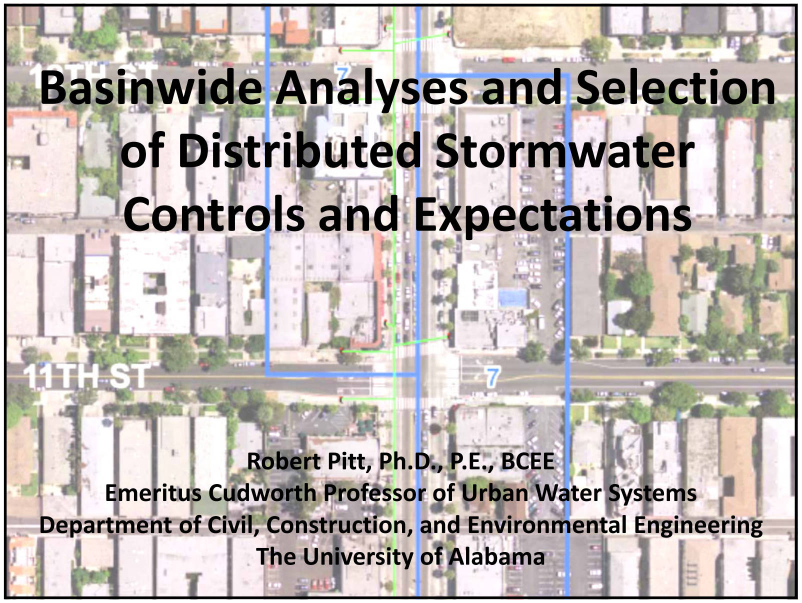


Basinwide Analyses and Selection of Distributed Stormwater Controls and Expectations

Robert Pitt, Ph.D., P.E., BCEE
Emeritus Cudworth Professor of Urban Water Systems
Department of Civil, Construction, and Environmental Engineering
The University of Alabama

1

Presentation Topics

- Watershed based stormwater controls
- Design issues for <4.5 mm rains
- Design issues for 4.5 to 70 mm rains
- Design issues for 70 to 200 mm rains
- Design issues for >200 mm rains
- Examples of multiple watershed controls
- Conclusions

2

Watershed-Based Stormwater Controls

Multiple names for a similar goal/design process:

- Low Impact Development (LID)
- Conservation Design
- Water Sensitive Urban Design (WSUDs)
- Sustainable Urban Drainage Systems (SUDS)
- Distributed Runoff Controls (DRC)

These approaches emphasize infiltration, however, other stormwater treatment approaches will also likely be required to meet the wide range of beneficial use objectives of urban receiving waters.

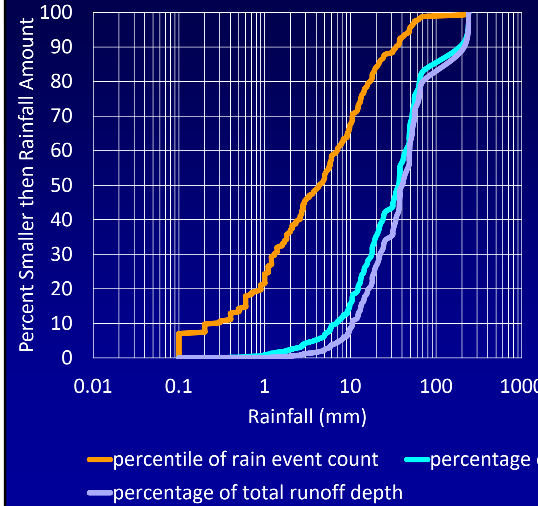
3

Conservation Design Approach for New Development

- Better site planning to maximize resources of site (natural drainageways, soils, open areas, etc.)
- Emphasize water conservation and water reuse on site
- Encourage infiltration of runoff at site (after proper treatment)
- Treat water at critical source areas
- Treat and manage runoff that cannot be infiltrated at site

4

Beijing 2012 - 2016 Daily Rains and Runoff (high density urban areas)



Probability distribution of typical Beijing rains (by count) and runoff (by depth).

<4.5 mm: 50% of rains (<5% of runoff)

4.5 to 70 mm: 45% of rains (80% of runoff)

70 to 200 mm: 4% of rains (10% of runoff)

>200 mm: <1% or rains (10% or runoff)

5

Design Issues (<4.5 mm)

- Most of the events (numbers of rain storms)
- Little of annual runoff volume
- Little of annual pollutant mass discharges
- Probably few receiving water effects
- Problem:
  - pollutant concentrations likely exceed regulatory numeric discharge limits (especially for bacteria and total recoverable heavy metals) for each event

6

Suitable Controls for Almost Complete Elimination of Runoff Associated with Small Rains (<4.5 mm)

- **Disconnect roofs and pavement from impervious drainages**
- **Grass swales**
- **Permeable pavement walkways**
- **Rain barrels and cisterns**

7

One of the simplest and most effective approaches for the control of stormwater is to reduce the amount of impervious areas that are directly connected to the drainage system. This can be accomplished by using less paved and roof areas (hard to do and meet design objectives), disconnect the impervious areas, or reduce the runoff from the impervious areas by infiltration, or other, methods. Reducing the runoff volume also reduces the pollutant discharges, reduces peak flows, and reduces combined sewer overflows.

Disconnected roof drain

Directly connected roof drain

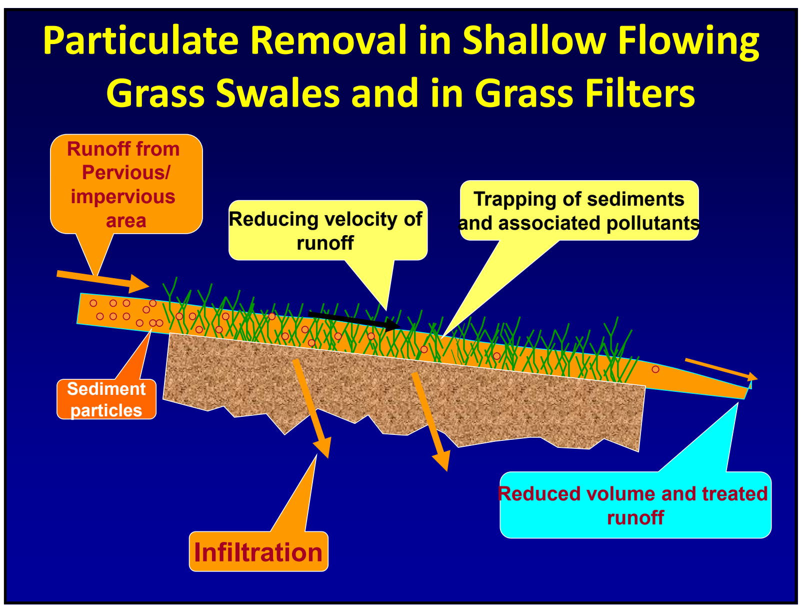
8


Roof drain disconnections
Not this!

