Impacts of Construction on Soil Permeability

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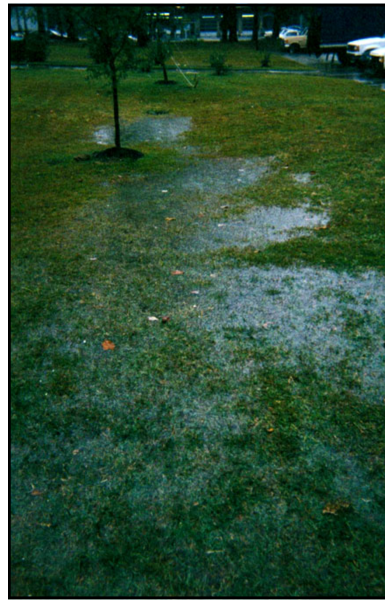

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Disturbed Urban Soils during Land Development Leads to Compacted Soils

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Compaction of Soils After Development Also Common

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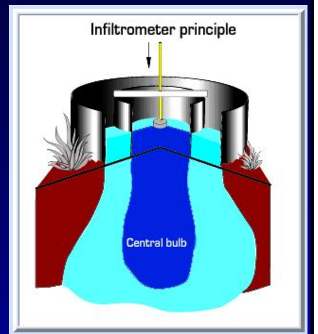
Double-Ring Infiltrometer – ASTM D3385



WI DNR Double-Ring Infiltrometer Test Results (in/hr), Oconomowoc (mostly A and B soils)

Initial Rate	Final Rate	Range of Observed Rates
25	15	11 to 25
22	17	17 to 24
14.7	9.4	9.4 to 17
5.8	9.4	0.2 to 9.4
5.7	9.4	5.1 to 9.6
4.7	3.6	3.1 to 6.3
4.1	6.8	2.9 to 6.8
3.1	3.3	2.4 to 3.8
2.6	2.5	1.6 to 2.6
0.3	0.1	0 to 0.3
0.3	1.7	0.3 to 3.2
0.2	0	0 to 0.2
0	0.6	0 to 0.6
0	0	all 0
0	0	all 0

Abstract

- Previous research identified significant reductions in infiltration rates in disturbed urban soils.
- More than 150 initial tests were conducted in predominately sandy and clayey urban soils in the Birmingham and Mobile, Alabama, areas.
- Infiltration in clayey soils was found to be affected by an interaction of soil moisture and compaction, while infiltration in sandy soils was affected by soil compaction alone.

Applications of These Data

- Newer tests were conducted under more controlled laboratory conditions and represent a wider range of soil textures and specific soil density values.
- The high head conditions during these tests make these results suitable for biofiltration/infiltration devices that have 1 to 2 ft of head.

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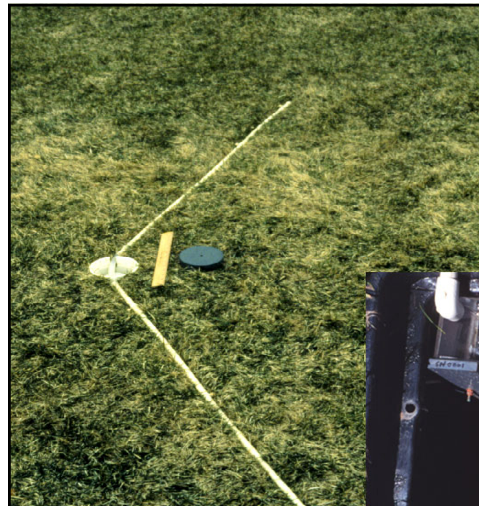
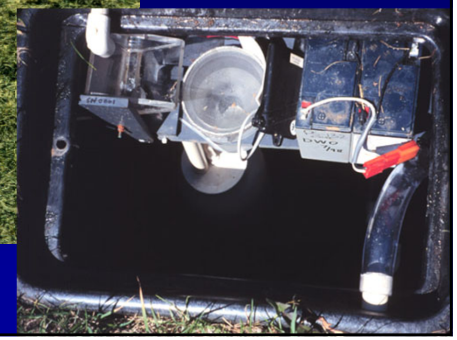


Direct measurements of turf runoff for different soil conditions.



