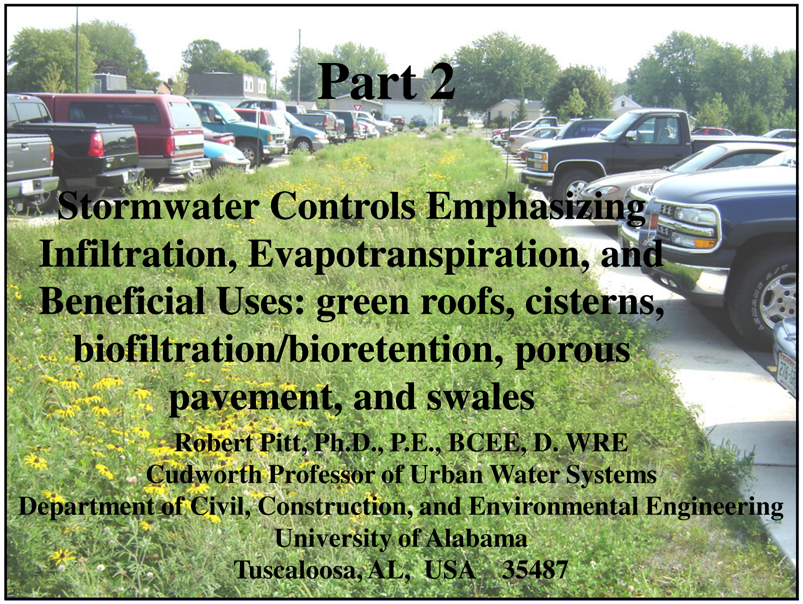


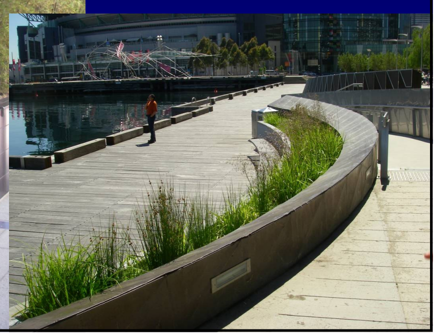
Part 2

Stormwater Controls Emphasizing Infiltration, Evapotranspiration, and Beneficial Uses: green roofs, cisterns, biofiltration/bioretention, porous pavement, and swales

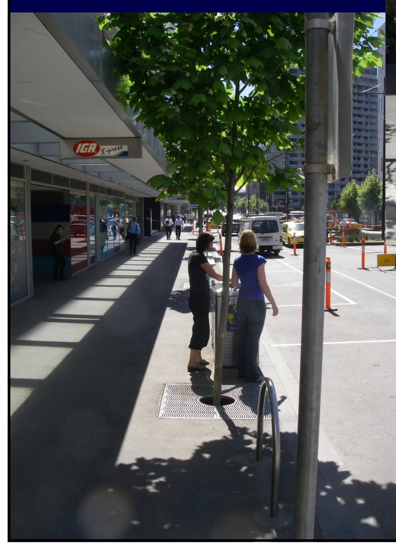
Robert Pitt, Ph.D., P.E., BCEE, D. WRE
Cudworth Professor of Urban Water Systems
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

- Biofilters utilize an under-drain to capture stormwater after filtration in the soil/media mixture and discharge it back to the drainage system. Some of this water may be infiltrated, depending on soil conditions and lining. In Australia, they are commonly lined as they want the treated water discharged back to the receiving water for use as a downstream water supply. Surface overflows capture excessive water and direct that to the drainage system with little treatment.

- Bioretention devices are constructed without an under-drain and are designed to infiltrate most of the water, after filtering in the soil/media mixture. They also usually have a surface overflow.



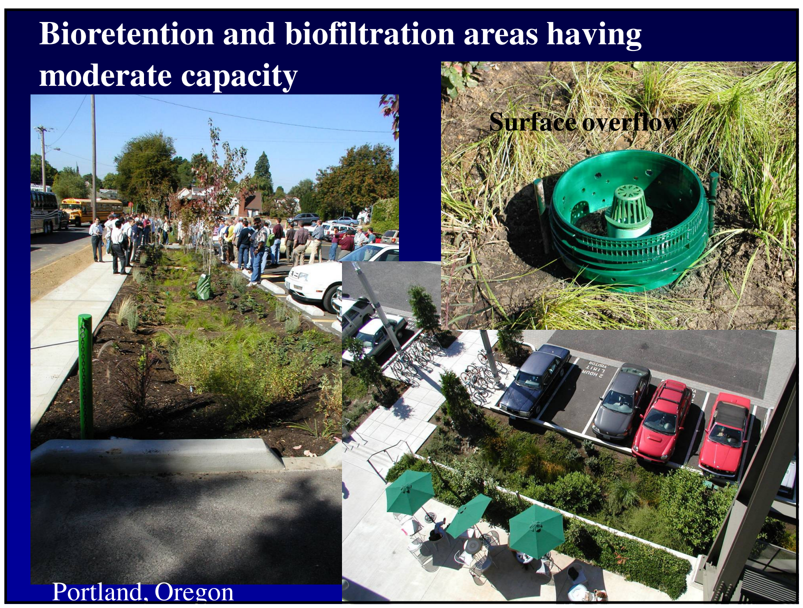
Stormwater filters and bioretention areas in ultra urban setting (Melbourne, Australia)



Street-side tree biofilters in downtown area (Melbourne, Australia)


Parking lot medians easily modified for bioretention (OR and MD).
Larry Coffman
Larry Coffman