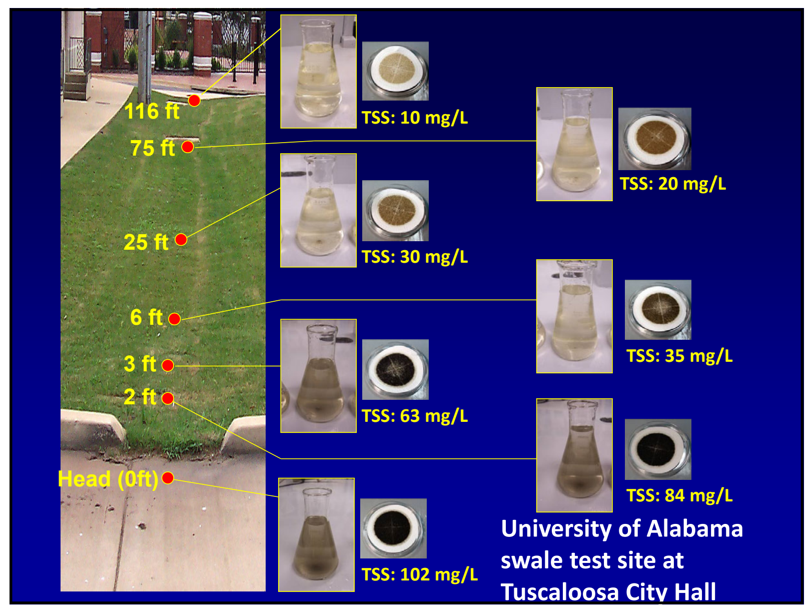
9


Disconnect impervious areas
Milwaukee, WI, examples from the early 1980s during watershed planning efforts

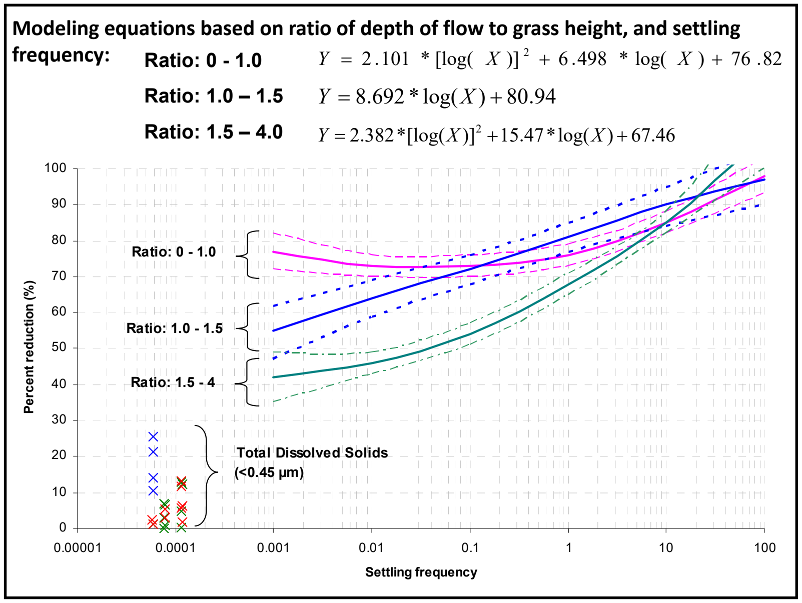
10


Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters
Runoff from Pervious/ impervious area
Reducing velocity of runoff
Trapping of sediments and associated pollutants
Sediment particles
Infiltration
Reduced volume and treated runoff

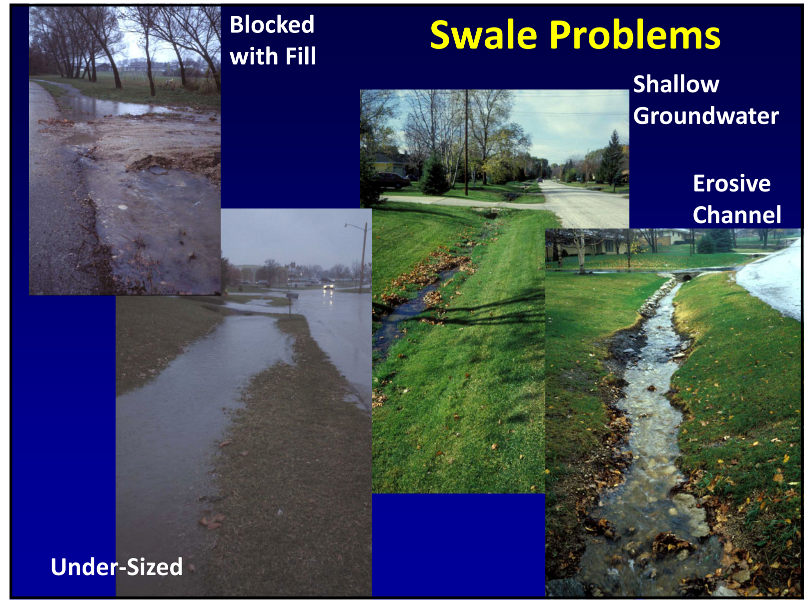
11


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


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 $Y = 2.382 * [\log(X)]^2 + 15.47 * \log(X) + 67.46$
Ratio: 0 - 1.0
Ratio: 1.0 - 1.5
Ratio: 1.5 - 4
Total Dissolved Solids (<0.45 µm)
Percent reduction (%)
Settling frequency
0
10
20
30
40
50
60
70
80
90
100
0.00001
0.0001
0.001
0.01
0.1
1
10
100

13


Swale Problems
Blocked with Fill
Shallow Groundwater
Erosive Channel
Under-Sized

14


Permeable paver blocks have been used in many locations to reduce runoff to combined systems, reducing overflow frequency and volumes (Sweden, Germany, and WI).
Essen, Germany
Malmo, Sweden
Madison, WI

