# Part 2 of Green Infrastructure Components to Reduce Combined Sewer Overflows – Soils and Bioretention/Biofiltration Applications

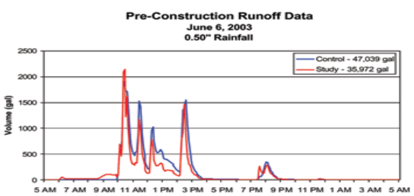
- Biofiltration and bioretention stormwater controls
  - Swales
  - Parking lot and transportation controls
- Street bioretention for combined sewer control example
- Site evaluations for soil characteristics
- Soil compaction and restoration

1

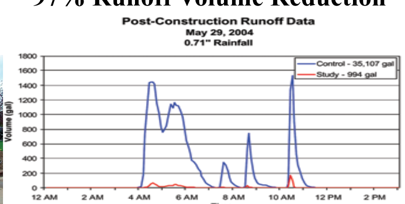
**Rain Garden Designed for Complete Infiltration of Roof Runoff**

2

**Burnsville, Minnesota, Rainwater Gardens**




**97% Runoff Volume Reduction**

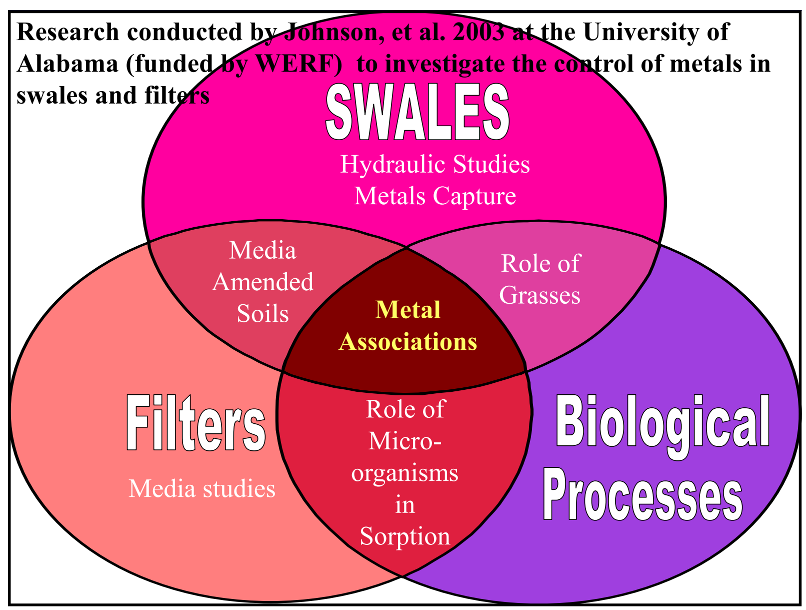



An example of the dramatic runoff volume reductions possible through the use of conservation design principles (17 rain gardens, at about $3,000 each, at 14 homes in one neighborhood)

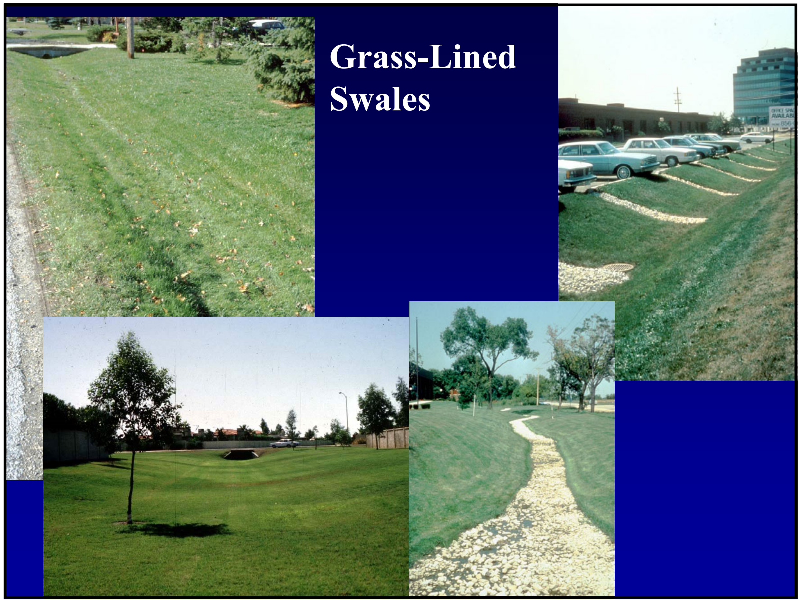
***Land and Water*, Sept/Oct. 2004**

3

**Research conducted by Johnson, et al. 2003 at the University of Alabama (funded by WERF) to investigate the control of metals in swales and filters**

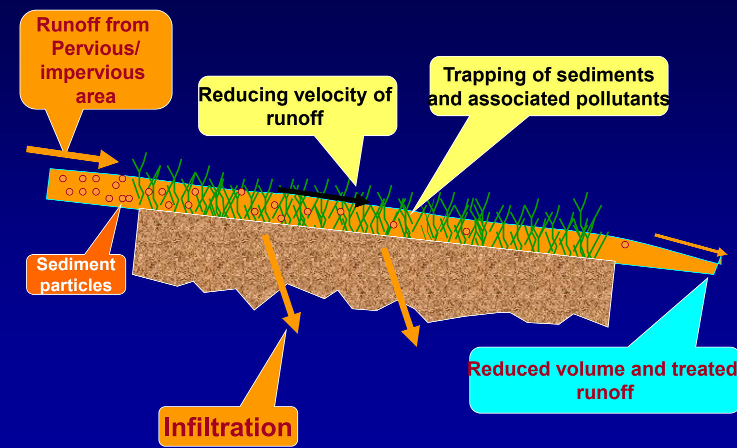



4




5

## Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters




6

## Runoff Heavy Metals Retained and Released during Indoor Swale Experiments

| Metals retained, % | Cu | Cr | Pb | Zn | Cd |
|---|---|---|---|---|---|
| Zoysia | 40 | 16 | 65 | 13 | 21 |
| Centipede | 39 | 14 | 57 | 20 | 28 |
| Bluegrass | 40 | 37 | 67 | 26 | 25 |

The removals of these metals are correlated to their associations with stormwater particulates.

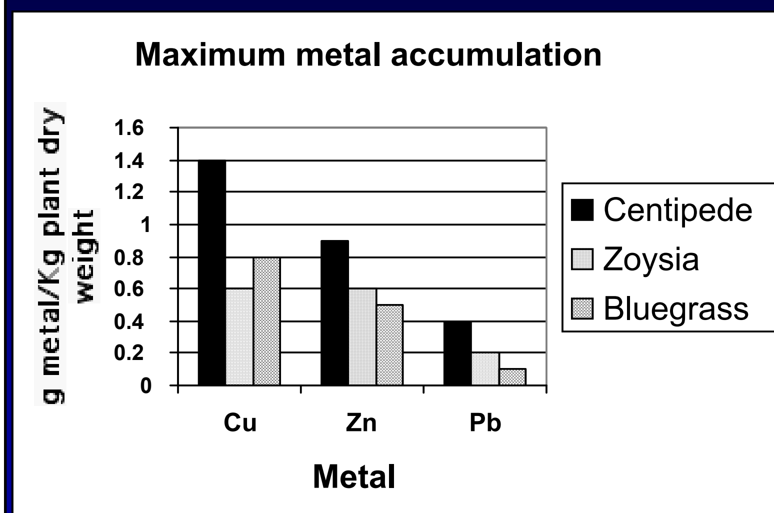
**Major ions released, % (these are soil constituents)**

| | Fe | Na | Mg | Ca | K |
|---|---|---|---|---|---|
| Zoysia | 6 | 23 | 17 | 12 | 76 |
| Centipede | 45 | 62 | 87 | 44 | 125 |
| Bluegrass | 338 | 77 | 52 | 17 | 23 |