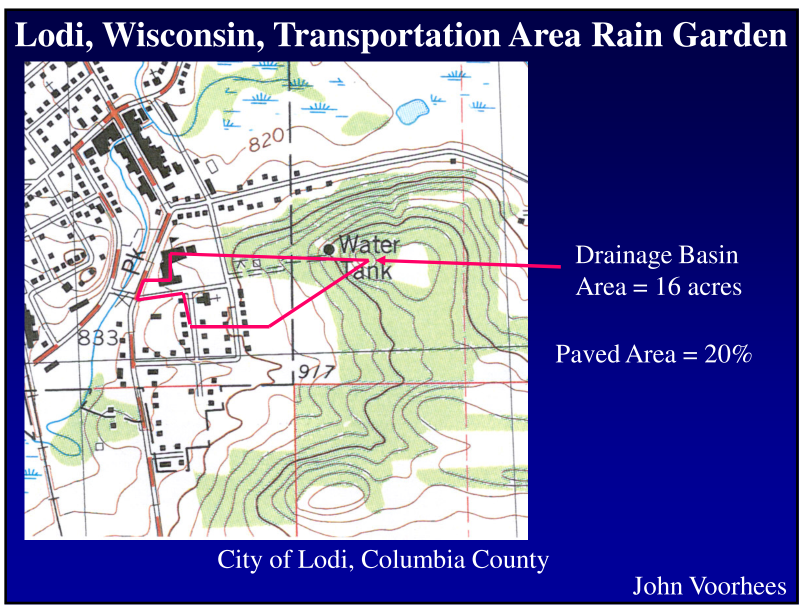

Portland, Oregon, bioretention areas to capture and treat parking lot runoff.

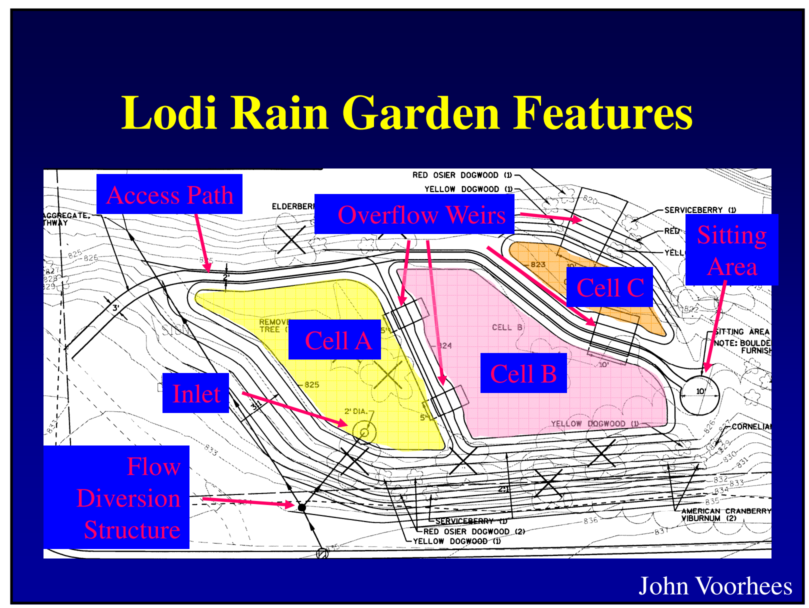

Bioretention and biofiltration areas having moderate capacity
Surface overflow
Portland, Oregon

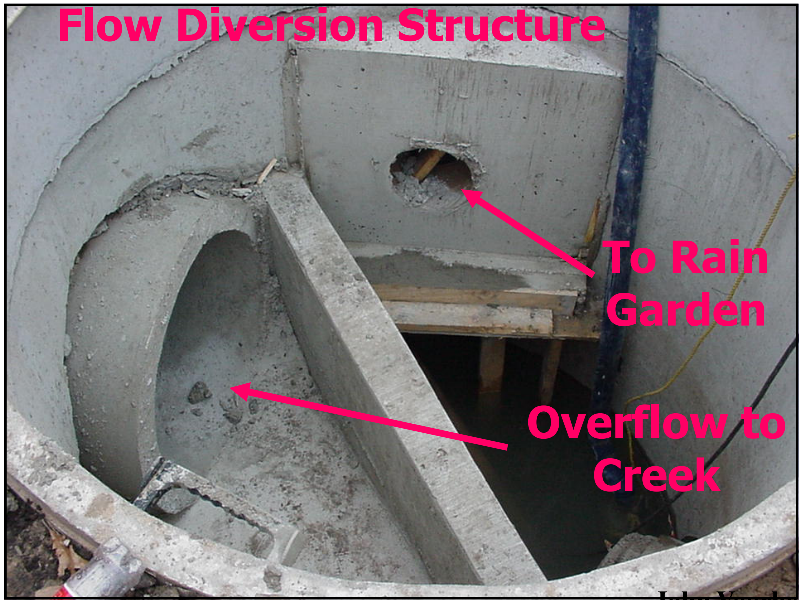

Recent Bioretention Retrofit Projects in Commercial and Residential Areas in Madison, Wisconsin

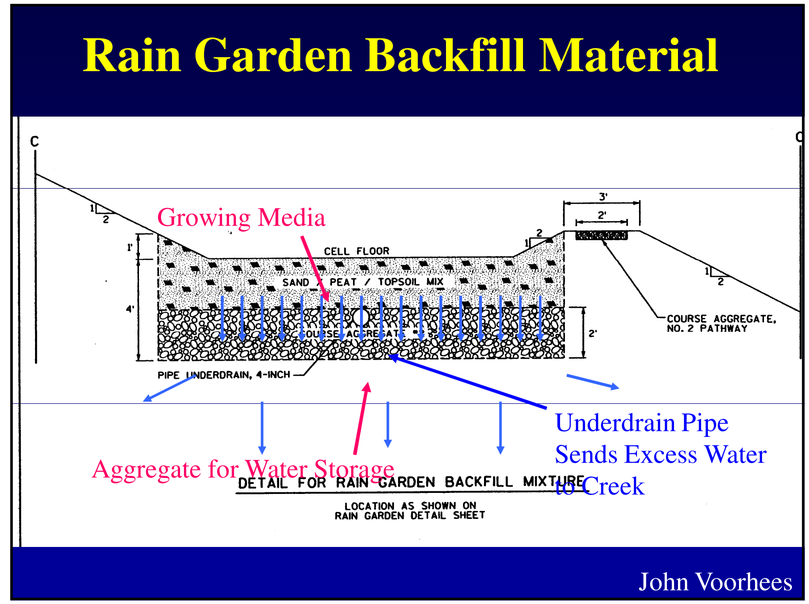

Neenah Foundry Employee Parking Lot Grass Filter/Biofilter, Neenah, Wisconsin
John Voorhees photo