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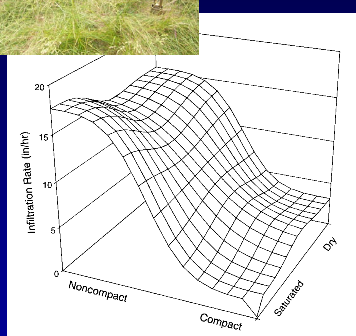
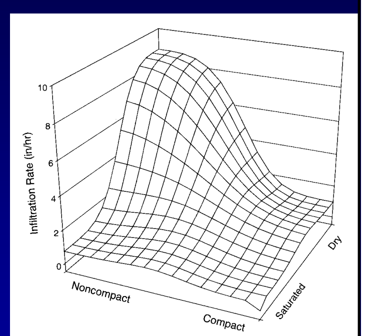
Infiltration Rates in Disturbed Urban Soils (AL tests)



Sandy Soils



Clayey Soils

Field measurements have shown that the infiltration rates of urban soils are strongly influenced by compaction, probably more than by moisture levels.

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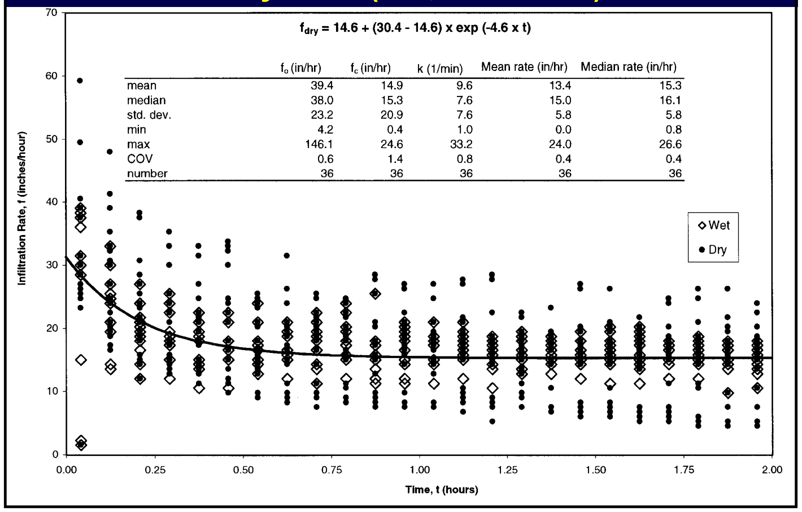
Infiltration Measurements for Noncompacted, Sandy Soils (Pitt, *et al.* 1999)



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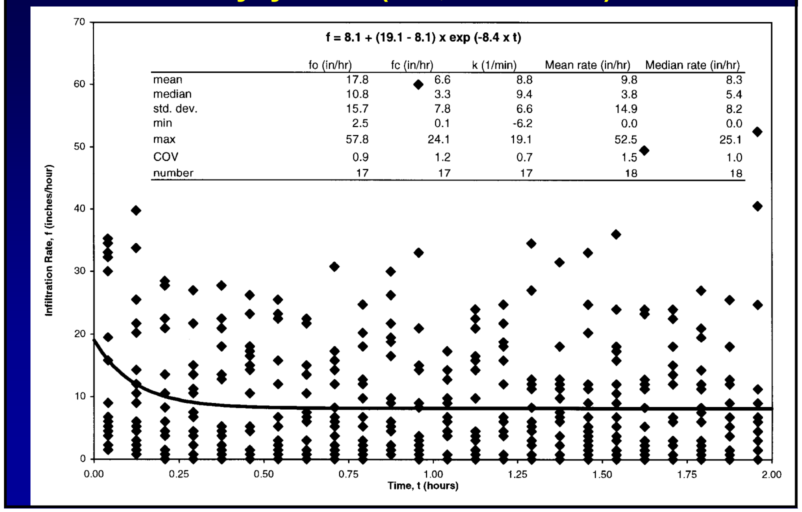
Infiltration Measurements for Dry-Noncompacted, Clayey Soils (Pitt, *et al.* 1999)



	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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Method

- Additional tests were run for up to 20 days in the soils laboratory, although most were completed (when steady low rates were observed) within 3 or 4 days.
- Initial soil moisture levels were about 8% (sand was about 3%), while the moisture levels after the tests ranged from about 20 to 45%.
- Three methods were used to compact the test specimens: hand compaction, plus two Proctor test methods.
- Both Modified and Standard Proctor Compactions follow ASTM standard (D 1140-54).

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Method (cont.)

- Hand compaction (gentle hand pressing to force the soil into the mold with as little compaction as possible),
- Standard Proctor Compaction (24.4 kN hammer dropped 25 times form 300 mm on each of 3 soil layers).
- Modified Proctor Compaction (44.5 kN hammer dropped 25 times from 460 mm on each of 5 soil layers).

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Method (cont.)