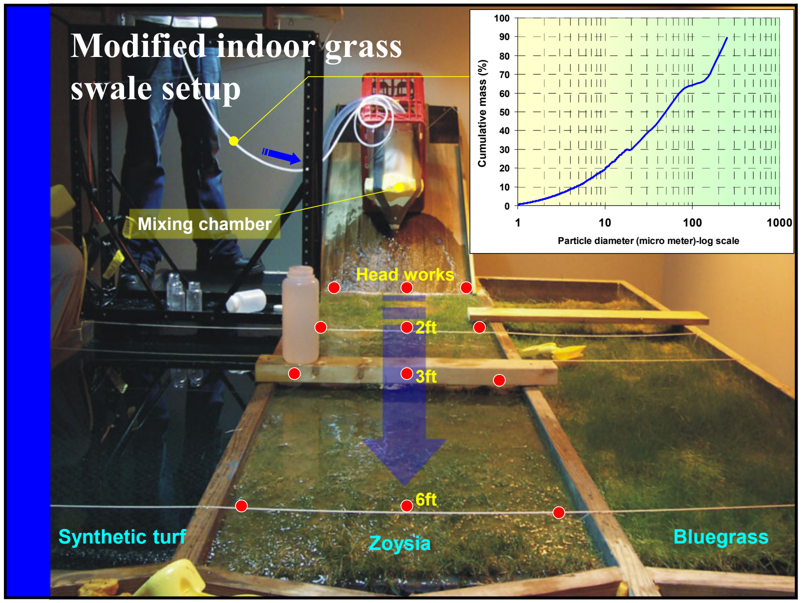
These are concentration changes only and do not reflect discharge loading reductions associated with concurrent infiltration. Typical mass discharge reductions for grass swales are greater than 80%.

7

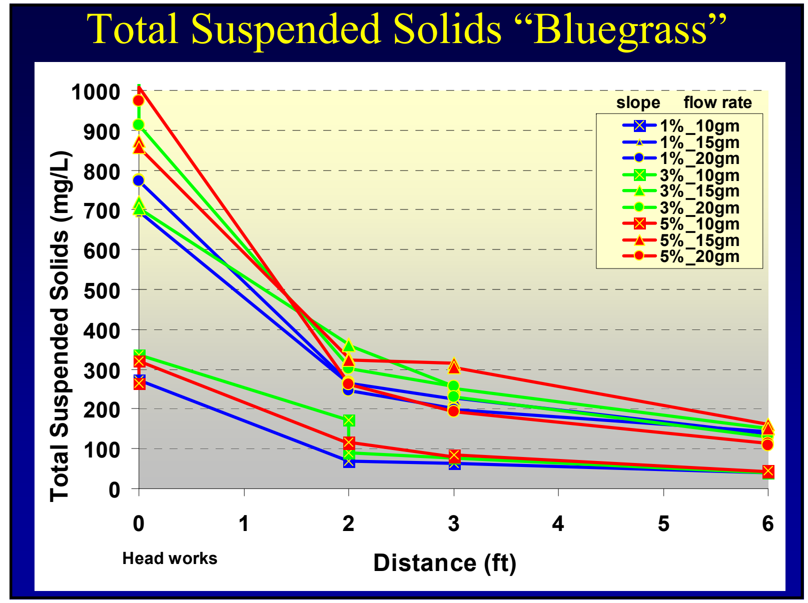
## Phytoremediation



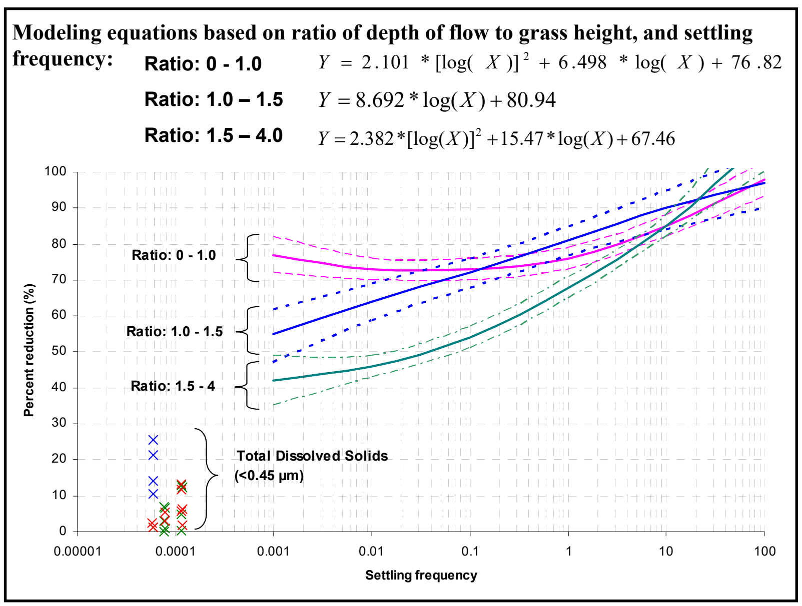

8


Modified indoor grass swale setup
Mixing chamber
Head works
2ft
3ft
6ft
Synthetic turf
Zoysia
Bluegrass
Cumulative mass (%)
Particle diameter (micro meter)-log scale

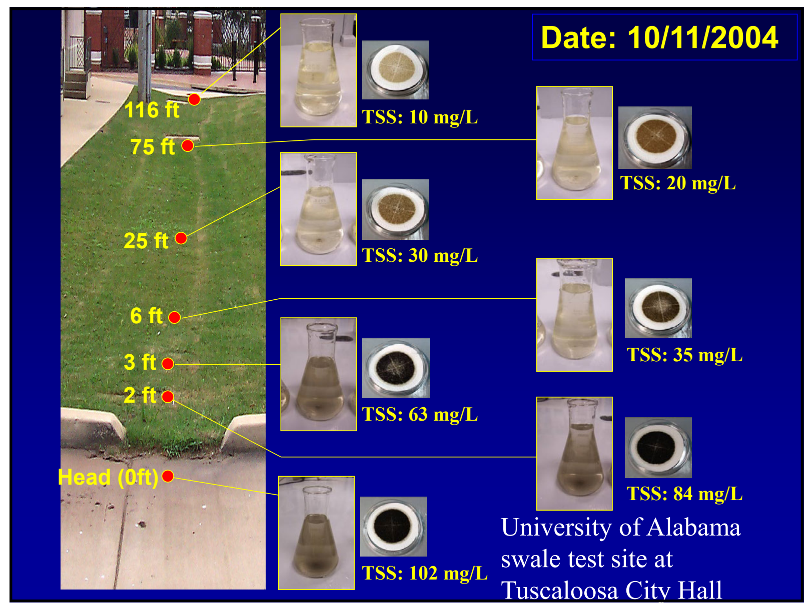
9


Total Suspended Solids "Bluegrass"
Total Suspended Solids (mg/L)
slope flow rate
1%_10gm
1%_15gm
1%_20gm
3%_10gm
3%_15gm
3%_20gm
5%_10gm
5%_15gm
5%_20gm
Head works
Distance (ft)

10


Modeling equations based on ratio of depth of flow to grass height, and settling frequency:
Ratio: 0 - 1.0 $Y = 2.101 * [\log(X)]^2 + 6.498 * \log(X) + 76.82$
Ratio: 1.0 – 1.5 $Y = 8.692 * \log(X) + 80.94$
Ratio: 1.5 – 4.0 $Y = 2.382 * [\log(X)]^2 + 15.47 * \log(X) + 67.46$
Percent reduction (%)
Ratio: 0 - 1.0
Ratio: 1.0 - 1.5
Ratio: 1.5 - 4
Total Dissolved Solids
(<0.45 µm)
Settling frequency

11


Date: 10/11/2004
116 ft
75 ft
25 ft
6 ft
3 ft
2 ft
Head (0ft)
TSS: 10 mg/L
TSS: 20 mg/L
TSS: 30 mg/L
TSS: 35 mg/L
TSS: 63 mg/L
TSS: 84 mg/L
TSS: 102 mg/L
University of Alabama swale test site at Tuscaloosa City Hall

