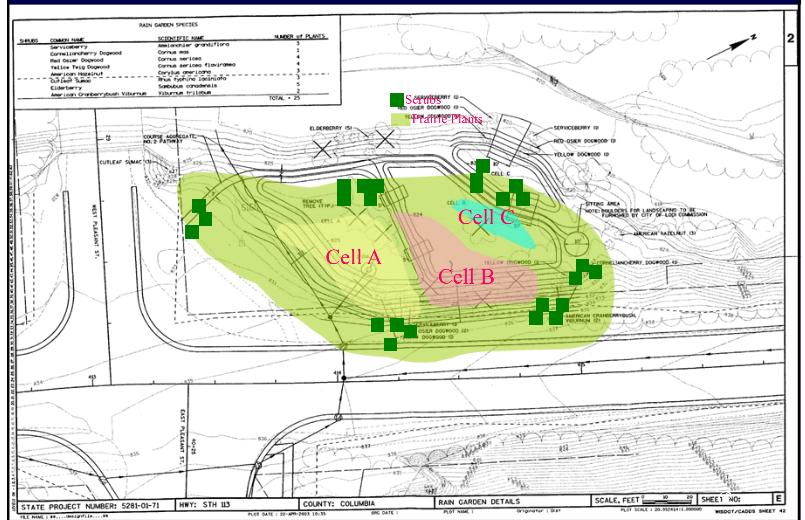
Planting Plan



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Lodi Infiltration Area Costs

Pipe Underdrain and Endwalls	$700
Flow Regulation Structure	$3,000
Plants	$2,650
Backfill media	$11,600
Excavation	$2,200
Crushed Material/Riprap	$3,850
Storm Sewer and Manholes	$3,500
Total $4.70/ft^2 of rain garden; $8,600 per paved acre of drainage area	$27,500

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Elements of Low Impact Design for Cedar Hills Development (near Madison, WI)

- Grass Swales
- Wet Detention Pond
- Infiltration Basin/Wetland
- Reduced Street Width

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Cedar Hill Site Design, Crossplains WI
Explanation
Wetpond
Infiltrations Basin
Swales
Sidewalk
Driveway
Houses
Lawns
Roadway
Woodlot
N
500 0 500 1000 Feet
65

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Wide grass swales with conventional curb and gutters (curb inlets drain to grass swales through very short pipes)
WI DNR photo
66

66

Wet pond above infiltration area wetland
WI DNR photo
67

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Infiltration area/wetland below wet pond
Joyce Powers, CRM Ecosystems & Prairie Ridge Nursery
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Reductions in Runoff Volume for Cedar Hills (calculated using WinSLAMM)

Type of Control	Runoff Volume, inches	Expected Change (being monitored)
Pre-development	1.3	
No Controls	6.7	515% increase
Swales + Pond/wetland + Infiltration Basin	1.5	78% decrease, compared to no controls

Biofilter Media Flow Rates
(usually the most important characteristic in biofilter design)

Sileshi (2013), as part of his PhD dissertation at the University of Alabama, conducted about 200 laboratory column tests to identify the important factors affecting treatment flow rates for different biofiltration media:

http://unix.eng.ua.edu/~rpitt/Publications/11_Theses_and_Dissertations/Redi_dissertation.pdf

Twenty-two test mixtures (including four Tuscaloosa area soils and three bioretention media mixtures from actual facilities) were prepared to cover the typical range of bioretention media characteristics: the median particle sizes ranged from 270 to 1,900 micrometers and the uniformity coefficients ranged from 1.3 to 39. The organic matter content ranged from a low of 1.5 to a high of about 50%. Each test was conducted in triplicate and the resulting saturated flows were measured, along with their coefficients of variation, for three levels of compaction.

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.
- Four-inch (100 mm) diameter PVC pipes 3 ft (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 biofilter media: a) bottom of the columns secured with a fiberglass window screen, b) biofilter media, and c) compaction

Lab Column Tests (cont'd)

- Tests were also organized in a complete 4 factor, 2 level (2^4) factorial design, investigating main effects and all interactions of texture, uniformity, organic content, and compaction. Mid-point analyses were also conducted for response surface modeling.
- 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 1.5 ft (0.5 m) deep.
- 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 11 in. (28 cm) and 14 in. (36 cm) to correspond to the approximate maximum ponding depths at biofilters.