- A total of 7 soil texture types were tested representing all main areas of the standard soil texture triangle.
- Three levels of compaction were tested for each soil.
- Only 15 tests resulted in observed infiltration. The Standard and Modified Proctor clay tests, the Modified Proctor clay loam, and all of the clay mixture tests did not result in any infiltration, even after several days.

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Test Mixtures for Laboratory Tests

	Sand	Clay	Silt	Sandy loam	Clayey loam	Silty loam	Clay mix
% sand	100			72.1	30.1	19.4	30
% clay		100		9.2	30.0	9.7	50
% silt			100	18.7	39.9	70.9	20

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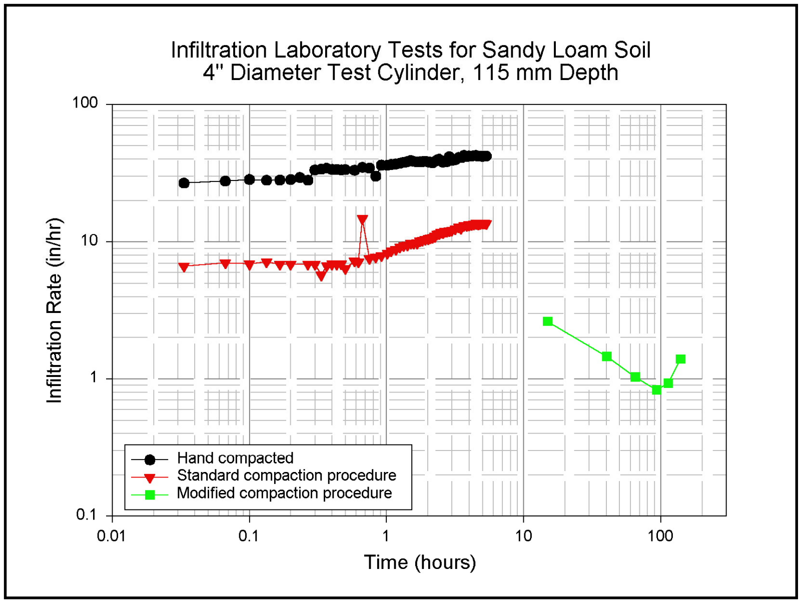

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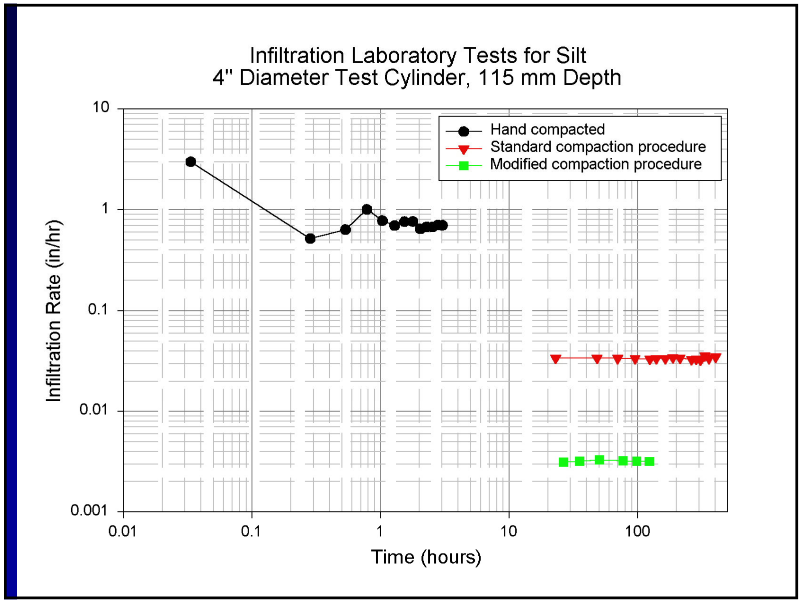