12

## Conventional curbs with inlets directed to site swales

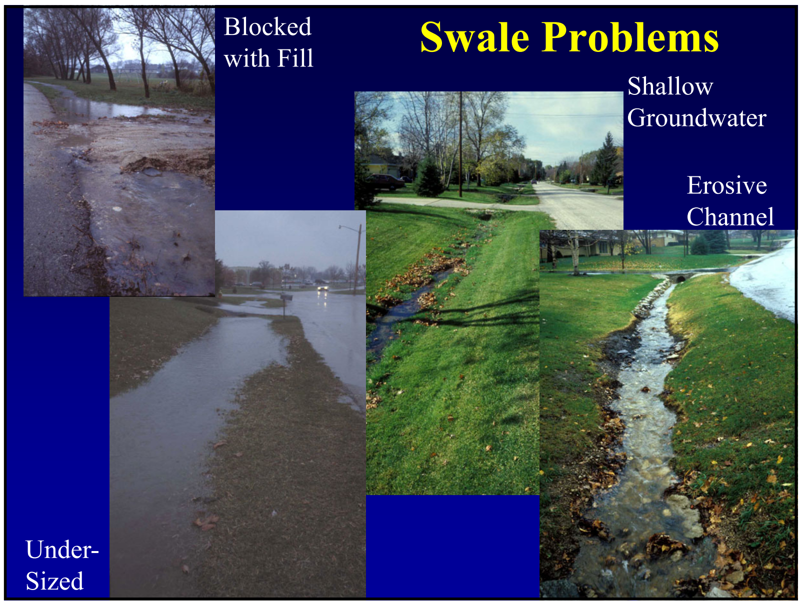
13

## Swales Designed to Infiltrate Large Fractions of Runoff (Alabama).

Also incorporate grass filtering before infiltration

14

## Swale Problems



Blocked with Fill

Shallow Groundwater

Erosive Channel

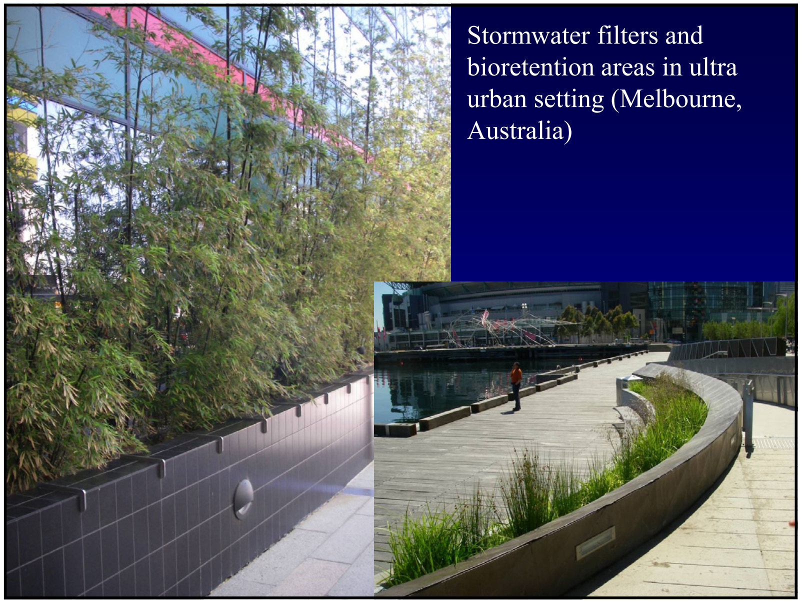
Under-Sized

15

- 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.