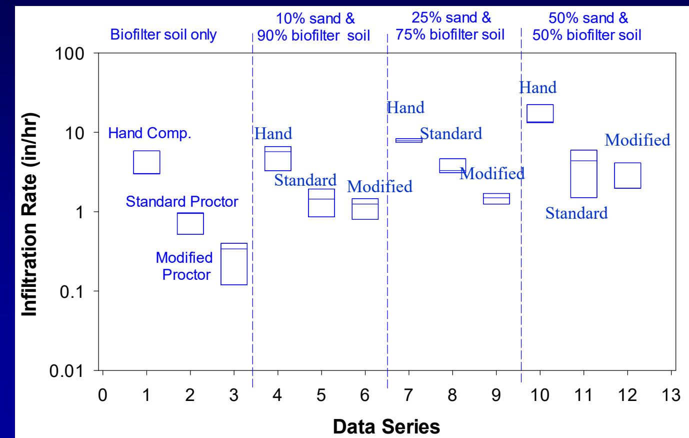
Full 2^4 Factorial Design

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
8	+	-	-	-	404
9	-	+	+	+	2.7
10	-	+	+	-	18.3
11	-	+	-	+	0.7
12	-	+	-	-	7.8
13	-	-	+	+	4.2
14	-	-	+	-	22.3
15	-	-	-	+	3.0
16	-	-	-	-	7.5

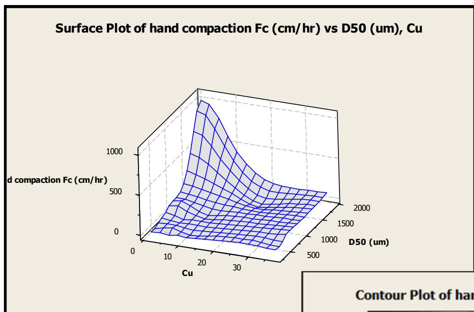
Largest flows associated with largest particle size, smallest uniformity coefficient, and low organic matter content. Compaction did not affect the low OM tests significantly. 73

73

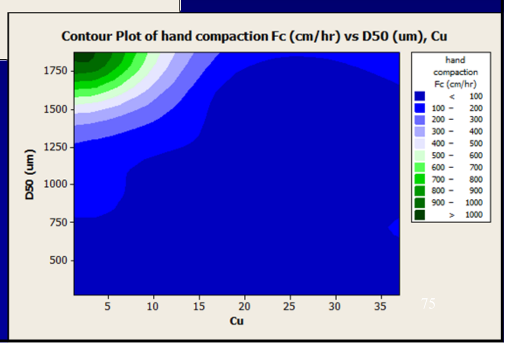
Example Test Results using Local Biofilter Media (very high uniformity coefficient): Different Compaction Conditions with Varying Amounts of Sand Amendments



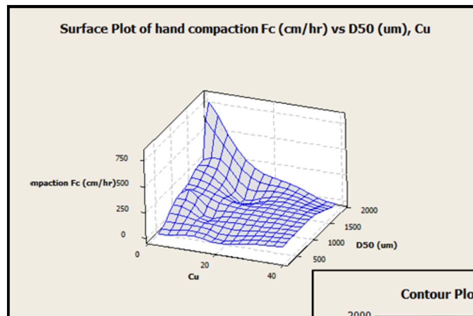
74



Effects of median particle size (D50) and uniformity (D60/D10) for hand compaction (very low) and low organic matter content (<10%)

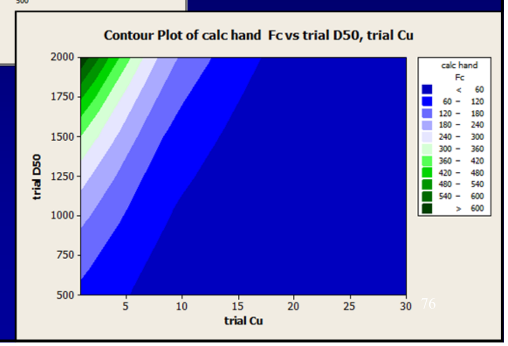


75



Effects of median particle size (D50) and uniformity (D60/D10) for hand compaction (very low) and high organic matter content (>10%)

Data also available for moderate and high compaction. High organic matter media more sensitive to compaction than low organic matter media.