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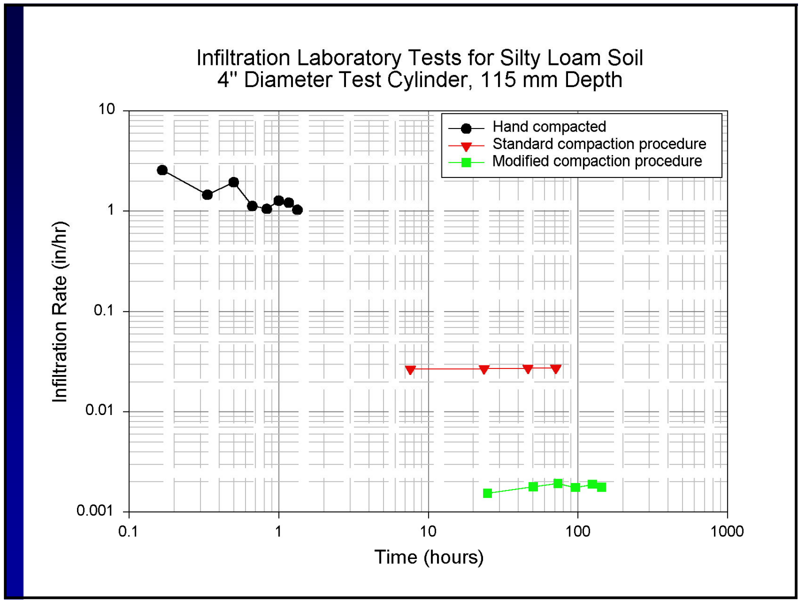

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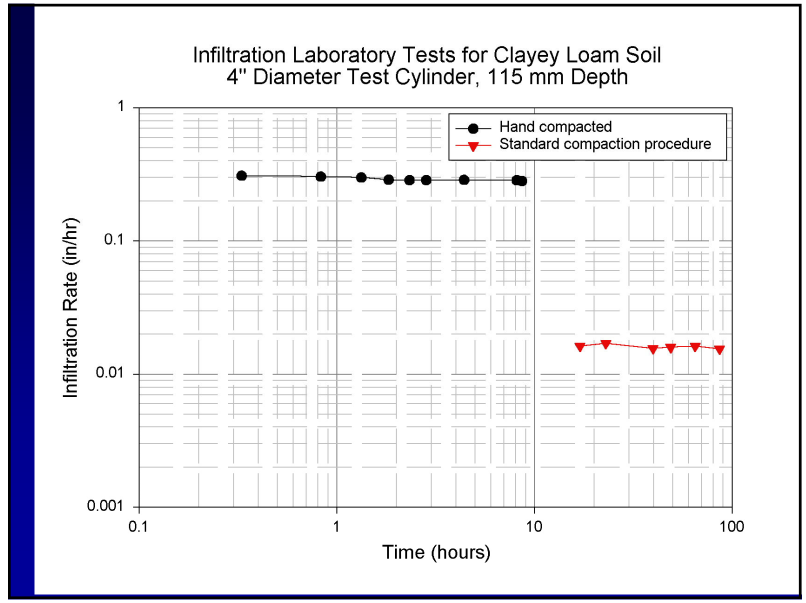

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Long-Term Sustainable Average Infiltration Rates

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (in/hr)
Silt	Hand	1.508	May affect	0.7
	Standard	1.680	May affect +	0.034
	Modified	1.740	Restrict	0.0030
Sand	Hand	1.451	Ideal	Very high
	Standard	1.494	Ideal	0.5 ?
	Modified	1.620	May affect -	3.2
Clay	Hand	1.241	May affect	0.12
	Standard	n/a	n/a	0
	Modified	n/a	n/a	0

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Long-Term Sustainable Average Infiltration Rates (cont.)

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (in/hr)
Sandy Loam	Hand	1.595	May Affect	35
	Standard	1.653	May Affect	9
	Modified	1.992	Restrict	1.5
Silt Loam	Hand	1.504	May Affect	1.3
	Standard	1.593	May Affect	0.027
	Modified	1.690	May Affect +	0.0017
Clay Loam	Hand	1.502	May Affect	0.29
	Standard	1.703	Restrict	0.015
	Modified	1.911	Restrict	0

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Typical household lawn aerators are ineffective in restoring infiltration capacity in compacted soils.

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Natural processes work best to solve compaction, but can take decades.

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Additional Laboratory and Field Verification Tests

- Conducted high resolution, low-head laboratory tests with soils, each at three compactions.
- Conducted field measurements of soil density and infiltration rates.
- These field soils were brought to the laboratory for moisture and texture analyses, plus laboratory infiltration measurements at the different compaction conditions.