16


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

17


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

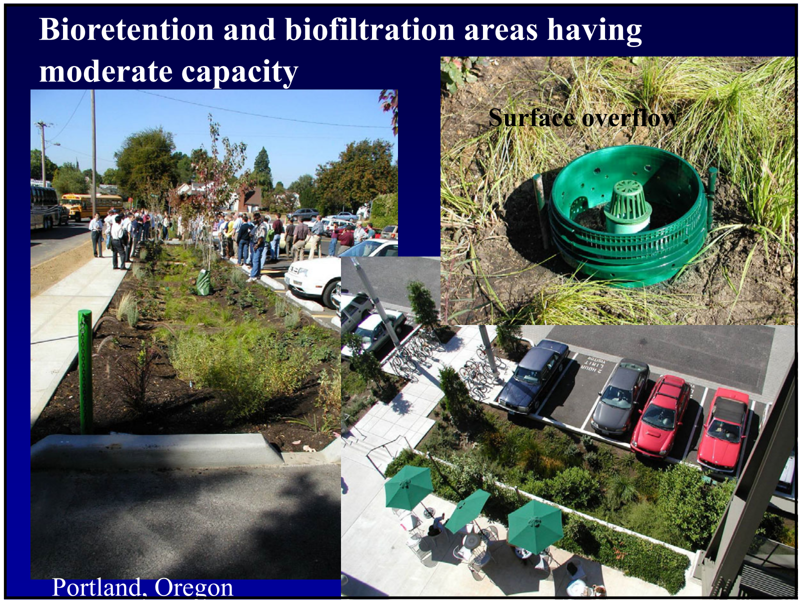
18


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

19


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

20


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

21


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

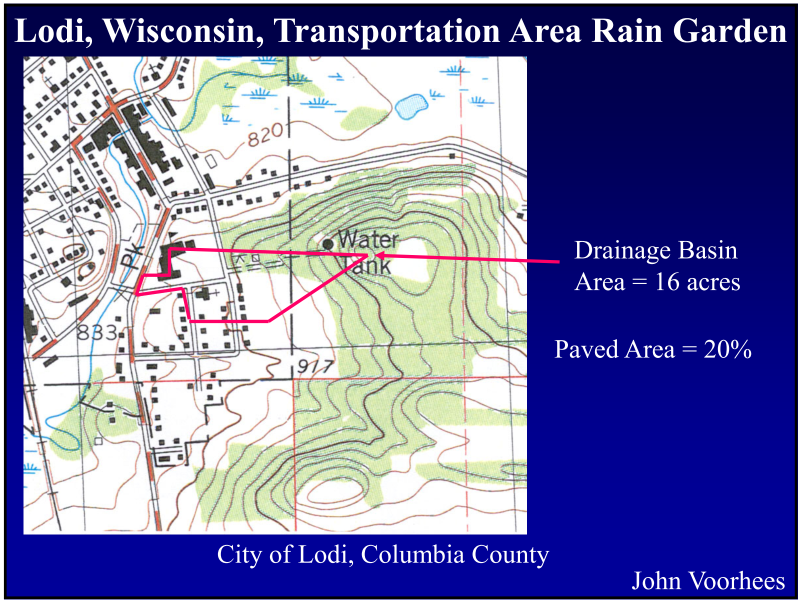
22


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

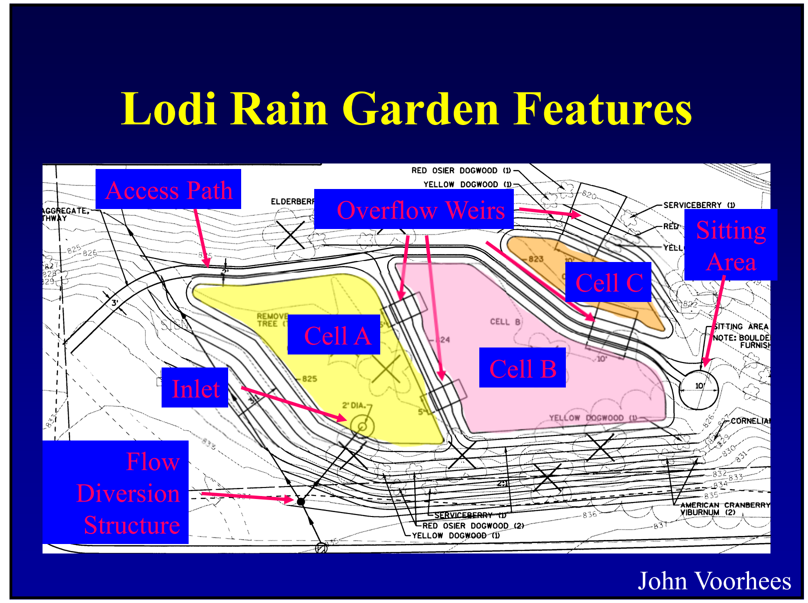
23


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

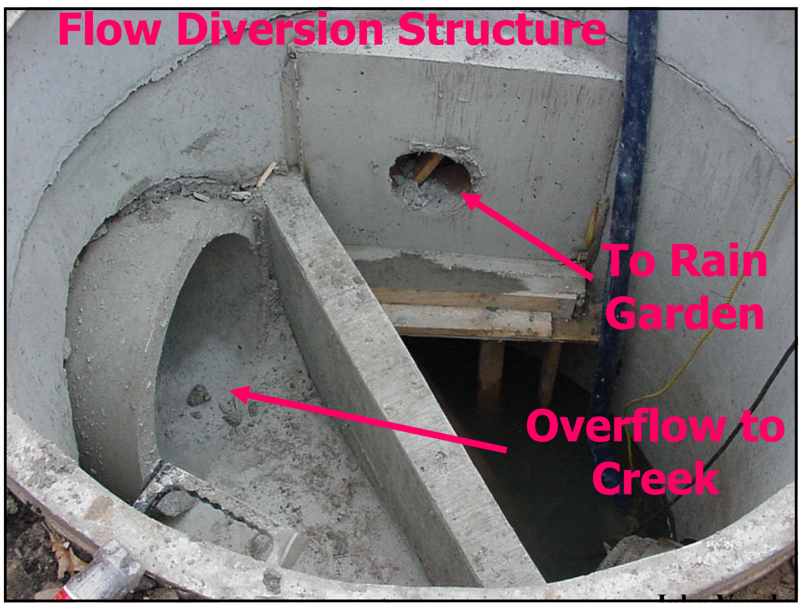
24


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

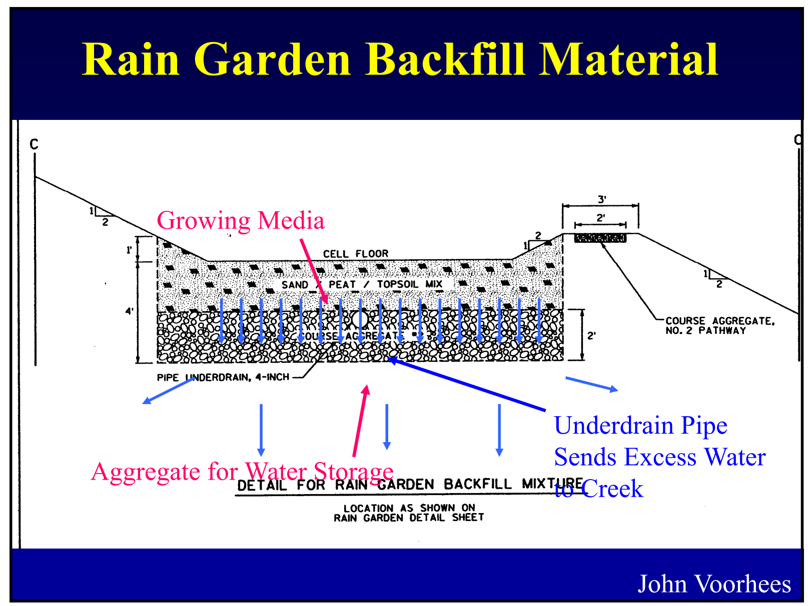
25


Lodi Rain Garden Features
Access Path
Overflow Weirs
Sitting Area
Cell C
Cell A
Cell B
Inlet
Flow Diversion Structure
John Voorhees

26


Flow Diversion Structure
To Rain Garden
Overflow to Creek

27


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

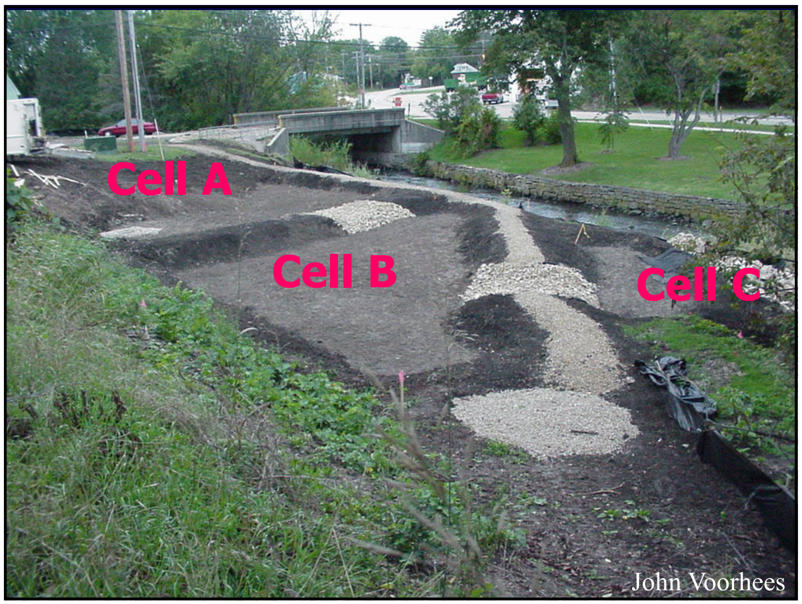
28


Soil/Peat/Sand
Mixing
John Voorhees

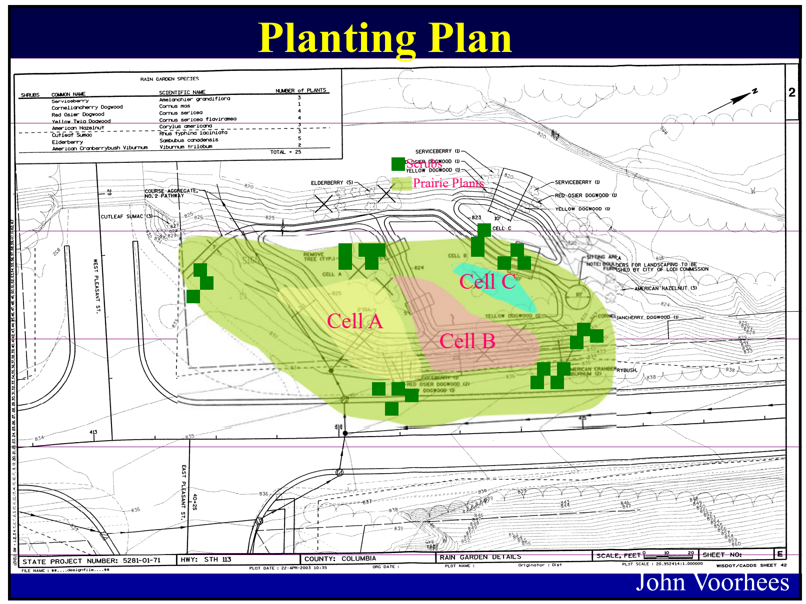
29


Cell A
Cell B
John Voorhees

30


Cell A
Cell B
Cell C
John Voorhees

31


Planting Plan
Shrubs
Prairie Plants
Cell A
Cell B
Cell C
John Voorhees

32




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

John Voorhees photos

33

# Lodi, WI, Rain Garden Costs

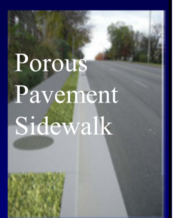
| | |
|---|---|
| Pipe Underdrain and Endwalls | $700 |
| Flow Regulation Structure | $3,000 |
| Plants | $2,200 |
| Shrubs | $450 |
| Backfill | $11,600 |
| Excavation | $2,200 |
| Select Crushed Material/Riprap | $3,850 |
| Storm Sewer and Manholes | $3,500 |
| Total $4.70/sf | $27,500 |