76

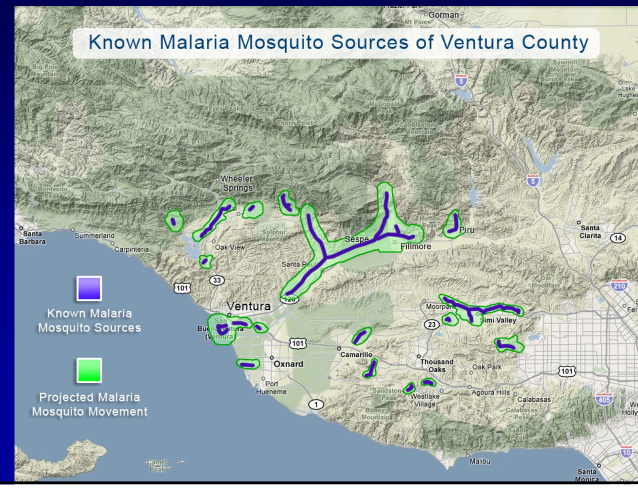
Outlet Controls and Underdrains

Underdrains are used in biofilters to decrease the duration of standing water to prevent nuisance conditions from developing. Some regulations restrict standing water to less than 24 or 72 hrs, for example. However, if an underdrain is used (and if not needed to meet this standing water criterion), short-circuiting of infiltration will occur with substantial decreases in runoff volume reduction performance. Therefore, underdrains should be evaluated using continuous WinSLAMM model analyses to produce production functions to help determine the need for underdrains and associated performance effects.

77

77

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

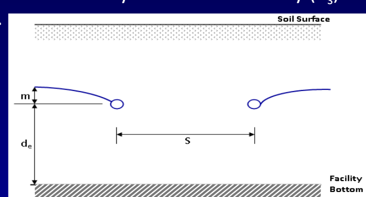


78

78

Underdrain Spacing

The Hooghoudt (1940) equation can be used to determine the underdrain spacing to meet specific ponding time criterion (to ensure that water reaches the underdrains in necessary time period). Important soil properties needed to use the Hooghoudt equation include the saturated hydraulic conductivity (K_s) and the depth to a restrictive layer (d_e).



The Hooghoudt equation is expressed:

$$s = \sqrt{\frac{4.k_s(m^2+2.d_e.m)}{q/24}}$$

Where:

s spacing between drains (ft)

q amount of water that the underdrain carries away (in/day),

K_s average saturated hydraulic conductivity of the facility media (in/hr),

d_e effective depth (ft) (the height of the underdrain above the biofilter bottom),

m depth of water, or head, created over the pipes (ft), in the drainage layer (to bottom of media layer)

79

79

Saturated Hydraulic Conductivities (in/hr) for Different Grain Size Sand

Grain size class	Degree of Sorting		
	Poor	Moderate	Well
medium sand	33.5	40	47
medium to coarse sand	37	47	-
medium to very coarse sand	42	49-56	-
coarse sand	40	54	67
coarse sand to very coarse sand	47	67	-
very coarse sand	54	74	94

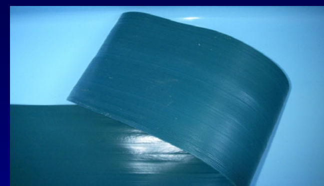
For a sand to be classified as well graded, $C_u \leq 6$

80

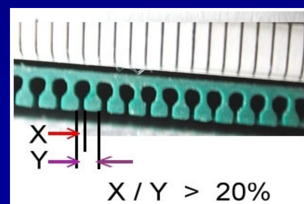
80

Restricted Flow Underdrain (SmartDrain ™) Material also Studied by Sileshi (2013)

- Most biofilter underdrains have large flow capacities which can severely reduce the infiltration benefits of a biofilter (short-circuits the flows). More restrictive underdrains many times needed.
- The SmartDrain™ was tested for applications in biofilters as a more restricted flow option by Sileshi (2013). Factors tested for effects on flow were: length, slope, hydraulic head, and type of sand media, under a range of typical biofilter conditions. Clogging tests were also conducted.