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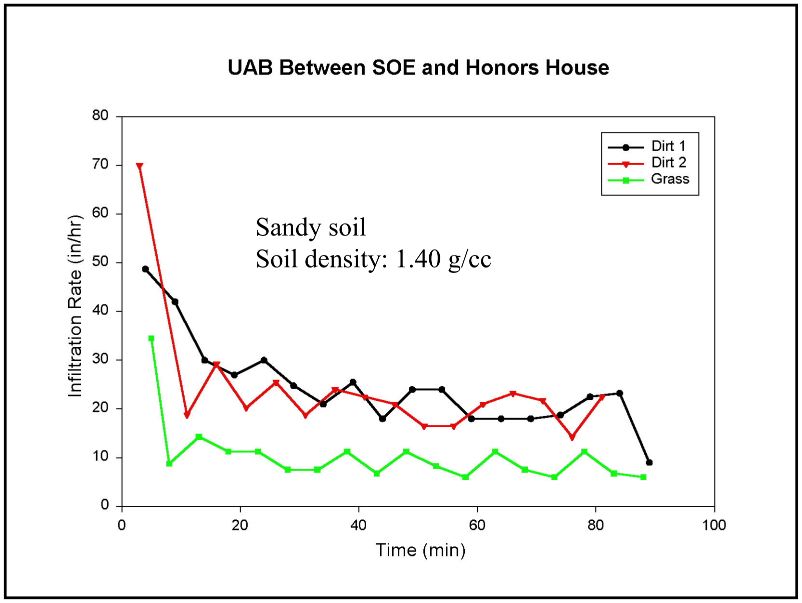

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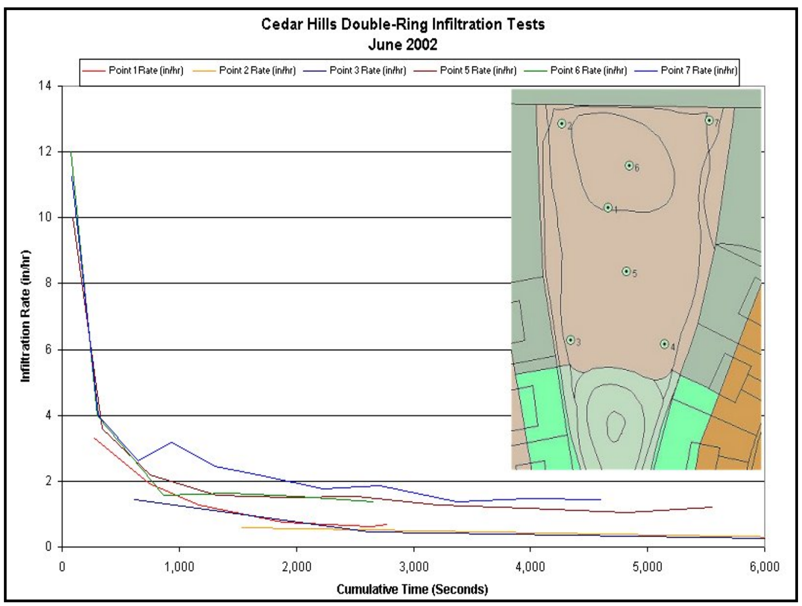

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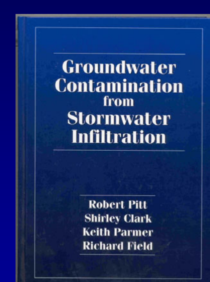
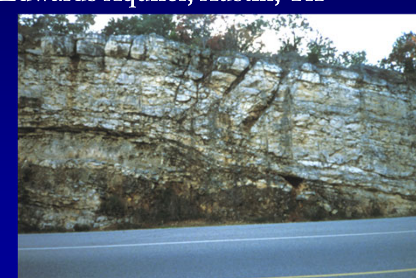
Groundwater Contamination

The potential for groundwater contamination associated with stormwater infiltration is often asked.



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

Road cut showing direct recharge of Edwards Aquifer, Austin, TX



http://civil.eng.ua.edu/~rpitt/Publications/BooksandReports/Groundwater%20EPA%20report.pdf

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Potential Problem Pollutants were Identified by Pitt, *et al.* (1994 and 1996) 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 before discharge.

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Soil Modifications and Rain Gardens

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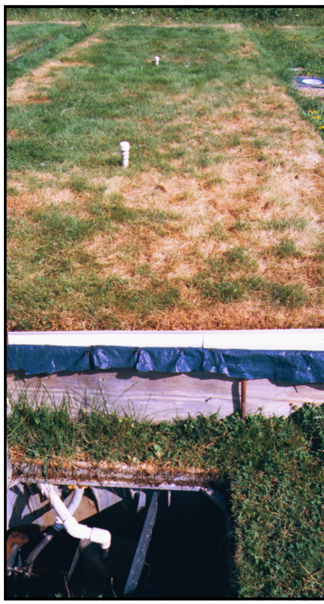

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Many soil processes reduce the mobility of stormwater pollutants

- Ion exchange, sorption, precipitation, surface complex ion formation, chelation, volatilization, microbial processes, lattice penetration, etc.
- If soil is lacking in these properties, then soil amendments can be added to improve the soil characteristics.
- Cation exchange capacity (CEC) and sodium adsorption ratio (SAR) are two soil factors that can be directly measured and water characteristics compared. Other soil processes (especially in complex mixtures) need to be evaluated using controlled experiments.