Many examples given in the "San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook"
http://www.flowstobay.org/ms_sustainable_streets.php

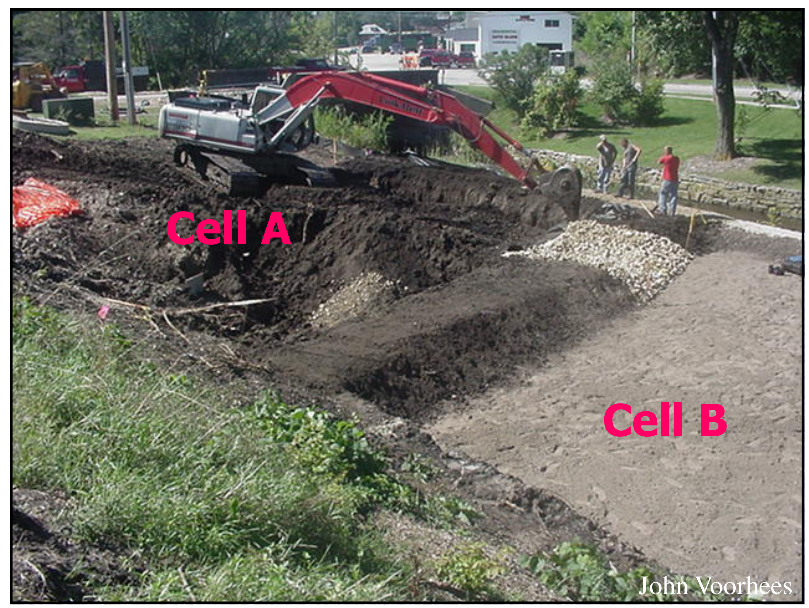

Lodi, Wisconsin, Transportation Area Rain Garden
Water Tank
820
833
917
Drainage Basin Area = 16 acres
Paved Area = 20%
City of Lodi, Columbia County
John Voorhees


Lodi Rain Garden Features
Access Path
Overflow Weirs
Sitting Area
Cell C
Cell A
Cell B
Inlet
Flow Diversion Structure
RED OSIER DOGWOOD (1)
YELLOW DOGWOOD (1)
SERVICEBERRY (1)
John Voorhees


Flow Diversion Structure
To Rain Garden
Overflow to Creek

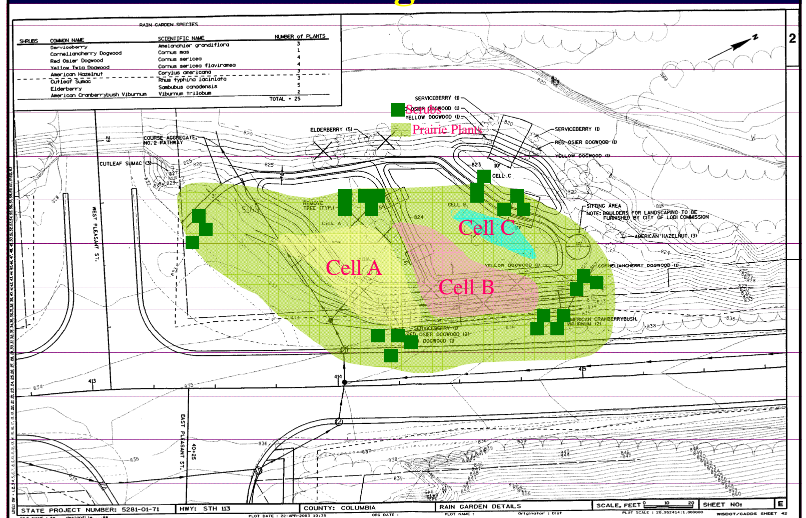

Rain Garden Backfill Material
Growing Media
CELL FLOOR
SAND / PEAT / TOPSOIL MIX
COURSE AGGREGATE
COURSE AGGREGATE, NO. 2 PATHWAY
PIPE UNDERDRAIN, 4-INCH
3'
2'
1'
4'
2'
Aggregate for Water Storage
Underdrain Pipe Sends Excess Water to Creek
DETAIL FOR RAIN GARDEN BACKFILL MIXTURE
LOCATION AS SHOWN ON RAIN GARDEN DETAIL SHEET
John Voorhees


Soil/Peat/Sand Mixing
John Voorhees


Cell A
Cell B
John Voorhees

John Voorhees

Planting Plan



John Voorhees


Fall 2004


Summer 2005


Spring 2005

Lodi rain garden vegetation (Planted in Spring 2004); excellent cover 6 to 15 months after planting

John Voorhees photos

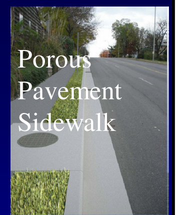
Lodi, WI, Rain Garden Costs

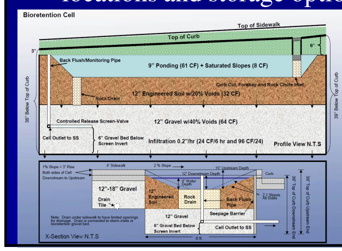
Pipe Underdrain and Endwalls	$700
Flow Regulation Structure	$3,000
Plants	$2,200
Shrubs	$450
Backfill	$11,600
Excavation	$2,200
Select Crushed Material/Riprap	$3,850
Storm Sewer and Manholes	$3,500
Total $4.70/sf	$27,500

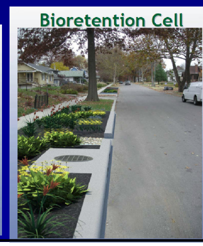
John Voorhees

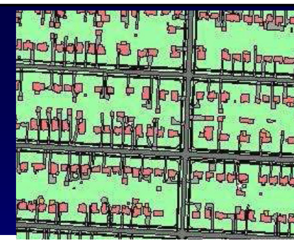
Current Kansas City Project using Green Infrastructure to reduce CSOs

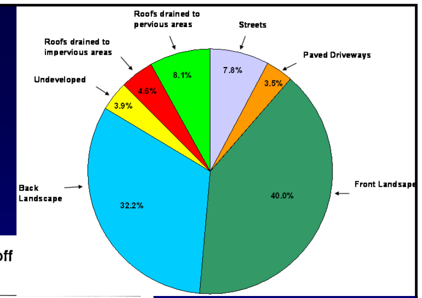
- Conventional CSO evaluations were conducted using XP_SWMM in order to identify the design storm for the demonstration area that will comply with the discharge permits.
- XP_SWMM was also used by KCMO Water Services Department, Overflow Control Program, to examine different biofiltration and porous pavement locations and storage options in the test watershed.