SmartDrain™ material showing the microchannels on the underside of the 8 inch wide strip. It has132 micro channels; cross-section shown below:



81

Drainage Characteristics of the SmartDrain™

- A pilot-scale biofilter was used to test the variables affecting the drainage characteristics of the underdrain.
- The SmartDrain™ was installed on top of a 4 in. layer of the drainage sand, and another 4 in. 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 22 in. above the center of the pipe and then allowed to drain, resulting in head vs. discharge data.
- Clogging (with both fines and algae) were also evaluated with little effect on the flows.

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

82

82

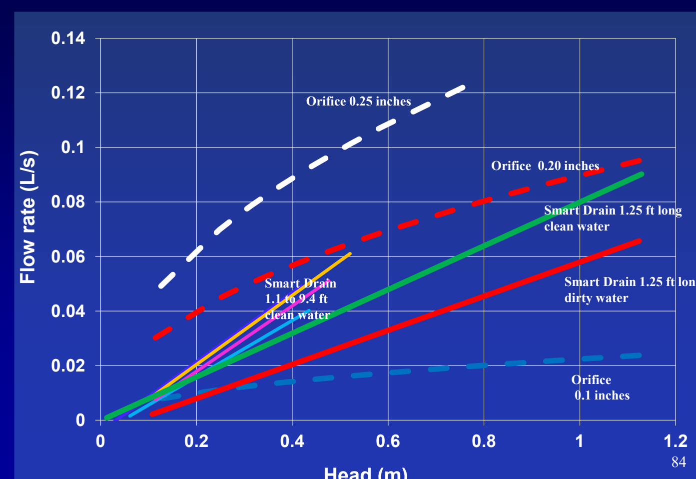
Biofouling Testing of SmartDrain™

- 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

Algae floating in the tank and trapped on top of the filter sand after the water was completely drained from the tank. 83

83

SmartDrain™ Flow Rates Compared to Very Small Orifices



84

84

Spreadsheet to Assist in Preliminary Design of Biofilters

	A	B	C	D	E	F	G	H	I
1	**Loading and Life of Infiltration Device (verify designs with continuous models and field verification) and media drainage time and underdrain spacing**								
2	R. Pitt September 28 2017	Fill in values highlighted in yellow, and don't change other cells. Examine orange cells.							
3									
4	**"Simple" method:**								
5	**Area (ha)**	**Surface or area:**			**Annual Rv**	**Particulate Solids, mg/L**			
6	0	low density residential			0.15	40			
7	0	medium density residential			0.3	48			
8	0	high density residential			0.5	50			
9	0.5	commercial			0.8	43			
10	0	industrial			0.6	77			
11	0	freeways/highways			0.9	100			
12	0	pitched roofs			0.95	10			
13	0	flat roofs			0.85	10			
14	0	paved parking, streets and walks			0.75	50			
15	0	unpaved parking and storage			0.75	500			
16	0	landscaped with sandy soils			0.1	50			
17	0	landscaped with silty soils			0.15	150			
18	0	landscaped with clayey soils			0.25	250			
19	**0.5**		**annual weighted:**		**0.8**	**43**			
20									
21	**Annual rain total (mm):**		1,170		**inches per year:**		46.1		
22	**Annual total runoff (m3):**		4,680		**ft3 per year:**		168,491		
23	**Annual total particulate solids (kg):**		201.24		**lb per year:**		315		
24					**acres:**		1.25		
25									
26	**Infiltration Device and Media/Soil Properties (samples represent 0.5 m in depth):**								
27	Surface area (m2) (from E66-74):	138	% of drainage:	2.8	**total CEC content of soil (meq):**			43,125,000	
28	CEC (meq/100g):	25							
29	dry soil density (g/cc):	2.5		meq					
30	Na (ppm):	100		4.35	**Media/Soil SAR:**	**0.45**	problem if >5 for some clays, otherwise		
31	Ca (ppm):	2500		125.00			problem if >15, but depends on soil		
32	Mg (ppm):	750		61.48			conductivity		
33	est clogging (kg/m2):	25							
34									
35	**Surface loading rate:**	**34**	meters/year	**0.09**	avg meters/day (should be <1)				
36		**1**	kg/m2/year		**est life before flow problem (years):**			**17.14**	can be
37								extended with vigorous	
38								vegetation	
39	**Runoff Water Characteristics:**		meq/L						
40	Na (mg/L) (snowmelt?):	10	0.43		**total cations meq/year:**		5,937,224		
41	Ca (mg.L):	10.5	0.53		**approx. CEC life (years):**		**7.26**	does not consider sorption	
42	Mg (mg.L):	3.3	0.27						
43	K (mg/L):	1.5	0.04		**Water SAR:**	**1.63**			
44		total cations:	1.27						
45					**Ratio of water SAR to original soil SAR:**			3.6	degrading
46								media/soil SAR conditions if >1	