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Amended Soil Compared to Unamended 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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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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Filtration/Sorption Media Investigated

- **Activated carbon**
- **Bone char**
- **Zeolite**
- **Cationic exchange resin**
- **Sand**
- **Iron-enriched sand**
- **Peanut hulls**
- **Kudzu fiber**
- **Municipal leaf compost**
- **Peat moss**
- **Kenaf fiber**
- **Cotton textile waste**
- **Cotton milling waste**
- **Wood fibers**
- **Natural soils**
- **Sewage sludge**

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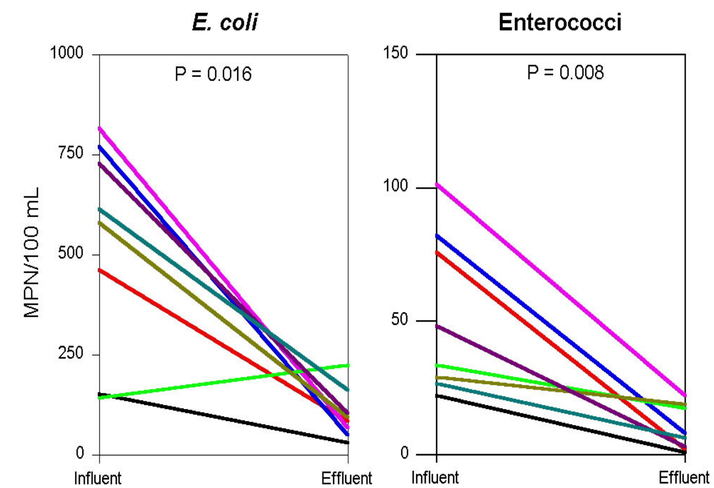

PEAT-SAND FILTER: Pilot-Scale Testing, Fall 1999

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Capture of Stormwater Particulates by Different Soils and Amendments

	0.45 to 3µm	3 to 12µm	12 to 30µm	30 to 60µm	60 to 120µm	120 to 250µm	>250µm
Porous pavement surface (asphalt or concrete)	0%	0%	0%	10%	25%	50%	100%
Coarse gravel	0%	0%	0%	0%	0%	0%	10%
Fine filter sand	10%	33%	85%	90%	100%	100%	100%
Loam soil	0%	0%	0%	0%	25%	50%	100%
Activated carbon, peat, and sand mixture	40%	45%	80%	100%	100%	100%	100%

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The Source Loading and Management Model (SLAMM)

- Developed during past 30 years during EPA, state, and Canadian funded research.
- Identifies pollutant sources during different rain and climatic conditions.
- Prioritizes subwatersheds and critical source areas.
- Evaluates alternative development scenarios, pollution prevention, and combinations of source area and outfall control options.

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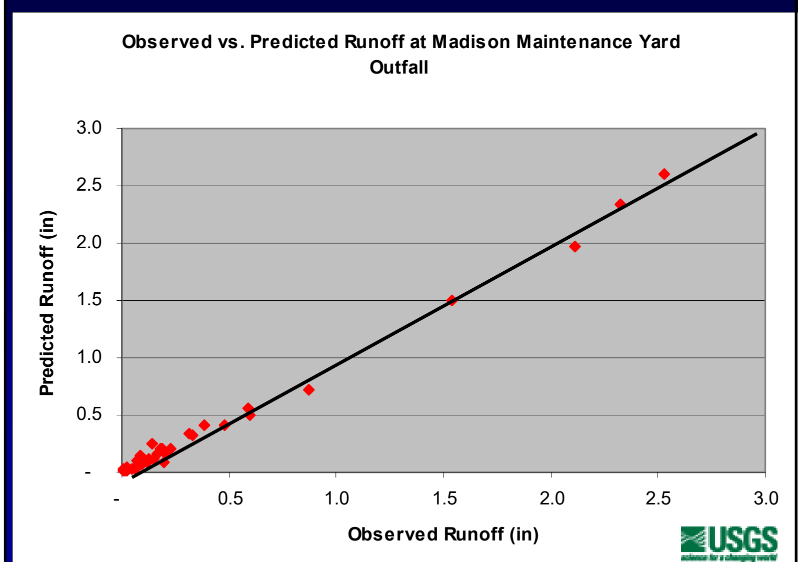