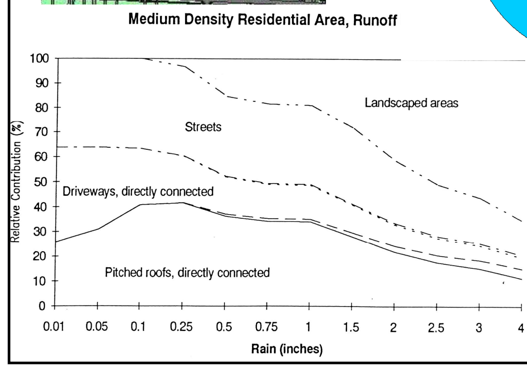








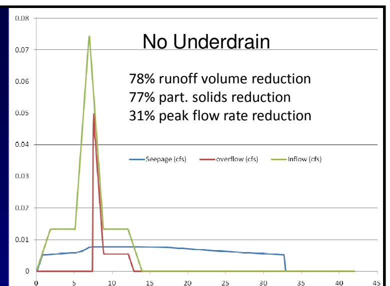


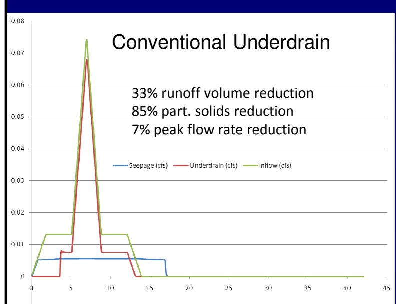


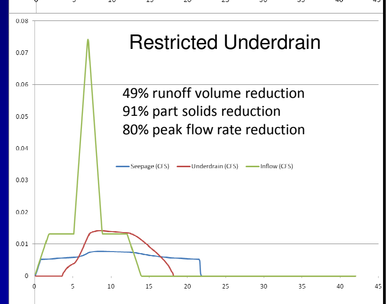
Surveys were conducted for each house and lot in the study area by UMKC graduate students. This information was used with the GIS data and WinSLAMM to determine the sources of the runoff during different rain conditions.

Example Biofilter Performance and Design using WinSLAMM

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.

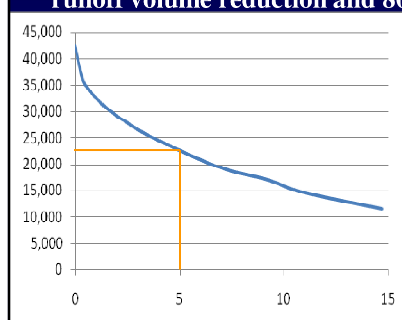




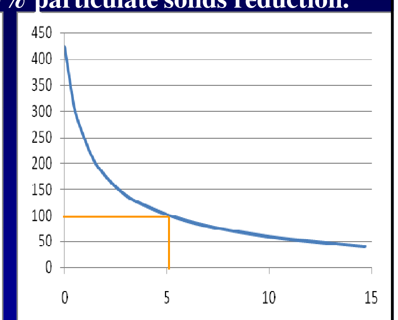


Long-Term (28 years) Continuous WinSLAMM Simulations

Need about 5% of the area as biofilter area to obtain about 50% runoff volume reduction and 80% particulate solids reduction.

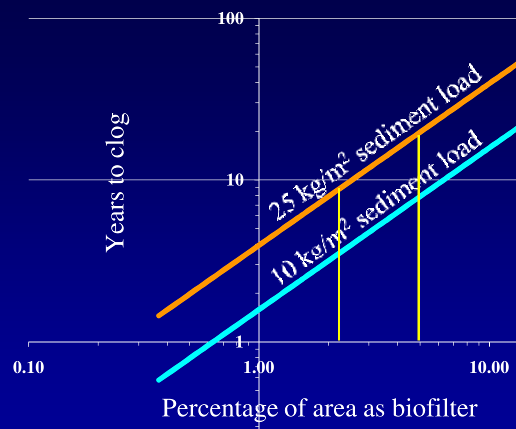


Total runoff (ft³/acre/year) vs. % of area as biofiltration devices



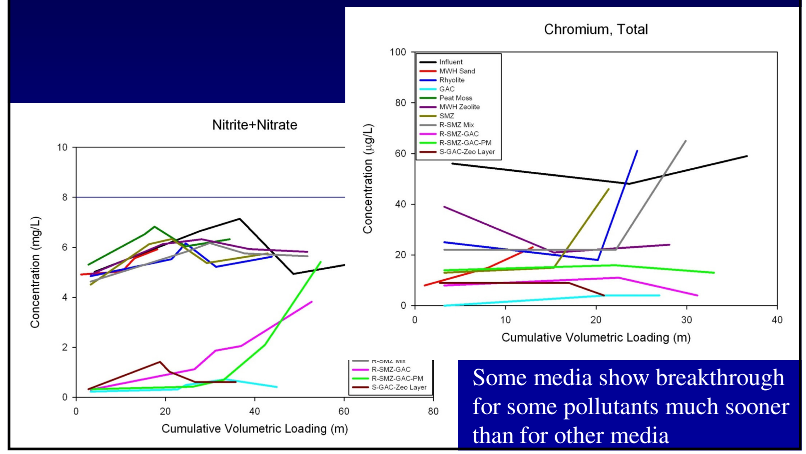
Annual total particulate solids yield (lbs/ac/year) vs. % of area as biofiltration devices