Enter values in yellow cells and examine calculated results in orange cells. Do not overwrite any cell but the yellow cells!!

85

85

Flow Rates through Biofilter Media

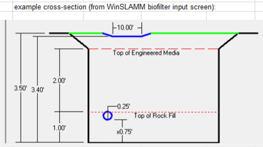
	A	B	C	D	E	F	G	H	I	J	K	L	M
47													
48	**Flow Rate Through Biofilter Media:**												
49	Low Organic Matter Content (<10%):												
50		compaction	D50 (mm)	Cu	log Fc	Fc (cm/hr)	Fc (in/hr)	media thickness (m)	media thickness (in)	porosity	effective thickness (in)	residence time (min)	residence time (hr)
51		low	1000	15	1.46	29.1	11.5	1.5	59.1	0.45	26.6	139	2.32
52		moderate			0.96	9.0	3.6					448	7.46
53		high			0.73	5.4	2.1					448	7.46
54													
55	High Organic Matter Content (>10%):												
56		compaction			log Fc	Fc (cm/hr)	Fc (in/hr)						
57		low			1.39	24.3	9.6					167	2.78
58		moderate			1.10	12.6	5.0					321	5.35
59		high			0.88	7.5	3.0					539	8.99
60													
61													
62	**Required Biofilter Surface Area**		design rain intensity (mm/hr):	design rain intensity (in/hr):	very approx. peak flow rate (cfs):		Note: these biofilter area calculations do not consider natural infiltraiton or flow routing; just conservative drainage.						
63			25	0.98	0.39		These are just preliminary estimates and need to be verified thru production curves made using WinSLAMM						
64													
65													
66		Low Organic Matter Content (<10%):	compaction	very approx. biofilter area (ft2):	select for cell B27: very approx. biofilter area (m2):	% of drainage area (%)							
67			low	1,483	138	2.8							
68			moderate	4,777	444	8.9							
69			high	8,020	745	14.9							
70													
71		High Organic Matter Content (>10%):	compaction	very approx. biofilter area (ft2):	very approx. biofilter area (m2):	% of drainage area (%)							
72			low	1,778	165	3.3							
73			moderate	3,422	318	6.4							
74			high	5,754	535	10.7							

86

86

Underdrain Characteristics

	A	B–M
77	**Underdrain**	Not all biofilter/bioretention facilities require underdrains! They are usually used to decrease periods of standing water that may cause nuisance conditions. Check with continuous WinSLAMM analyses.
78		Use of underdrains will usually short-circuit infiltration through bottom of bioretention facility, but can also result in increased concentration reductions by having more water pass through the media.
80		Objective is the drain the entire capacity of the biofilter (free storage plus media void storage) in designated maximum time period (usually 24 or 72 hrs).
82		example cross-section (from WinSLAMM biofilter input screen):