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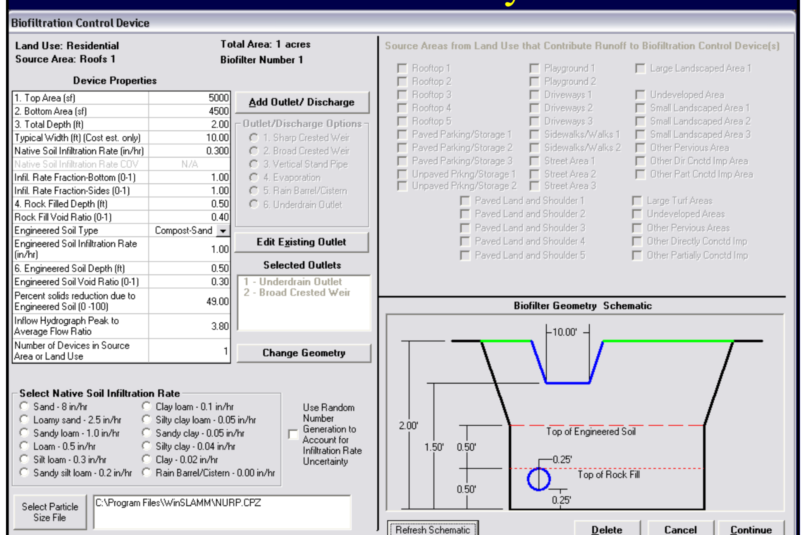
Biofilter Data Entry Form



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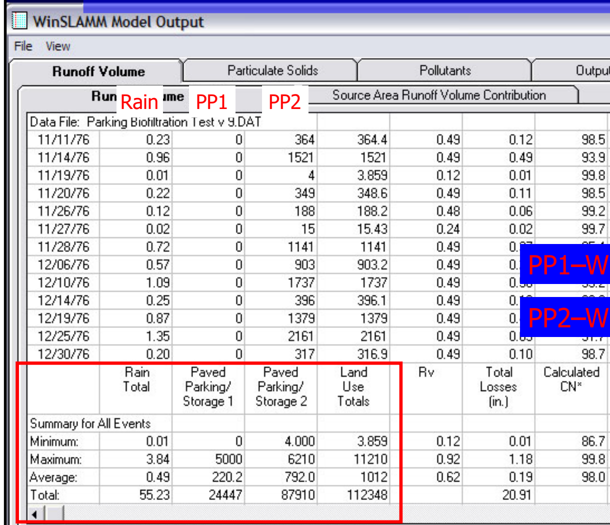
Source Area Runoff Volume



WinSLAMM Model Output

File View

Runoff Volume | Particulate Solids | Pollutants | Output

Runoff Volume | Source Area Runoff Volume Contribution

Rain PP1 PP2

Data File: Parking Biofiltration Test v 9.DAT

11/11/76	0.23	0	364	364.4	0.49	0.12	98.5
11/14/76	0.96	0	1521	1521	0.49	0.49	93.9
11/19/76	0.01	0	4	3.859	0.12	0.01	99.8
11/20/76	0.22	0	349	348.6	0.49	0.11	98.5
11/26/76	0.12	0	188	188.2	0.48	0.06	99.2
11/27/76	0.02	0	15	15.43	0.24	0.02	99.7
11/28/76	0.72	0	1141	1141	0.49	[illegible]	[illegible]
12/06/76	0.57	0	903	903.2	0.49	[illegible]	[illegible]
12/10/76	1.09	0	1737	1737	0.49	[illegible]	[illegible]
12/14/76	0.25	0	396	396.1	0.49	[illegible]	[illegible]
12/19/76	0.87	0	1379	1379	0.49	[illegible]	[illegible]
12/25/76	1.35	0	2161	2161	0.49	[illegible]	[illegible]
12/30/76	0.20	0	317	316.9	0.49	0.10	98.7
	Rain Total	Paved Parking/ Storage 1	Paved Parking/ Storage 2	Land Use Totals	Rv	Total Losses (in.)	Calculated CN*
Summary for All Events							
Minimum:	0.01	0	4.000	3.859	0.12	0.01	86.7
Maximum:	3.84	5000	6210	11210	0.92	1.18	99.8
Average:	0.49	220.2	792.0	1012	0.62	0.19	98.0
Total:	55.23	24447	87910	112348		20.91	