Years to clog as a function of biofilter size

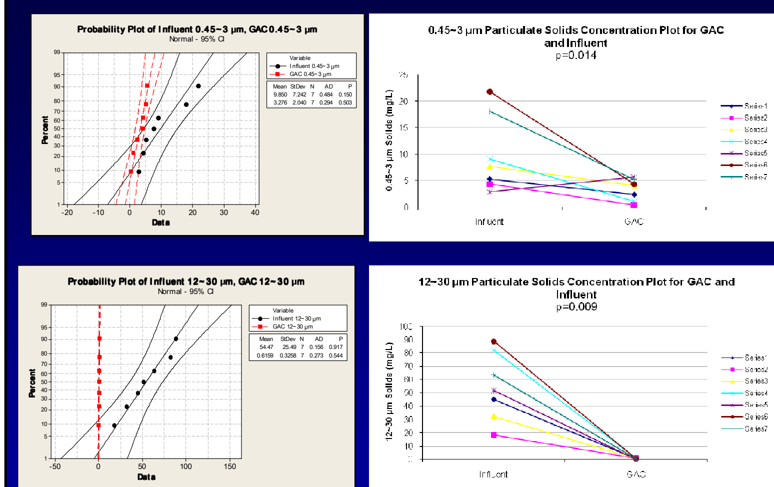


5% of the area as biofilter would provide 7 to 20 years before clogging (plants would likely extend operating period). 2.2% of the area as biofilters would only allow about 3 to 8 years before clogging, possibly too short for vegetation to have a significant benefit.

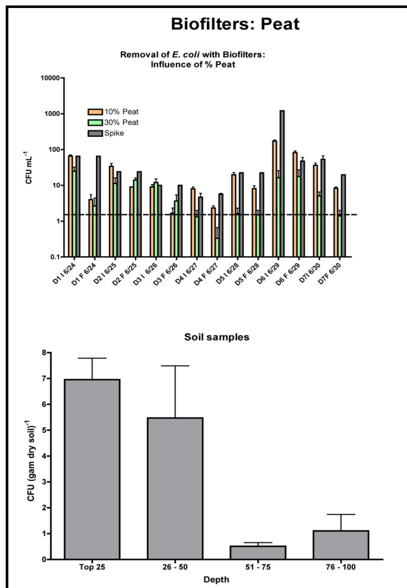
Current evaluations of treatment media show that they can be used for treatment before infiltration, or as a soil amendment



Some media show breakthrough for some pollutants much sooner than for other media



Treatment media can be very effective for a wide range of particle sizes



Bacteria Retention in Biofiltration Soil/Peat Media Mixtures

- Need at least 30% peat for most effective *E. coli* reductions
- Bacteria captured in top several inches of soil
- Continued tests to evaluate other organic amendments and longer testing periods

Preliminary data, Penn State - Harrisburg

Site Evaluation Tests

- Needed to characterize and quantify:
  - Site soil conditions (infiltration capacity, soil texture, soil density and bulk density, cation exchange capacity, sodium adsorption capacity, etc.)
  - Groundwater conditions (depth and movement, along with potential for groundwater mounding)

Site Evaluations Needed to Better Predict Bioretention Device

- Small-scale soil testing is suitable for small rain gardens, with suitable factors of safety and care in construction.
- Large-scale testing is needed if failure would result in serious consequences (such as if an integral part of a drainage system having little redundancy, or if critical environmental protection is needed).

Basic Characteristics for Soils and Materials Used in Biofilters

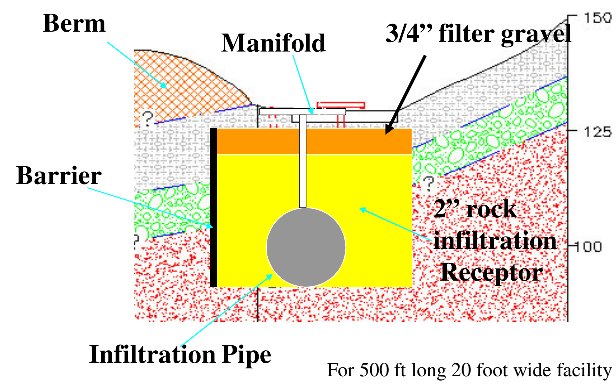
Soil Texture	Saturation Water Content (%) (Porosity)	Available Soil Moisture (Field Capacity to Permanent Wilting Point) inches water/inches soil	Infiltration Rate (in/hr) assumed to be slightly compacted	CEC (cmol/kg or meq/100 gms)	Dry density (grams/cm^3), assumed to be slightly compacted
Coarse Sand and Gravel	32	0.04	40	1	1.6
Sandy Loams	40	0.13	1	8	1.6
Fine Sandy Loams	42	0.16	0.5	10	1.6
Silty Clays and Clays	55	0.155	0.05	30	1.6
Peat as amendment	78	0.54	3	300	0.15
Compost as amendment	61	0.60	3	15	0.25

Double-Ring Infiltration Tests

Soil Density Measurements

Large-Scale Infiltration Bench and Verification Testing in Washington

Infiltration Facility



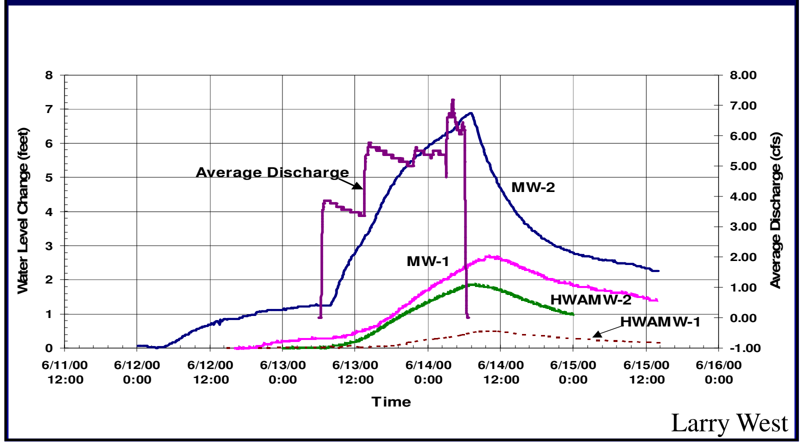
For 500 ft long 20 foot wide facility
Short-Term capacity 10 to 20 CFS
Expect 1.5 to 3.0 CFS long-term