98 assume that the surface area (calculated above for different media characteristics and compactions) remains the same for all depth (conservative):

	D	E	
100	media void ratio:	0.45	
101	drainage time	24	hrs
102	depth above media (free water)	5	inches
103	depth of media+drain layer above underdrain	24	inches

	D	E	F	G	H	I	J
105			very approx. biofilter area (ft2)	free water volume (ft3)	water volume in media (ft3)	total biofilter water capacity (ft3)	drainage rate (CFS)
106	Low Organic Matt	compaction					
107		low	1,483	618	1,335	1,953	0.023
108		moderate	4,777	1,990	4,299	6,289	0.073
109		high	8,020	3,342	7,218	10,560	0.122
110			very approx. biofilter area (ft2)				
111	High Organic Matt	compaction					
112		low	1,778	741	1,601	2,342	0.027
113		moderate	3,422	1,426	3,080	4,506	0.052
114		high	5,754	2,398	5,179	7,576	0.088

87

Restricted Flow SmartDrain™

116 **Restricted Flow Smart Drain**

117 The restricted flow SmartDrain flow rate was determined by Sileshi (2013) to be:

118 $Q = 0.0286 + 0.0015(L) + 0.0246(H)$

120 Where: Q = Predicted flowrate (L/s) [28.32 L per ft^3]

121 H = SmartDrain head (in) = 24 inches

122 L = SmartDrain length (ft) [assumed to the square root of the biofilter area]:

	D	E	F	G	H	I	J
124			very approx. biofilter area (ft2):	SmartDrain length (ft)	Flow rate per SmartDrain (L/s)	Flow rate per SmartDrain (CFS)	number of SmartDrains to meet drainage rate
125	Low Organic Matter Content (<10%):	compaction					
126		low	1,483	39	0.677	0.024	1
127		moderate	4,777	69	0.723	0.026	3
128		high	8,020	90	0.753	0.027	5
129							
130	High Organic Matter Content (>10%):	compaction					
131		low	1,778	42	0.682	0.024	1
132		moderate	3,422	59	0.707	0.025	2
133		high	5,754	76	0.733	0.026	3

88

88

Orifice Outlet Control

Orfice Outlet Control

general orifice equation to calculate diameter of conventional perforated pipe underdrain, short pipe assumption (or diameter of controlling orifice):

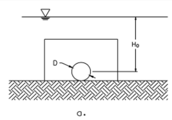
For a single orifice as illustrated in Figure 10-11 (a), orifice flow can be determined using equation 10.17.

$$Q = C_o A_o (2 g H_o)^{0.5} \quad (10.17)$$

where: Q = the orifice flow rate, m^3/s (ft^3/s)
C_o = discharge coefficient (0.40 - 0.60)
A_o = area of orifice, m^2 (ft^2)
H_o = effective head on the orifice measured from the centroid of the opening, m (ft)
g = gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)

If the orifice discharges as a free outfall, then the effective head is measured from the centerline of the orifice to the upstream water surface elevation. If the orifice discharge is submerged, then the effective head is the difference in elevation of the upstream and downstream water surfaces. This latter condition of a submerged discharge is shown in Figure 10-11(b).

For square-edged, uniform orifice entrance conditions, a discharge coefficient of 0.6 should be used. For ragged edged orifices, such as those resulting from the use of an acetylene torch to cut orifice openings in corrugated pipe, a value of 0.4 should be used.



http://www.ct.gov/dot/lib/dot/documents/ddrainage/10.8.pdf

solving for the orifice area (A):
$A = Q/[C(2gh)^{0.5}]$

C	0.55			
H	24	inches	2	feet

		Q, drainage rate (CFS)	A (ft2)	minimum D (inches)
Low Organic Matt	compaction			
	low	0.023	0.004	0.8
	moderate	0.073	0.012	1.5
	high	0.122	0.020	1.9
High Organic Mat	compaction			
	low	0.027	0.004	0.9
	moderate	0.052	0.008	1.2
	high	0.088	0.014	1.6

Spacing of Underdrains (part 1)