PP1–With Biofilter

PP2–Without Biofilter

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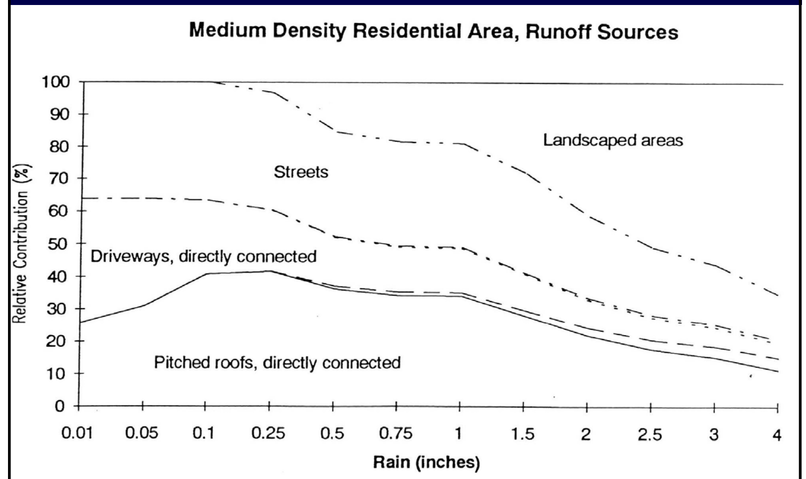

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Stormwater Infiltration Controls in Urban Areas

- Bioretention areas
- Rain gardens
- Porous pavement
- Grass swales
- Infiltration Basins
- Infiltration Trenches
- Subsurface Dispersal

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Roof drain disconnections directing roof runoff to surrounding soils can substantially reduce stormwater discharges in residential areas.

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Porous pavers in Malmo, Sweden, located on walkways to collect roof and yard runoff, reducing stormwater from entering combined sewer (street runoff not infiltrated).

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Portland, OR, biofiltration around parking areas

50


Retrofit biofiltration facility with overflow to drainage system, Portland, OR

51


Monitored rain garden with modified soils (Madison, WI)

52

Old style infiltration area for parking lot. Common siltation problems, damp pond area, and hard to maintain.

53

Infiltrating swale located below wet detention pond. Pond located in apartment complex and received runoff from upland commercial area. This swale was located in office park, as part of the large-scale treatment train. (Lake Oswego, OR)

54

“Sea Street” extensive retrofit, Seattle, WA

Current Seattle Street Design

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Neenah Foundry Employee Parking Lot, Neenah, WI

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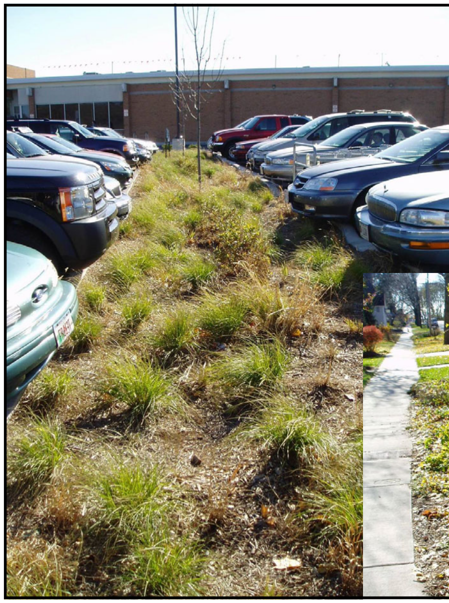


Recent Bioretention Retrofit Projects in Commercial and Residential Areas in Madison, WI

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Conclusions

- These tests indicated that both texture and compaction were important in determining the infiltration rates, with time since the beginning of rain only important for less than half of the conditions tested.
- These tests were conducted using a 1.1 m head and are most appropriate for biofiltration and infiltration designs where ponded water may occur. A series of tests were also conducted for sandy loam using 0.1 m head and the resulting infiltration rates were substantially less.

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Conclusions (cont.)

- These results (and those from the previous tests), however, do indicate significant effects associated with soil compaction. The prior field tests of infiltration rates for disturbed urban soils provided basic rates (and COV values) that are recommended for typical urban hydrology studies.
- SLAMM can be used to quantify the benefits of alternative soil structures and modifications on infiltration and biofiltration options.

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References

Pitt, R., J. Lantrip, R. Harrison, C. Henry, and D. Hue. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory. EPA 600/R-00/016. Cincinnati, Ohio. 231 pgs. December 1999.

NRCS. Soil Quality Institute 2000, Urban Technical Note 2, as reported by Ocean County Soil Conservation District, Forked River, NJ. 2001.

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