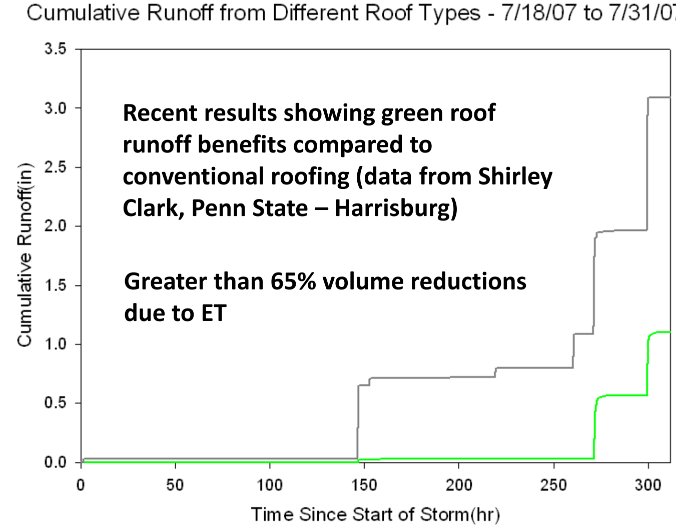
15


Essen, Germany
Singapore
Austin, TX
Zurich
Davos, Switzerland
Singapore

16

"Green Roof" in Portland, OR

17



Recent results showing green roof runoff benefits compared to conventional roofing (data from Shirley Clark, Penn State – Harrisburg)

Greater than 65% volume reductions due to ET

18

The water tank cisterns modeled for the Kansas City area were about 10 ft in diameter and 10 ft tall. The expected per household water use (gallons/day) from cisterns for toilet flushing and outside irrigation (ET deficit only) for the KC study area is:

January	113 gal/day	July	428
February	243	August	479
March	126	September	211
April	175	October	71
May	149	November	71
June	248	December	71

19

Street and catchbasin cleaning, and inlet controls most effective for smaller rains in heavily paved areas.

Street cleaner outside of the Palace of the Engineers, Moscow, Russia

20

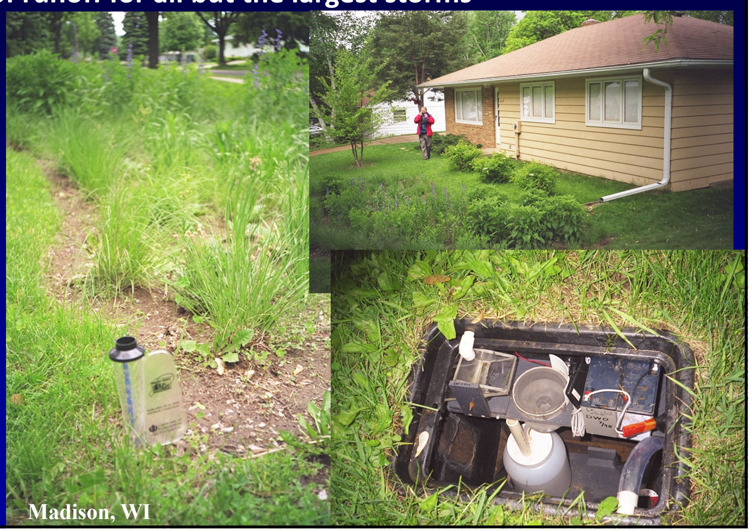
Design Issues (4.5 to 70 mm)

- Majority of annual runoff volume and pollutant discharges
- Occur approximately once a week
- Problems:
  - Produce moderate to high flows
  - Produce frequent high pollutant loadings

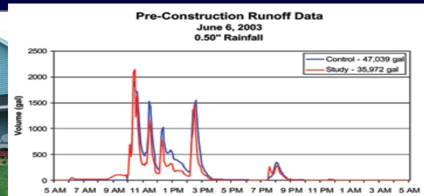
Suitable Controls for Treatment of Runoff from Intermediate-Sized Rains (4.5 to 70 mm)

- **Initial portion will be captured/infiltrated by on-site controls or grass swales**
- **Remaining portion of runoff in this rain category should be treated to remove particulate-bound pollutants**

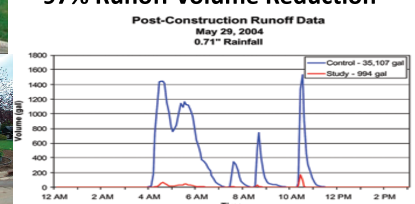
Rain gardens can be designed for complete infiltration of roof runoff for all but the largest storms



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**

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

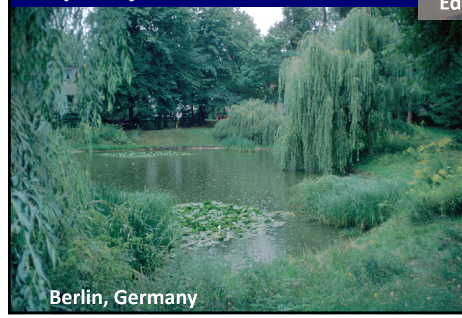
Annual roof runoff volume reductions	Birmingham, Alabama (55.5 in.)	Seattle, Wash. (33.4 in.)	Phoenix, Arizona (9.6 in.)
Cistern for reuse of runoff for toilet flushing and irrigation (10 ft. diameter x 5 ft. high)	66	67	88%
Planted green roof (but will need to irrigate during dry periods)	75	77	84%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

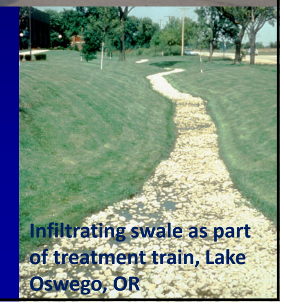
There are therefore a number of potential controls for roof runoff, from the conventional to the unusual, that can result in large runoff reductions.

25

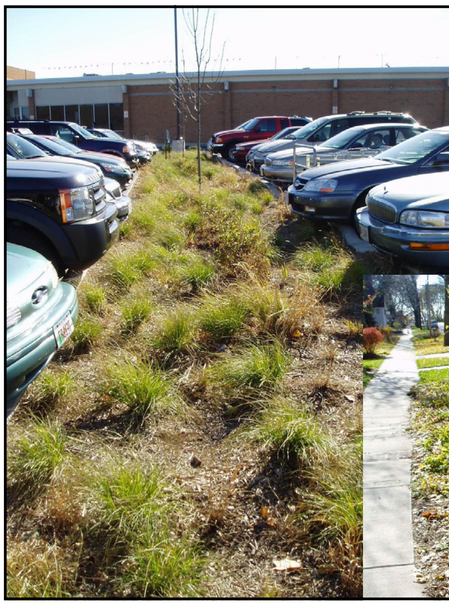
Percolation areas or ponds, biofiltration areas, and French drains can be designed for larger rains due to enhanced storage capacity.