Spacing of Underdrains

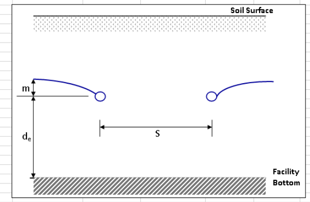
The Hooghoudt (1940) equation (described in Sileshi 2013) calculates the spacing of underdrains:

$$s = \sqrt{\frac{4.k_s(m^2 + 2.d_e.m)}{q/24}}$$

Where:

s	spacing between drains (ft)		
q	amount of water that the underdrain carries away (in/day),	calculated below	
K_s	average saturated hydraulic conductivity of the facility media (in/hr),	50	in/hr (see table below, based on drainage layer media)
d_e	effective depth (ft) (height of underdrain above the biofilter bottom)	0.5	ft
m	depth of water, or head, created over the pipes (ft) in the drainage layer	0.5	ft

calc numerator for S:
500



Spacing of Underdrains (part 2)

Saturated Hydraulic Conductivity (in/hr) of Different Grain Size Sand (US EPA 1986)

	Degree of Sorting		
Grain size class	Poor	Moderate	Well
medium sand	33.5	40	47
medium to coarse sand	37	47	-
medium to very coarse sand	42	49-56	-
coarse sand	40	54	67
coarse sand to very coarse sand	47	67	-
very coarse sand	54	74	94

*A hyphen indicates that no data are available

For a sand to be classified as well graded, $C_u \leq 6$ and $1 < C_c < 3$, where C_u and C_c are the coefficient of uniformity and coefficient of curvature respectively and were calculated using the following equations:

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{{D_{30}}^2}{D_{10} D_{60}}$$

where D_{60} is the grain diameter at 60% passing, D_{10} is the grain diameter at 10% passing, and D_{30} is the grain diameter at 30% passing.

Spacing of Underdrains (part 3)

		Q, drainage rate (CFS)	very approx. biofilter surface area (ft2)	q, amount underdrain carries away (in/day)	q/24 (in/hr)	calculated maximum underdrain spacing (ft)	width of biofilter (ft) (assuming square)	minimum number of underdrains needed across biofilter	example: previously calculated number of SmartDrains needed	Example: Number of SmartDrains needed to meet spacing or drainage time
Low Organic Matter Content (<10%):	compaction									
	low	0.023	1,483	15.8	0.66	27.6	38.5	1	1	1
	moderate	0.073	4,777	15.8	0.66	27.6	69.1	3	3	3
	high	0.122	8,020	15.8	0.66	27.6	89.6	3	5	5
High Organic Matter Content (>10%):	compaction									
	low	0.027	1,778	15.8	0.66	27.6	42.2	2	1	2
	moderate	0.052	3,422	15.8	0.66	27.6	58.5	2	2	2
	high	0.088	5,754	15.8	0.66	27.6	75.9	3	3	3

Conclusions – relative effectiveness of controls

	Cost	Effectiveness
Inappropriate discharge elimination	Low	High
Erosion control	Low to moderate	Low to moderate
Floatable and litter control	Low to moderate	Low to high
Oil & water separators	Moderate	Very low
Critical source control	High	Low to high
Extensive use of biofiltration (LID, SUDS, etc.)	Low to moderate	Moderate to high
Public education	Low to moderate	?????

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Conclusions (cont.)

- Biofilters can be very effective in reducing stormwater flows and improving stormwater quality.
- Their effectiveness depends on many factors, mostly on how much of the watershed area runoff is directed to the biofilters. Very small areas are more likely to have larger fractions of their runoff directed to biofilters than large areas. Retrofitting biofilters not as effective as using for new development.

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Conclusions (cont.)

- Many design attributes affect biofilter performance, mainly:
  - Treatment flow rate of biofilter media
  - Flow rates associated with most common storms
  - Native soil conditions
  - Groundwater depth
- The spreadsheet used with this workshop allows preliminary calculations to help in the selection of biofilter media, various design attributes, and performance/maintenance issues.
- The alternative designs need to be further evaluated using continuous modeling using WinSLAMM for a wide range of rain conditions.

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