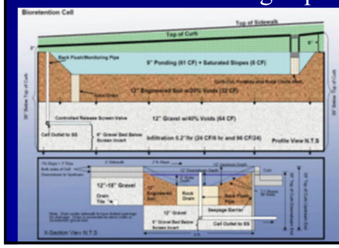
John Voorhees

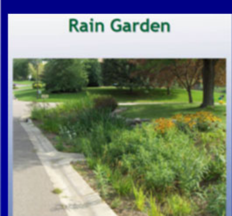
34

# 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.

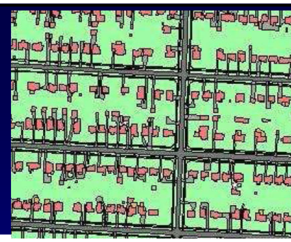


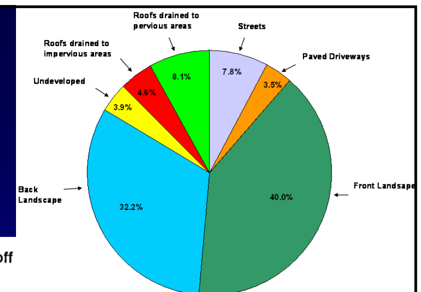



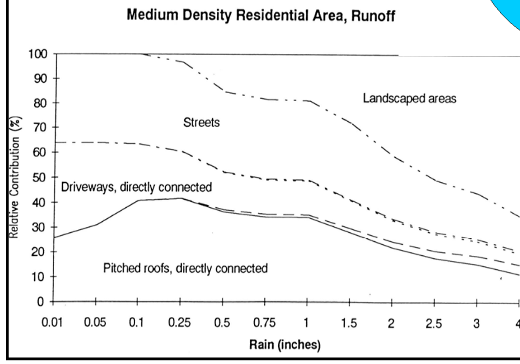





35

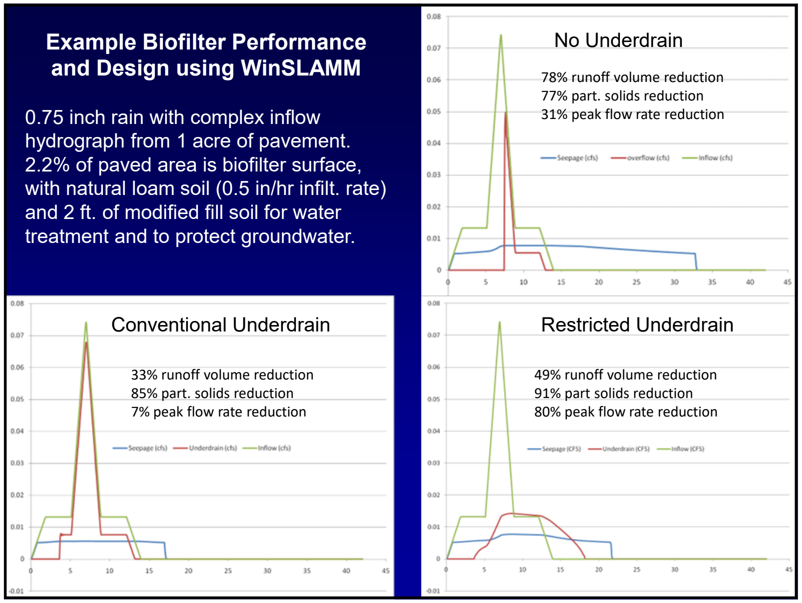




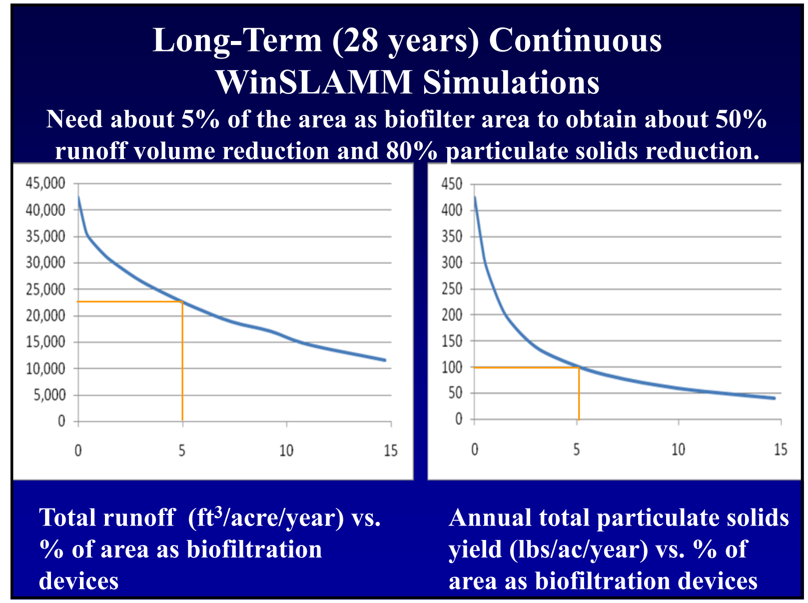




Surveys were conducted for each house and lot in the study area by UMKC graduate students. This information was used with the GIS data and WinSLAMM to determine the sources of the runoff during different rain conditions.

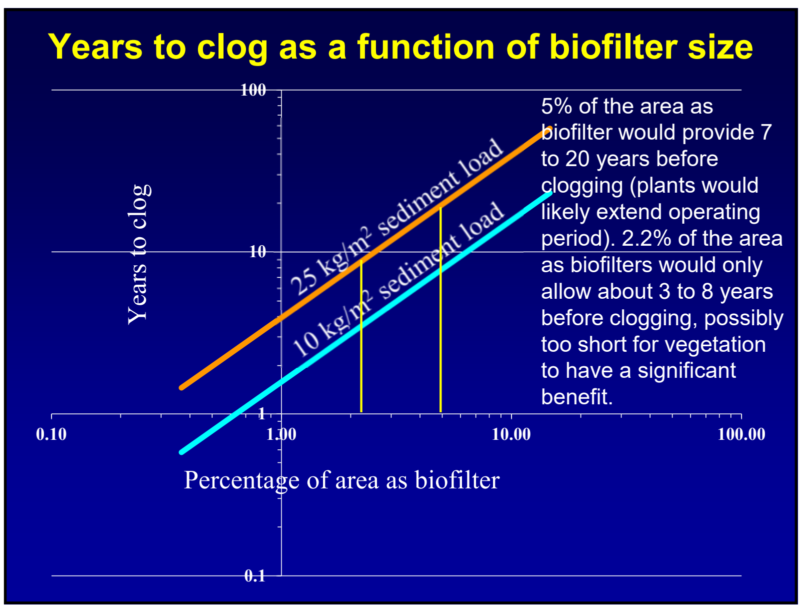
36


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.
No Underdrain
78% runoff volume reduction
77% part. solids reduction
31% peak flow rate reduction
Conventional 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

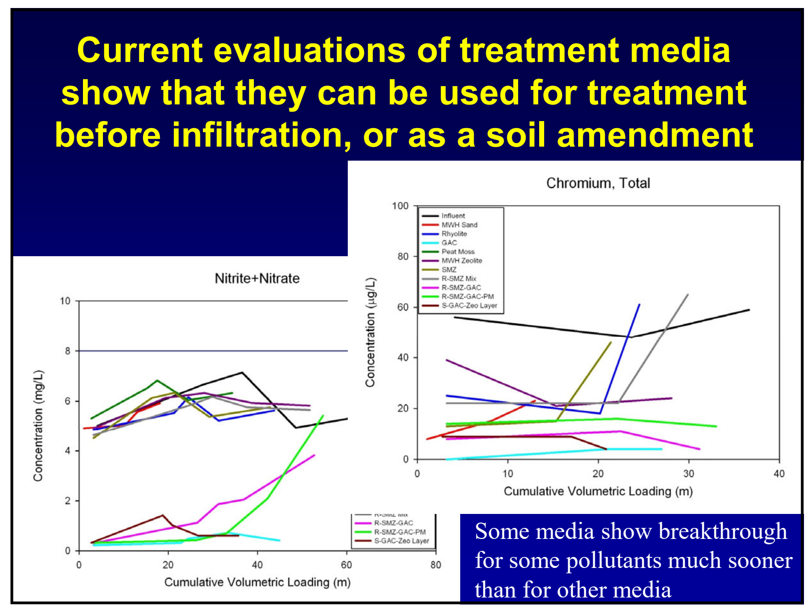
37


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

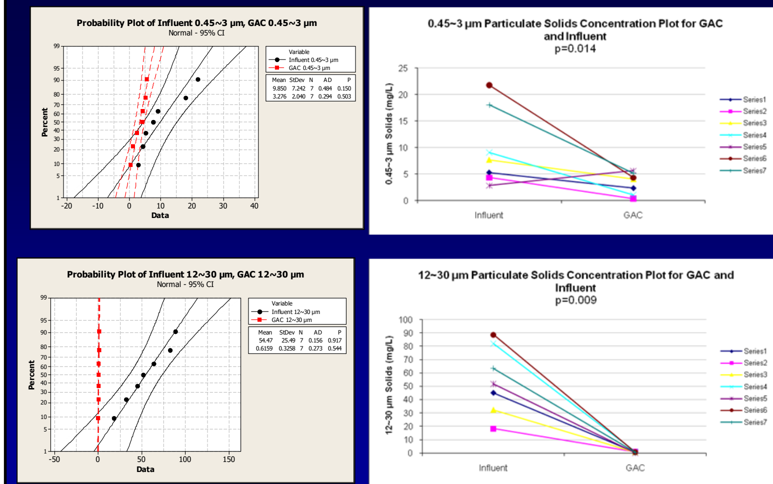
38


Years to clog as a function of biofilter size
Years to clog
25 kg/m² sediment load
10 kg/m² sediment load
Percentage of area as biofilter
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.