Edison Museum, Detroit, MI


Berlin, Germany


Infiltrating swale as part of treatment train, Lake Oswego, OR

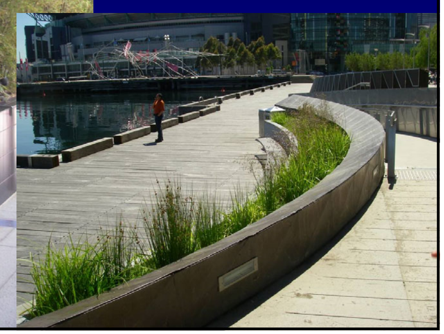
26



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

27

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



28


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

29


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

30


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

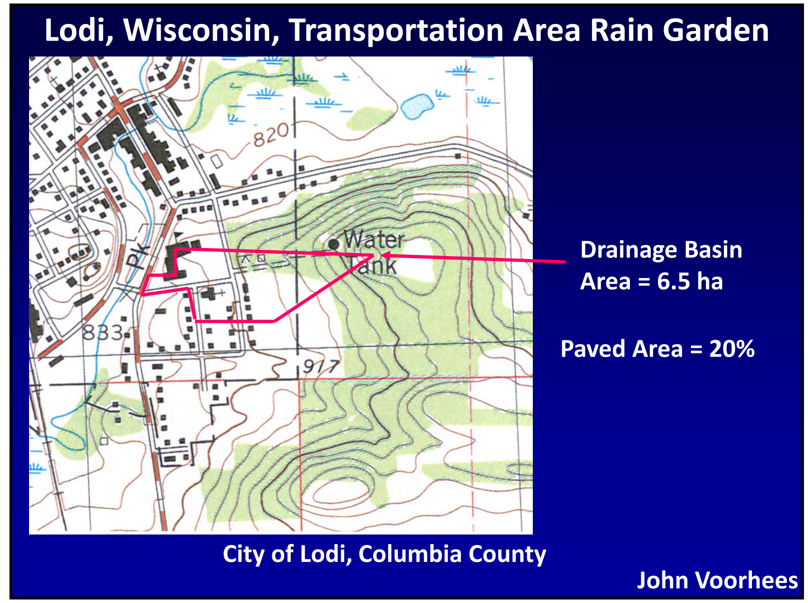
31


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

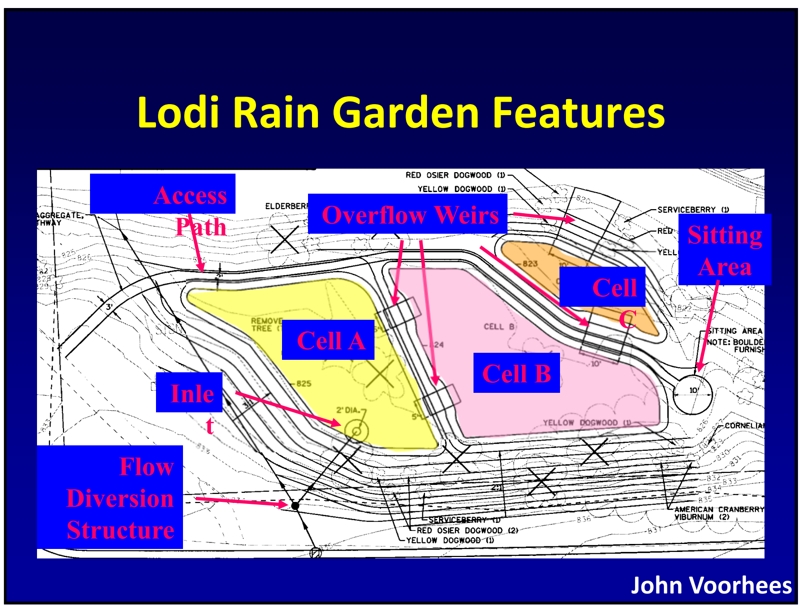
32


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

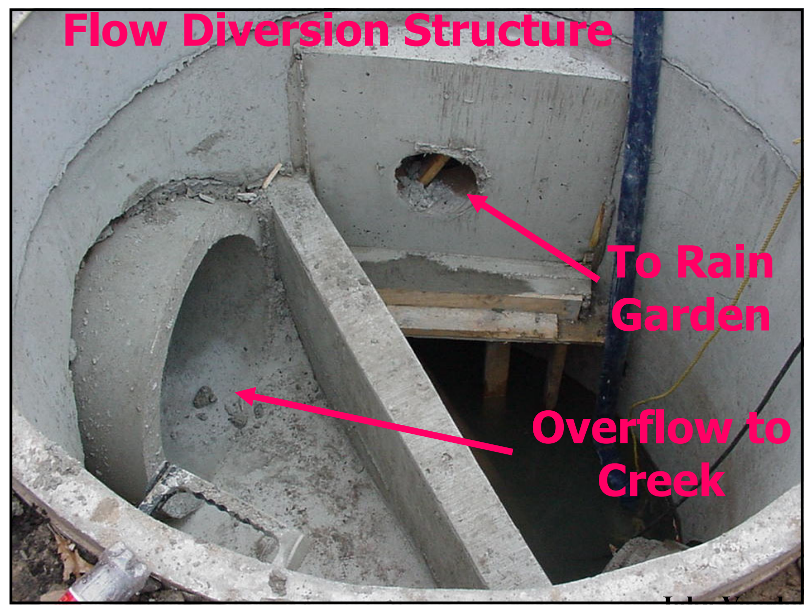
33


Lodi, Wisconsin, Transportation Area Rain Garden
Water Tank
820
833
917
Drainage Basin Area = 6.5 ha
Paved Area = 20%
City of Lodi, Columbia County
John Voorhees

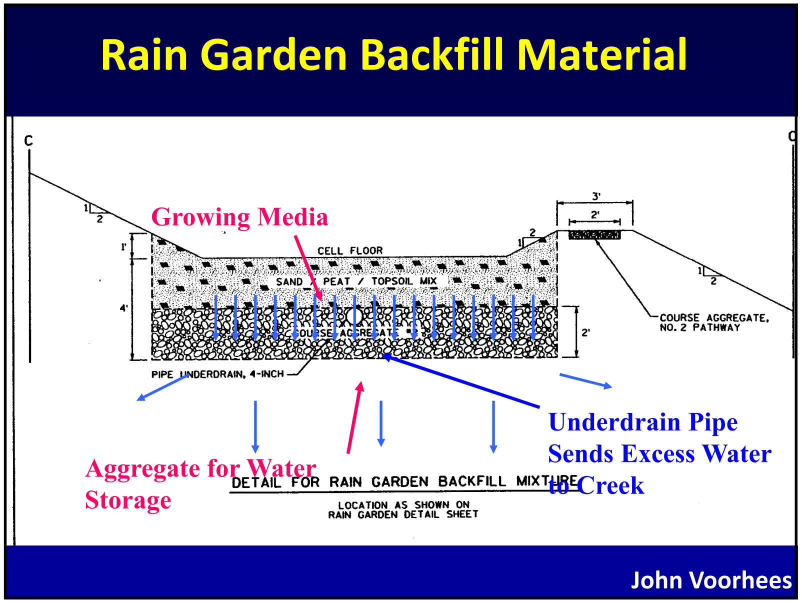
34


Lodi Rain Garden Features
Access Path
Overflow Weirs
Sitting Area
Cell C
Cell A
Cell B
Inle t
Flow Diversion Structure
RED OSIER DOGWOOD (1)
YELLOW DOGWOOD (1)
SERVICEBERRY (1)
YELLOW DOGWOOD (1)
SERVICEBERRY (1)
RED OSIER DOGWOOD (2)
YELLOW DOGWOOD (1)
AMERICAN CRANBERRY VIBURNUM (2)
John Voorhees