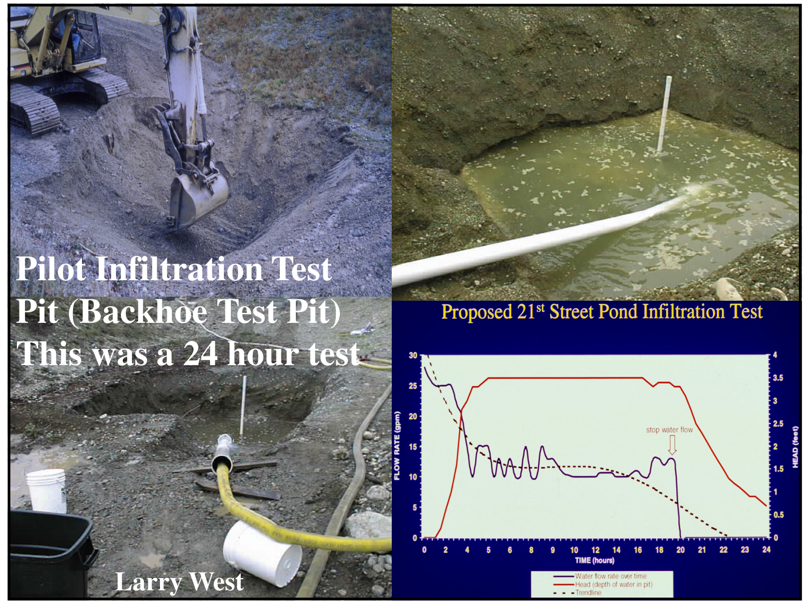
Larry West

Source Water Weir

Discharge Flow Dissipater

Full-scale 24-hr Infiltration Test
Ground Water Levels and Average Flow Discharge





Number of Pits and Borings Needed

Infiltration Device	***Tests Required***	***Minimum Number of Pits or Borings***	***Minimum Drill/Test Depth***
Bioretention	Pits or borings; mounding	1 test/50 linear feet of device with a minimum of 2	5 feet or depth to limiting layer
Infiltration Basin	Pits or borings; mounding	2 pits per area; with 1 pit or boring for every 10,000 sq. ft.	Pits to 10 ft. or borings to 20 ft.

Site Characterization Costs
typical unit costs (2000 costs)

- Test pits - $2,000/day (typically 4 to 8 per day)
- Grain-size determination - $100 each
- Test borings - 25 ft deep ~ $800 each
- Monitoring wells - 25 ft deep ~ $1,200 each
- Pilot infiltration test - $3,000 to $6,000
- Double-ring infiltration test - $2,000 to $4,000
- Ground water mounding analysis - $2,000 to $5,000
- Conduct site characterization during geotech study

Table 7.1 Western Washington Stormwater Management Manual

RECOMMENDED INFILTRATION RATES BASED ON USDA SOIL TEXTURAL CLASSIFICATION			
USDA Soil Classification	*Short-Term Infiltration Rate (in./hr)	Correction Factor, CF	Estimated Long-Term (Design) Infiltration Rate (in./hr)
Clean sandy gravels and gravelly sands (i.e., 90% of the total soil sample is retained in the #10 sieve)	20	2	10**
Sand	8	4	2***
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

* From WEF/ASCE, 1998

** Not recommended for treatment

*** Refer to SSC-4 and SSC-6 for treatment acceptability criteria

Design Infiltration Rates for Soil Textures Receiving Stormwater

Soil Texture	Design Infiltration Rates Without Measurements, inches/ hour
Sand	3.60
Loamy Sand	1.63
Sandy Loam	0.50
Loam	0.24
Silt Loam	0.13
Clay	0.07

New Wisconsin infiltration standards

Infiltration Rate Calculations
21st Street Percolation Pond (WA) (Clean Sandy Gravel)

Summary of Flow Rates for 24-hour Infiltration Test

Time (hours)	Size of Infiltration Area (feet)	Water Depth (feet)	Average Flow Rate (CFS)	Cumulative Discharge (cubic feet)	Estimated Infiltration Rate (inches/hour)
5.5	205 X 15	0.3 to 0.7	3.7	91,000	52
13.5	152 X 15	0.4 to 0.7	5.4	261,000	62
3	255 X 15	0.4 to 0.7	6.6	74,000	75

Comparison of Infiltration Rates

Type of Test	Infiltration Rate (inches/hour)	Test Method
Grain Size	20	USDA Textural
2-hour Double Ring Infiltrometer	7 to 15	ASTM 3385
24-hour Pilot Infiltration Test	32 to 65	DOE 2001, App. V-b
Full-scale Test	52 to 75	

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Long-Term Design Rates
21st Street Percolation Pond (Clean Sandy Gravel)

Issue	Correction Factor	Example	Actual Correction Factor
Site Variability # of Tests	1.5 - 6	Glacial Outwash	1.5
Maintenance	2 - 6	Large Buried Gallery	4
Pre-Treatment	2 - 6	Excellent 2 Ponds	2
Total Correction Factor	5.5 - 18		7.5

Therefore: Test Infiltration Rate = 52-75 inches/hour

Design Infiltration Rate = 52-75/6.5 = 7 to 10 inches/hour

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Design Infiltration Rate
Correction Factors for *In-situ* Field Testing