39

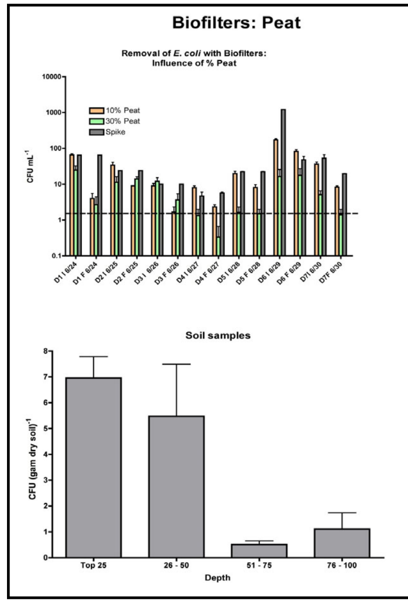

Current evaluations of treatment media show that they can be used for treatment before infiltration, or as a soil amendment
Nitrite+Nitrate
Concentration (mg/L)
Cumulative Volumetric Loading (m)
Chromium, Total
Concentration (µg/L)
Cumulative Volumetric Loading (m)
Some media show breakthrough for some pollutants much sooner than for other media

40




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

41




## 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

42

## 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)

43

## 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).

44

## 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/cm³), 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 |

45

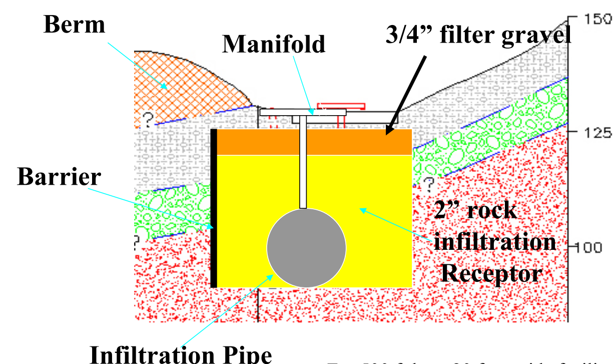
## Double-Ring Infiltration Tests Soil Density Measurements

46

## Large-Scale Infiltration Bench and Verification Testing in Washington


47

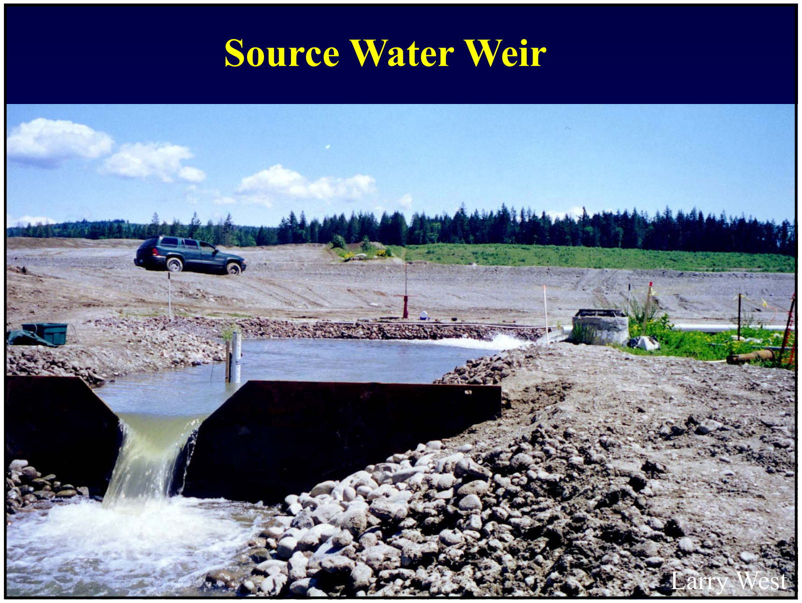
## Infiltration Facility




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

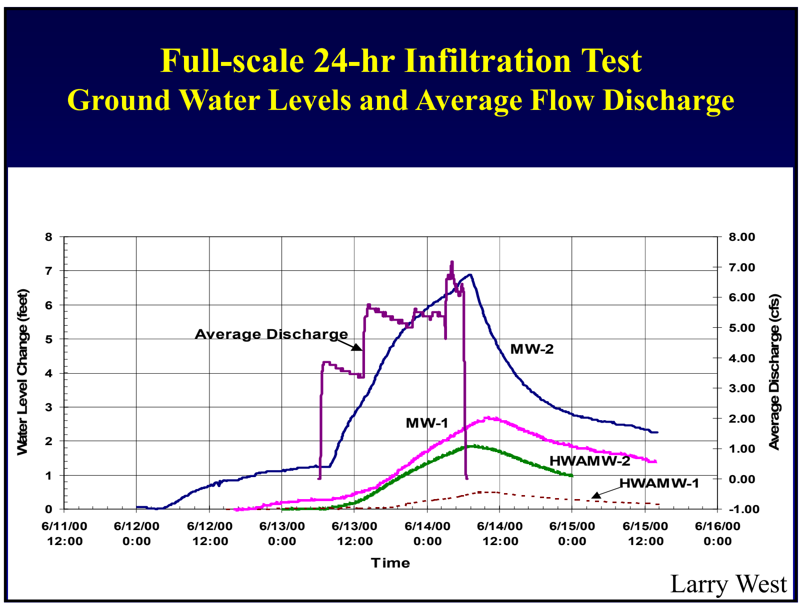
48


Source Water Weir
Larry West

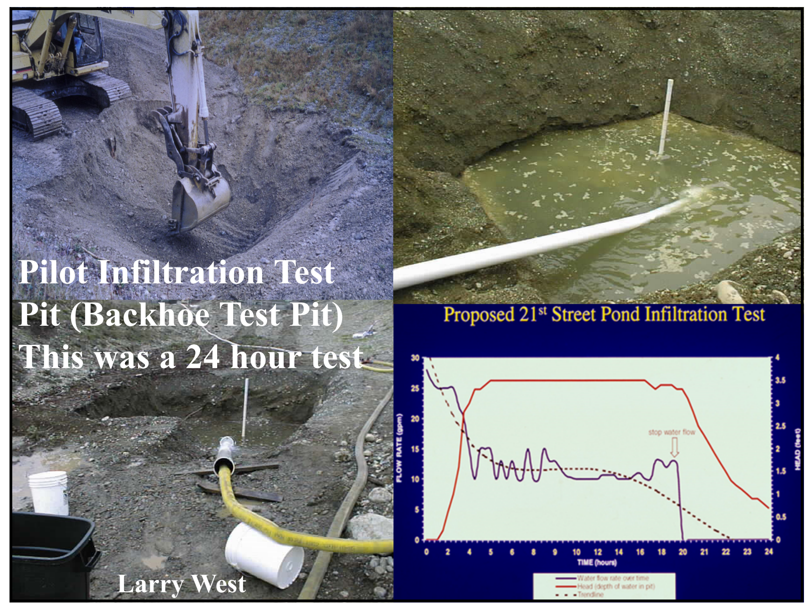
49


Discharge Flow Dissipater
Larry West

50


Full-scale 24-hr Infiltration Test
Ground Water Levels and Average Flow Discharge
Water Level Change (feet)
Average Discharge (cfs)
Average Discharge
MW-2
MW-1
HWAMW-2
HWAMW-1
6/11/00 12:00
6/12/00 0:00
6/12/00 12:00
6/13/00 0:00
6/13/00 12:00
6/14/00 0:00
6/14/00 12:00
6/15/00 0:00
6/15/00 12:00
6/16/00 0:00
Time
Larry West