35


Flow Diversion Structure
To Rain Garden
Overflow to Creek

36


Rain Garden Backfill Material
Growing Media
CELL FLOOR
SAND / PEAT / TOPSOIL MIX
COURSE AGGREGATE
PIPE UNDERDRAIN, 4-INCH
COURSE AGGREGATE, NO. 2 PATHWAY
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

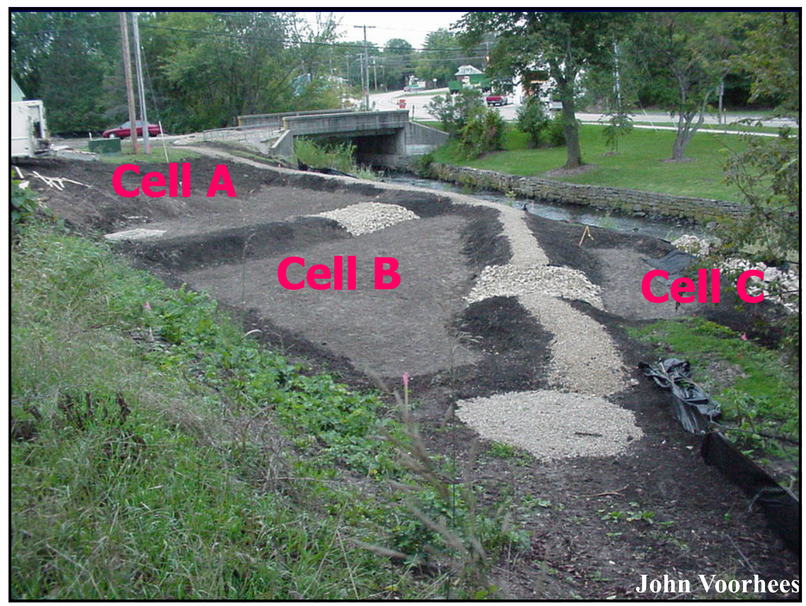
37


Soil/Peat/Sand Mixing
John Voorhees

38

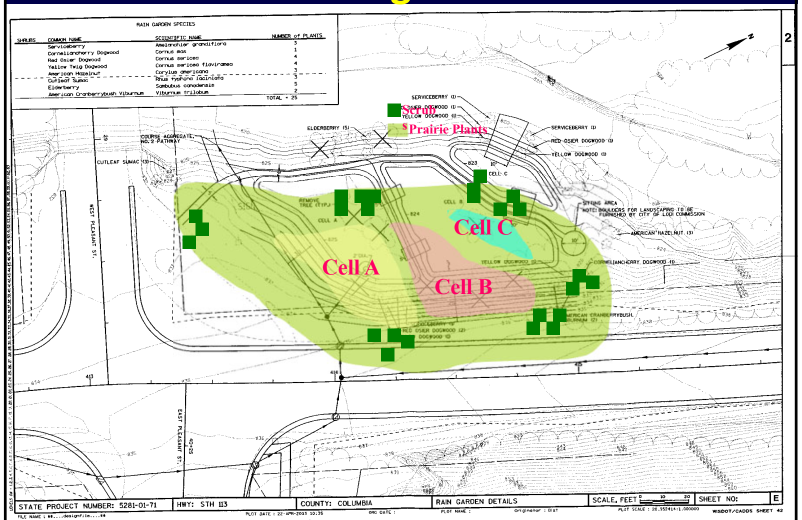

Cell A
Cell B
John Voorhees

39


Cell A
Cell B
Cell C
John Voorhees

40

Planting Plan



John Voorhees

41

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

John Voorhees photos

42

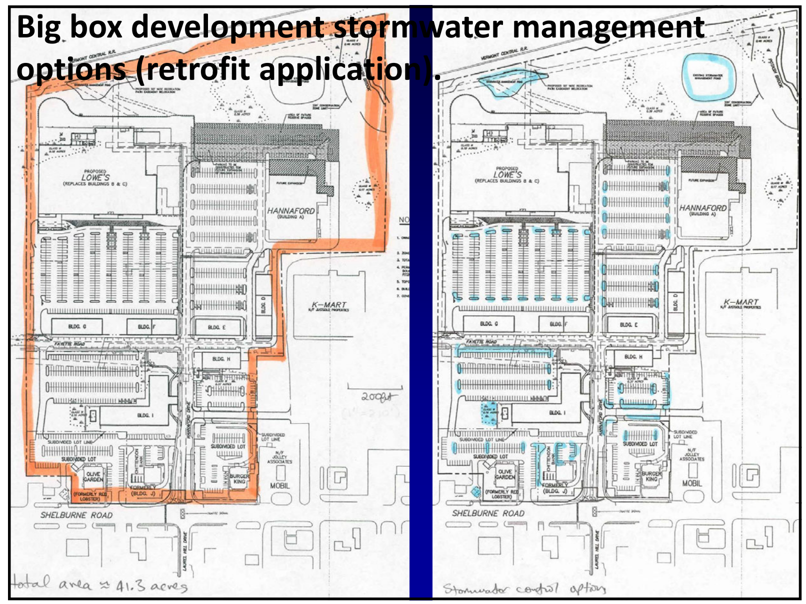
Lodi, WI, Rain Garden Costs

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

43

Big box development stormwater management options (retrofit application).



44

Summary of Measured Areas

- Totally connected impervious areas: 25.9 acres
  - parking 15.3 acres
  - roofs (flat) 8.2 acres
  - streets (1.2 curb-miles and 33 ft wide) 2.4 acres
- Landscaped/open space 15.4 acres
- Total Area 41.3 acres

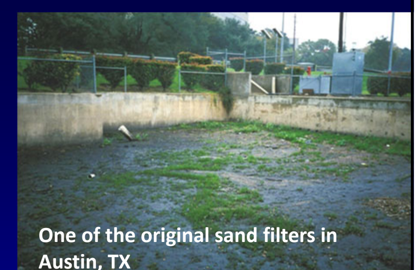
Stormwater Controls

- Bioretention areas (parking lot islands)
  - 52 units of 40 ft by 8 ft
  - Surface area: 320 ft^2
  - Bottom area: 300 ft^2
  - Depth: 1 ft
  - Vertical stand pipe: 0.5 ft. dia. 0.75 ft high
  - Broad-crested weir overflow: 8 ft long, 0.25 ft wide and 0.9 ft high
  - Amended sandy loam soil
- Also examined wet detention ponds

Modeled Runoff Volume Changes

	Base conditions	With bioretention
Runoff volume (10^6 ft^3/yr)	2.85	1.67
Average Rv	0.59	0.35
% reduction in volume	n/a	41%

Wet detention ponds, stormwater filters, or correctly-sized critical source area controls are needed to treat runoff that cannot be infiltrated.