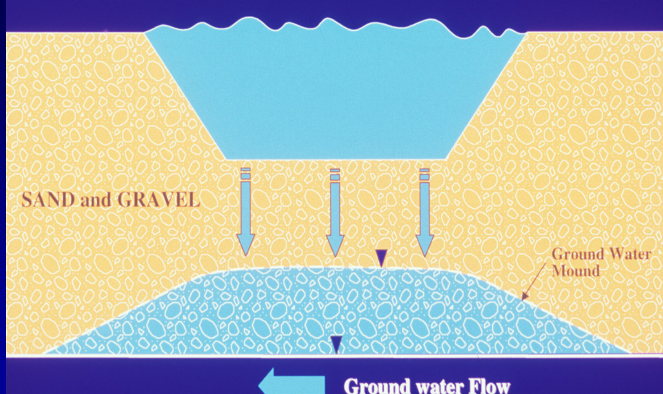
- Correction factors are typically used to reduce the field measured infiltration values to values that should be considered for design, reflecting expected long-term performance.
- These reduced rates consider:
  - site variability
  - long-term sustainability (reduced future rates due to clogging, mounding effects, etc.),
  - scaling issues when applying small scale test results to full-scale designs.

Correction Factors for *in-situ* Infiltration Results for Long-Term Design Rates

Issue	Correction Factor	Example	Actual Correction Factor
Site Variability # of Tests	1.5 - 6	Mixed Alluvial Deposits	4
Maintenance	2 - 6	Difficult - Buried Gallery	6
Pre-Treatment	2 - 6	Excellent - 2 Ponds	2
Total Correction Factor	5.5 - 18		12

Therefore: Test Infiltration Rate = 48 inches/hour
Design Infiltration Rate = 48/12 = 4 inches/hour

Ground Water Mounding



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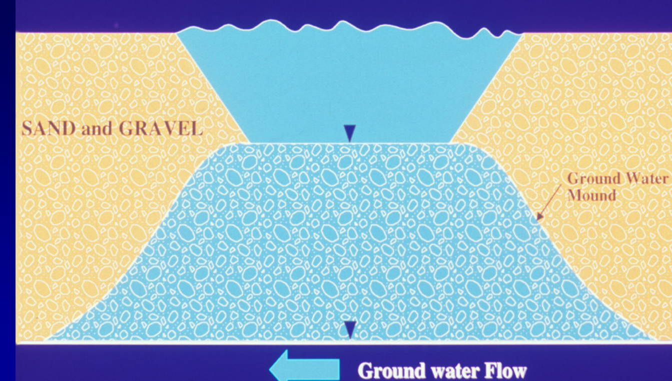
Ground Water Mounding
Cont.



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Ground Water Mounding "Rules of Thumb"

- Mounding reduces 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

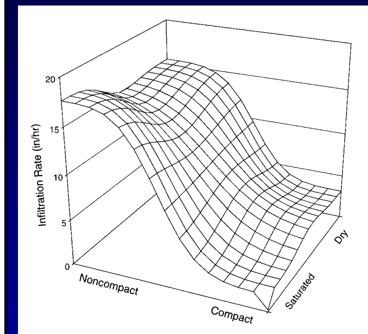
Soil Compaction and Recovery of Infiltration Rates

- Typical site development dramatically alters soil density.
- This significantly reduces infiltration rates, especially if clays are present.
- Also hinders plant growth by reducing root penetration (New Jersey NRCS was one of the first groups that researched this problem).

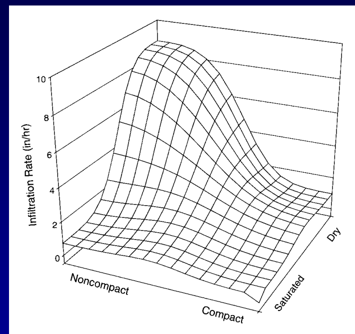
Ponding of runoff water in coarse sand at a coastal community, with overflow to conventional storm drainage system.

Urban Soils Compacted during and after Development

Infiltration Rates in Disturbed Urban Soils (AL tests)

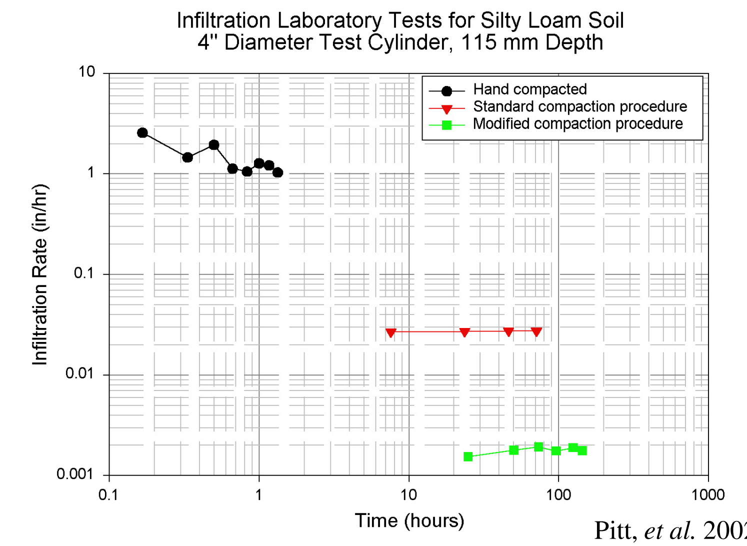


Sandy Soils



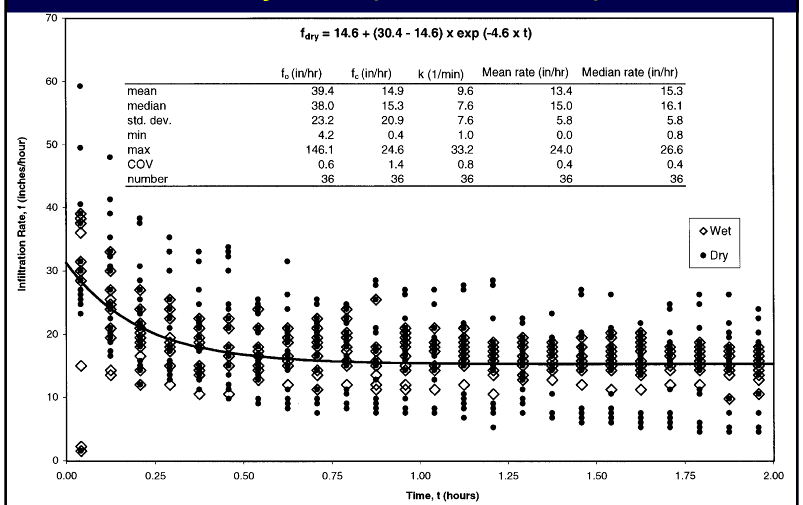
Clayey Soils

Research has shown that the infiltration rates of urban soils are strongly influenced by compaction, probably more than by moisture saturation.