51


Pilot Infiltration Test
Pit (Backhoe Test Pit)
This was a 24 hour test
Larry West
Proposed 21st Street Pond Infiltration Test

52

## 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. |

53

## 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

54

## 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

55

## 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

56

## 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 | |

Larry West

57

## 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

Larry West

58

## 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.

59

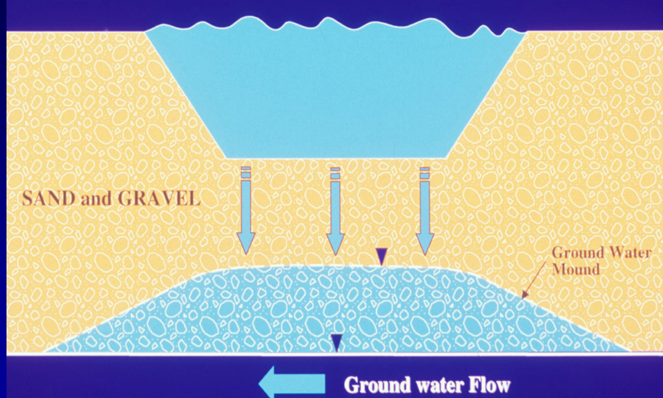
## Correction Factors for *in-situ* Infiltration Results for Long-Term Design Rates

| 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

60

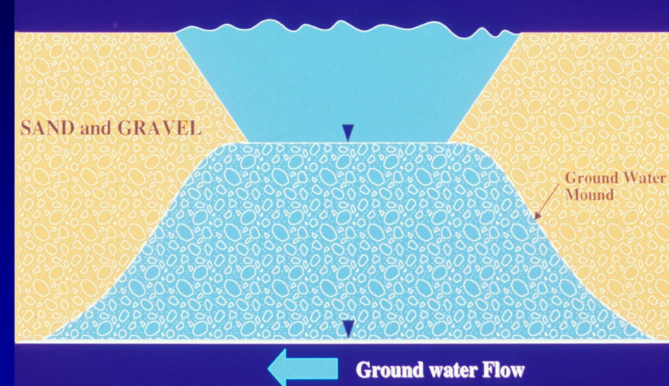
## Ground Water Mounding




Larry West

61

## Ground Water Mounding
Cont.




Larry West

62

## 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

63

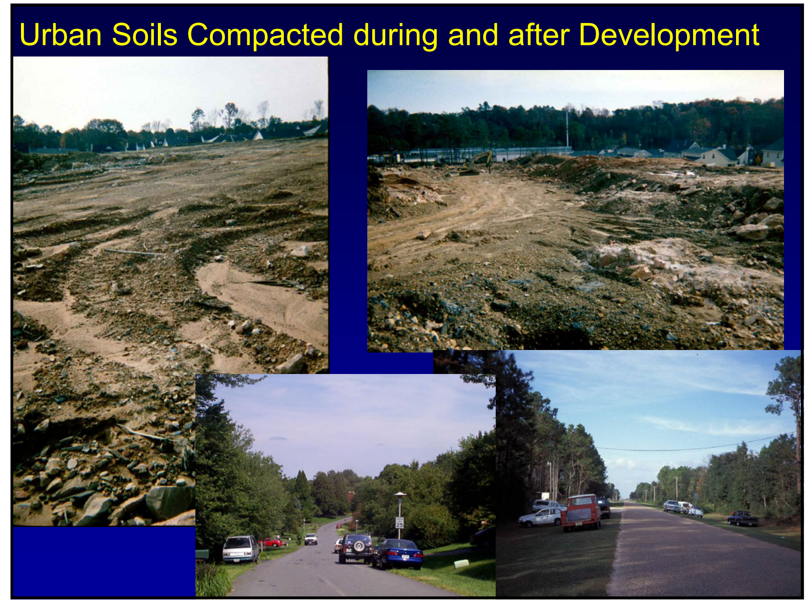
## Soil Compaction and Recovery of Infiltration Rates

- 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).

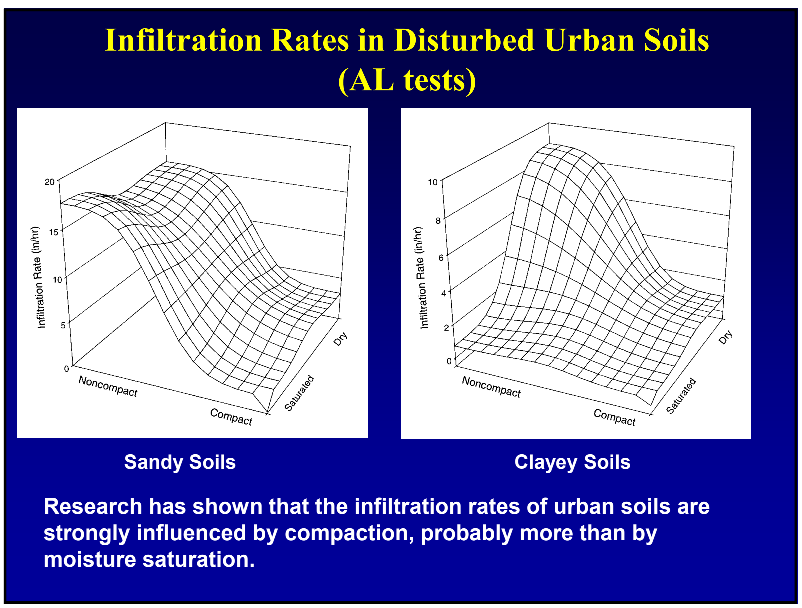
64


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

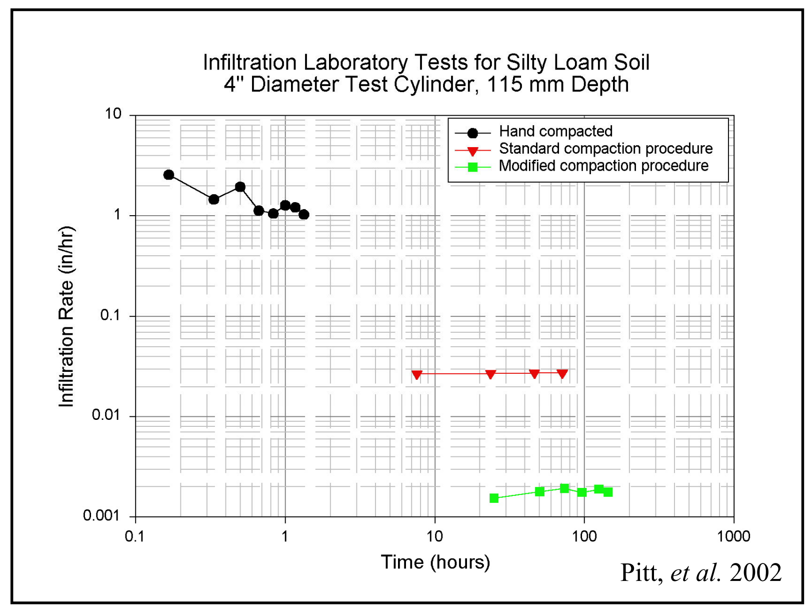
65


Urban Soils Compacted during and after Development

66

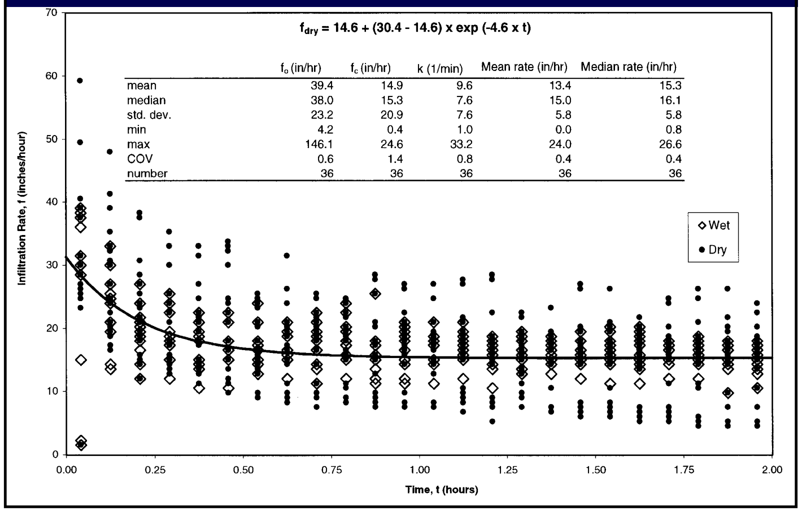

Infiltration Rates in Disturbed Urban Soils (AL tests)
Infiltration Rate (in/hr)
Noncompact
Compact
Saturated
Dry
Sandy Soils
Clayey Soils
Research has shown that the infiltration rates of urban soils are strongly influenced by compaction, probably more than by moisture saturation.