One of the original sand filters in Austin, TX

Pre-treatment pond before infiltrating swale, Lake Oswego, OR

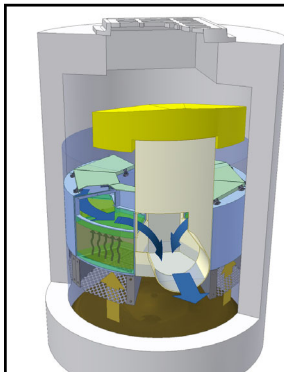
Multi-chambered treatment train (MCTT), Minocqua, WI

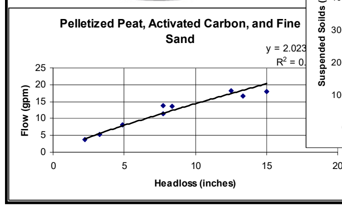
Multi-Chambered Treatment Train (MCTT) for stormwater control at large critical source areas

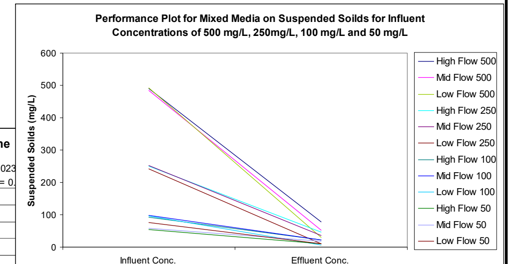
49

Upflow filter insert for catchbasins at smaller critical source areas

Able to remove particulates and targeted pollutants at small critical source areas. Also traps coarse material and floatables in sump and away from flow path.





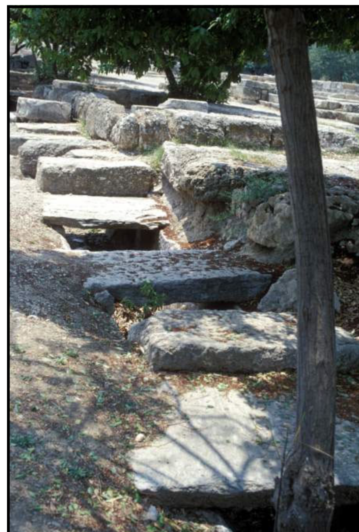


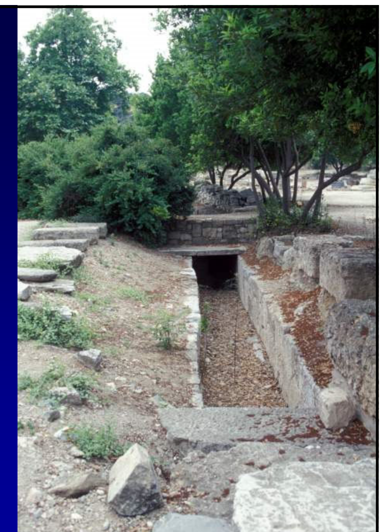
50

Design Issues (70 to 200 mm)

- This range of rains can include drainage-design storms (depending on rain intensity and site time of concentration). Most of these storms last for one to two days. Drainage design storms of these depths would last only for a few hours.
- Establishes energy gradient of streams
- Occur approximately every few months (two to five times a year). Drainage design storms having high peak intensities occur every several years to several decades)
- Problems:
  - Unstable streambanks
  - Habitat destruction from damaging flows
  - Sanitary sewer overflows
  - Nuisance flooding and drainage problems/traffic hazards

51





Stormwater drainage channels in the Agora, Athens, Greece, built by Peistratus in the 6th century, BC and still working today.

52

Excavation of ancient Roman stormwaterdraiange pipes, Rome (about 100 AD)

J. Harper photo

53

This conventional approach to urban drainage can be devastating to the environment, including recharge of groundwaters

54

Infrequent very high flows are channel-forming and may cause severe bank erosion and infrastructure damage.

55

Controls for Treatment of Runoff from Drainage Events (75 to 200 mm)

- Infiltration and other on-site controls will provide some volume and peak flow control
- Treatment controls can provide additional storage for peak flow reduction
- Provide adequate stormwater drainage to prevent street and structure flooding
- Provide additional storage to reduce magnitude and frequency of runoff energy
- Capture sanitary sewage overflows for storage and treatment

56

Storage at treatment works may be suitable solution in areas having SSOs that cannot be controlled by fixing leaky sanitary sewerage.

Leeds, AL, wastewater treatment plant, SSO storage tank

Golf courses can provide large volumes of storage.

Madison, WI

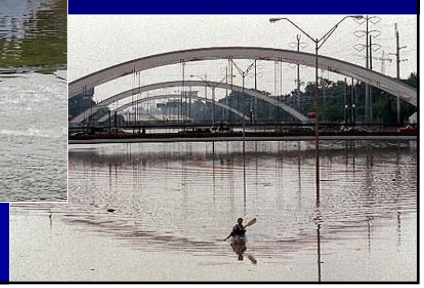
57

Design Issues (> 200 mm)

- Occur rarely (once every several years to once every several decades, or less frequently
- Produce relatively small fraction of the annual pollutant mass discharges
- Produce extremely large flows and the largest events exceed drainage system capacity (depending on rain intensity and time of concentration of drainage area)

58

WI DNR photo



Photos from *Houston Chronicle*.

59

Controls for Treatment of Runoff from Very Large Events (> 200 mm)

- Provide secondary surface drainage system to carefully route excess flood waters away from structures and roadways
- Restrict development in flood-prone areas

60

A suitable urban watershed management plan should incorporate many of the features described above to meet the many site objectives of interest, for a wide range of storm sizes.

- Good site design to fit site conditions (topography and natural drainage pattern; site soils; surrounding land uses and traffic patterns, etc.)
- Pollution prevention to minimize contamination due to material exposure (roofing, for example)
- Combination of infiltration and sedimentation unit processes in large-scale treatment train
- Critical source area treatment (storage areas, loading docks, etc.)