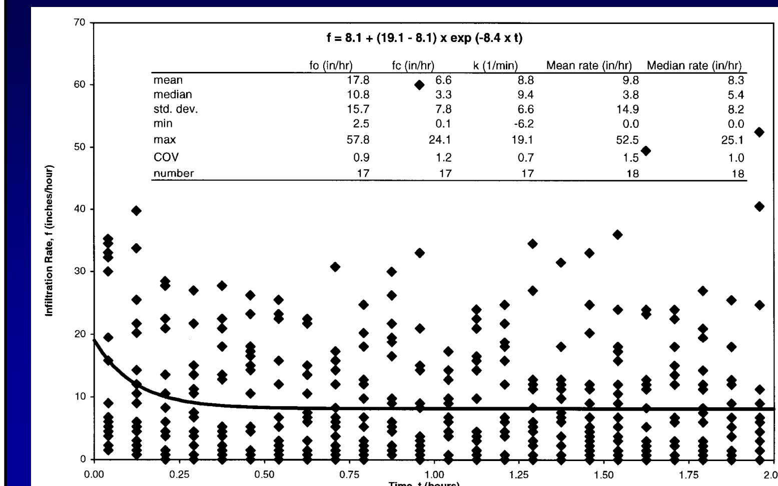
Pitt, *et al.* 2002

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

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

Long-Term Sustainable Average Infiltration Rates

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Long-term Average Infilt. Rate (in/hr)
Sandy Loam	Hand	1.60	35
	Standard	1.65	9
	Modified	1.99	1.5
Silt Loam	Hand	1.50	1.3
	Standard	1.59	0.027
	Modified	1.69	0.0017
Clay Loam	Hand	1.50	0.29
	Standard	1.70	0.015
	Modified	1.91	<<0.001

Compaction, especially when a small amount of clay is present, causes a large loss in infiltration capacity. No clay should be allowed in biofilter media.

Pitt, *et al.* 2002

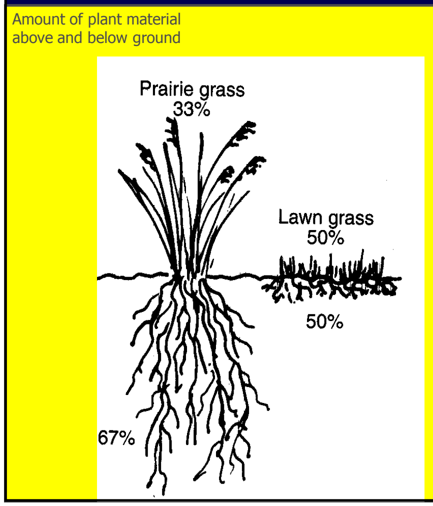
Types of Solutions to Infiltration Problems

- Use organic soil amendments to improve existing soil structure or restore soil structure after construction
- Remove soil layer with poor infiltration qualities
- Replace soil with improved soil mix
  - Mix sand, organic matter, and native soil (if no clay)
- Use deep rooted plants or tilling to improve structure (but only under correct moisture conditions)
  - Chisel plow, deep tilling, native plants
- Pre-treat water
- Select different site

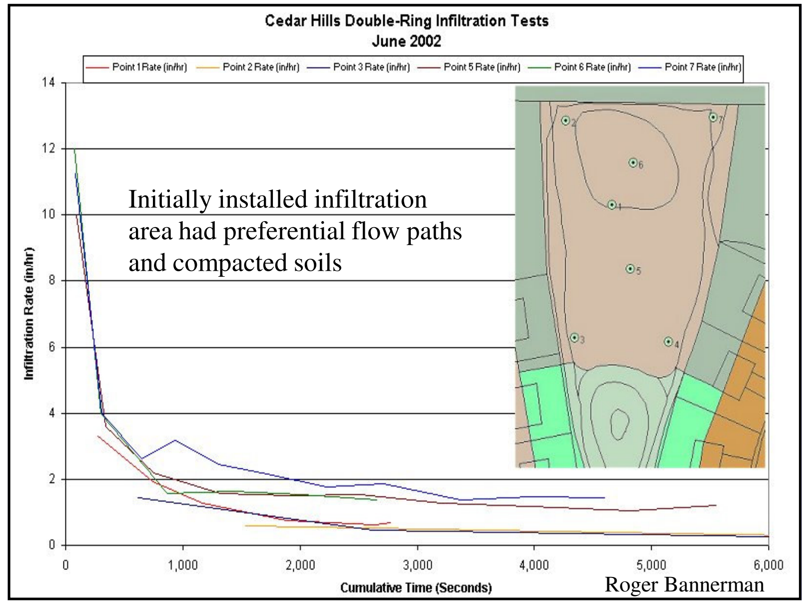
Typical household lawn aerators are ineffective in restoring infiltration capacity in compacted soils.

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

Value of Using Native Plants



- Deeper roots – absorbs more water and help loosen compacted soil
- Uses no fertilizer
- Uses little or no pesticides
- Maintenance similar to other gardens
- Does not require watering in droughts after establishment



Infiltration Basin with Compacted Soils

Deep Tilled to 18 inches and Planted Native Plants to Restore Infiltration

Working Infiltration Basin (West Bend, WI)

Wisconsin Technical Standard 1003 - Incorporate 2 inches of compost into 2 inches of topsoil using a chisel plow capable of reaching 12 inches below existing surface