67


Infiltration Laboratory Tests for Silty Loam Soil
4" Diameter Test Cylinder, 115 mm Depth
Hand compacted
Standard compaction procedure
Modified compaction procedure
Infiltration Rate (in/hr)
10
1
0.1
0.01
0.001
0.1
1
10
100
1000
Time (hours)
Pitt, et al. 2002

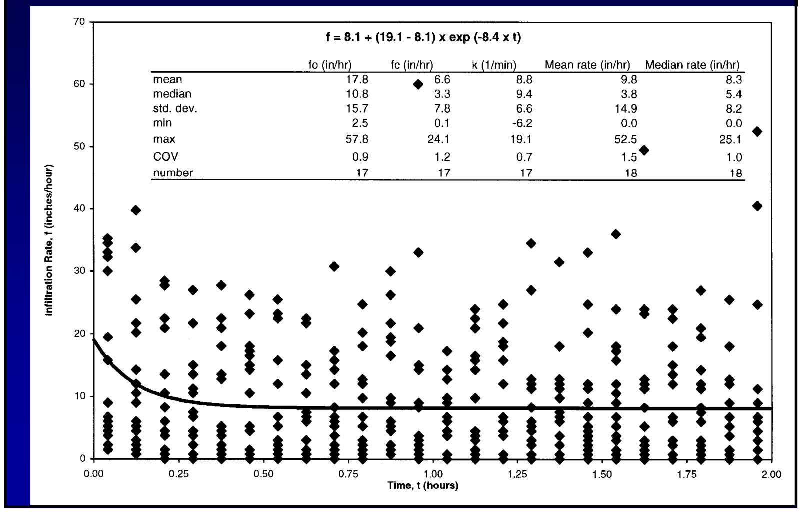
68

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




69

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




70

## 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

71

## 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

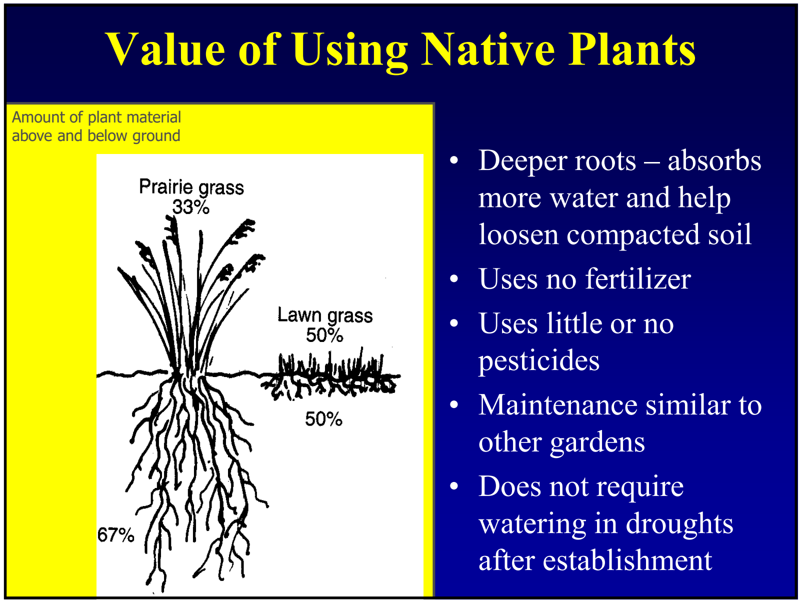
72


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

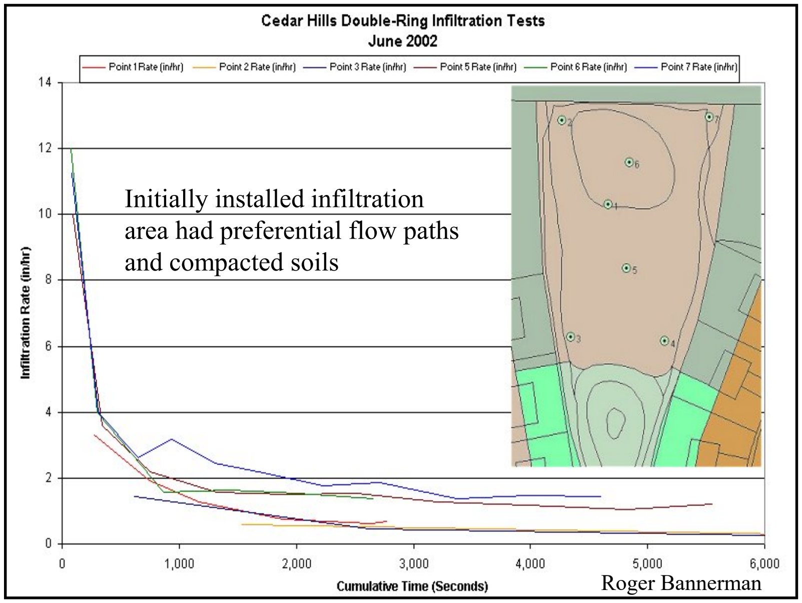
73


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

74


Value of Using Native Plants
Amount of plant material above and below ground
Prairie grass 33%
Lawn grass 50%
50%
67%
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

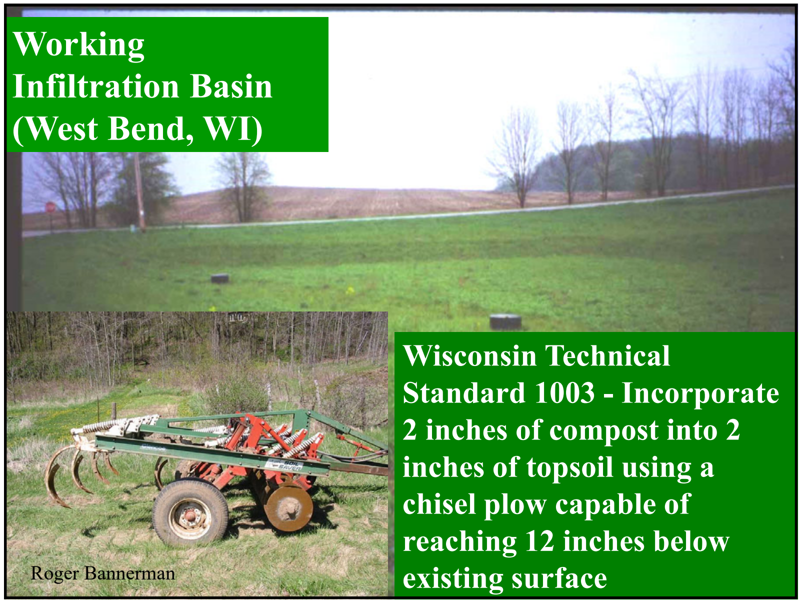
75


Cedar Hills Double-Ring Infiltration Tests
June 2002
Point 1 Rate (in/hr)
Point 2 Rate (in/hr)
Point 3 Rate (in/hr)
Point 5 Rate (in/hr)
Point 6 Rate (in/hr)
Point 7 Rate (in/hr)
Infiltration Rate (in/hr)
Cumulative Time (Seconds)
Initially installed infiltration area had preferential flow paths and compacted soils
Roger Bannerman

76


Infiltration Basin with Compacted Soils
Deep Tilled to 18 inches and Planted Native Plants to Restore Infiltration
Roger Bannerman

77


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
Roger Bannerman

78