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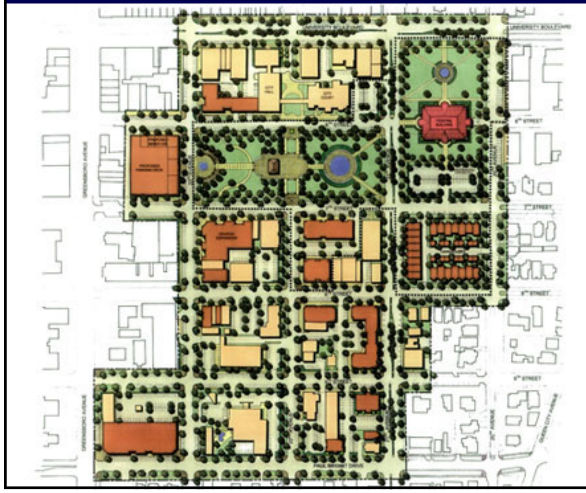
Downtown Tuscaloosa Redevelopment



DOWNTOWN TUSCALOOSA

62

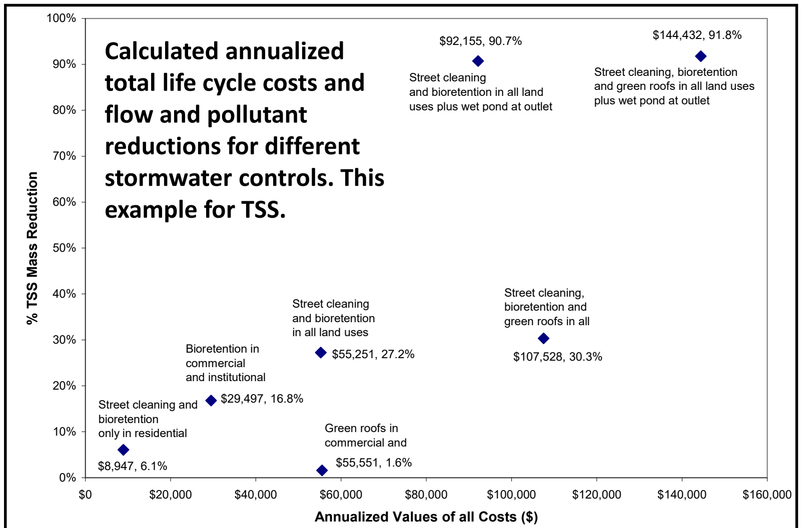
Conducted a preliminary evaluation of the downtown Tuscaloosa area that contains the redevelopment sites.

Land Use	Area (ac)	Area (%)
Commercial	72.9	66.0
Residential	15.7	14.2
Institutional	11.0	10.0
Other	10.8	9.77
TOTAL	***110***	***100***

Soils are mostly hydrologic group B and are classified as silt or loam, having typical infiltration rates of about 0.5 in/hr, although most of the soils are highly disturbed and will need to be restored.

63

Calculated annualized total life cycle costs and flow and pollutant reductions for different stormwater controls. This example for TSS.



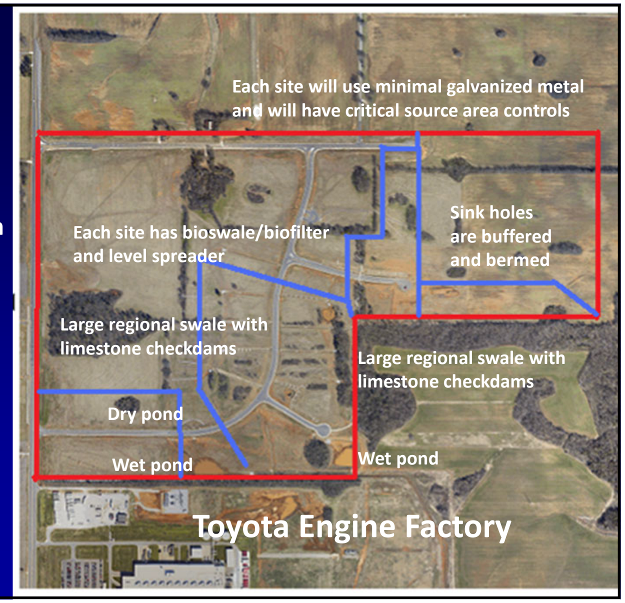
64

Case Study for Industrial Park Incorporating Stormwater Conservation Design

NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

65

The North Huntsville Industrial Park is a new development of 100 ha with 50 lots, each about 1 to 2 ha.



66

Regional swales to collect site runoff and direct to we detention ponds:

- Length: 1653 ft
- infiltration rate in the swale: 1 in/hr
- swale bottom width: 50 ft
- 3H:1V side slopes
- longitudinal slope: 0.026 ft/f
- Manning's n roughness coefficient: 0.024
- typical swale depth: 1 ft

67

Biofilters to drain site runoff (paved parking and roofs) to regional swales:

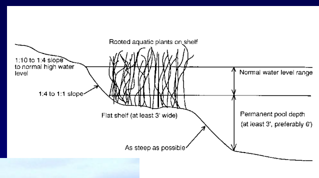
- Top area: 400 m^2
- Bottom area: 185 m^2
- Depth: 0.6 m
- Seepage rate: 50 mm/hr
- Typical width: 3 m
- Number of biofilters: 13 (one per site)

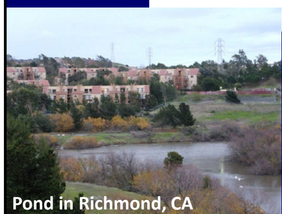
Parking lot biofilter example, Portland, OR

68

Wet Detention Ponds

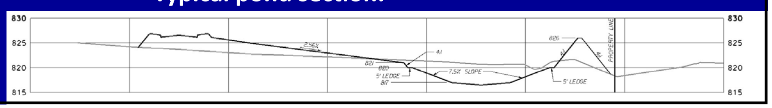
The regional swales will direct excess water into the four ponds.





The pond surface areas vary from 0.5 to 1% of the drainage areas, depending on the amount of upland infiltration. The ponds have 1 m of standing water above 0.6 m of sacrificial storage. Additional storage volume provides necessary peak flow control.

Typical pond section:



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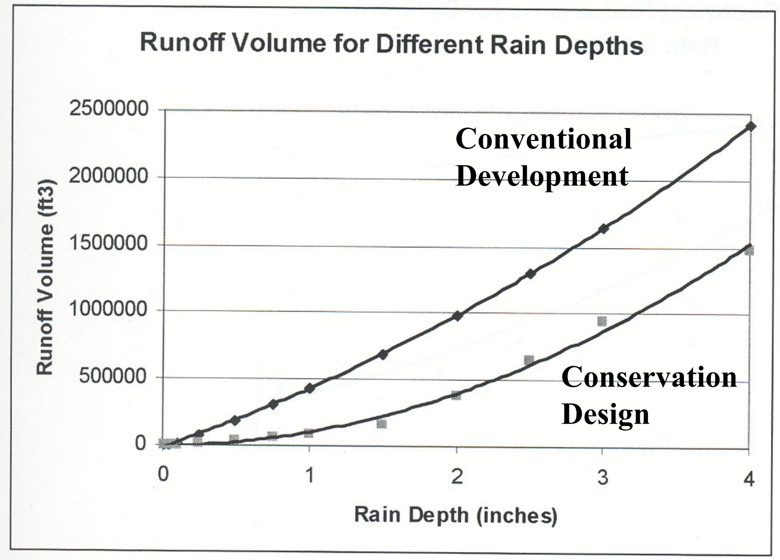

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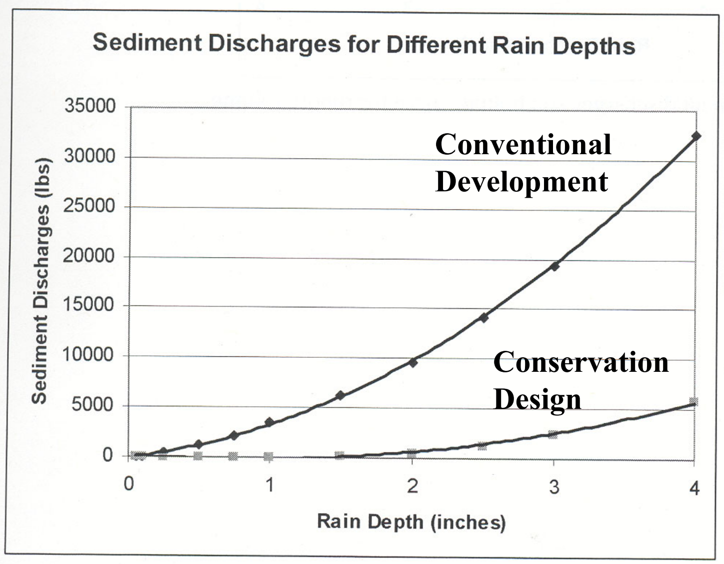

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Elements of Conservation Design for Cedar Hills Development

(near Madison, Wisconsin, project conducted by Bill Selbig, USGS, and Roger Bannerman, WI DNR)

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

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USGS
science for a changing world

In cooperation with the Wisconsin Department of Natural Resources

A Comparison of Runoff Quantity and Quality from Two Small Basins Undergoing Implementation of Conventional- and Low-Impact-Development (LID) Strategies: Cross Plains, Wisconsin, Water Years 1999–2005

Scientific Investigations Report 2008–5008

U.S. Department of the Interior
U.S. Geological Survey

The earliest, most comprehensive full-scale study comparing advanced stormwater controls available.

Available at: http://pubs.usgs.gov/sir/2008/5008/pdf/sir_2008-5008.pdf

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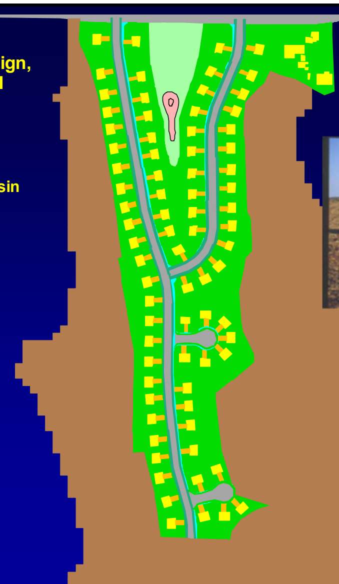
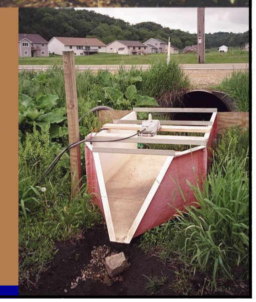
Cedar Hill Site Design, Crossplains WI

Explanation
- Wetpond
- Infiltrations Basin
- Swales
- Sidewalk
- Driveway
- Houses
- Lawns
- Roadway
- Woodlot

N

500 0 500 1000 Feet





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

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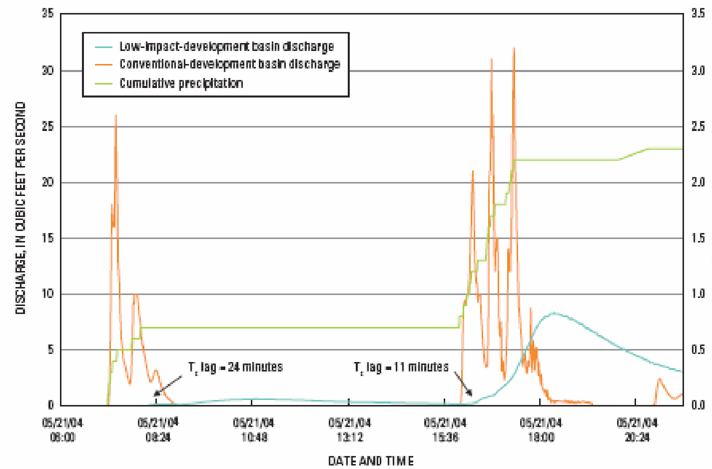

Figure 10. Hydrologic response of low-impact-development (LID) and conventional-development basins to two consecutive precipitation events, Cross Plains, Wis. [T_c, time of concentration]

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Reductions in Runoff Volume for Cedar Hills (calculated using WinSLAMM and verified by site monitoring)

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 15% increase over pre-development

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Monitored Performance of Controls at Cross Plains Conservation Design Development

Water Year	Construction Phase	Rainfall (inches)	Volume Leaving Basin (inches)	Percent of Volume Retained (%)
1999	Pre-construction	33.3	0.46	99%
2000	Active construction	33.9	4.27	87%
2001	Active construction	38.3	3.68	90%
2002	Active construction (site was approximately 75% built-out)	29.4	0.96	97%

WI DNR and USGS data

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Conclusions

- Many labels for similar approaches (distributed infiltration controls were described and used in the 1960s for stormwater management; ancient cities relied on beneficial uses of stormwater).
- Need to incorporate range of controls, not just from a list of "approved" technologies. Need to use both sedimentation and infiltration strategies, at least.
- The smallest rains can be effectively controlled by simple development options in low and medium density areas, but will always be challenging in densely developed areas.
- Stormwater controls for new development are always less costly and more effective than when retrofitting.

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Conclusions, cont.

- Controls used for small events have some, but decreasing benefits for larger events. Controls for larger events require more engineering design efforts and features.
- These controls can be designed to be nearly 100% effective for the runoff entering them; a difficult problem is directing most of the site runoff to controls in pre-existing areas.
- Unusual rain events (in the drainage design category and greater), will likely have minimal benefits from these controls.

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