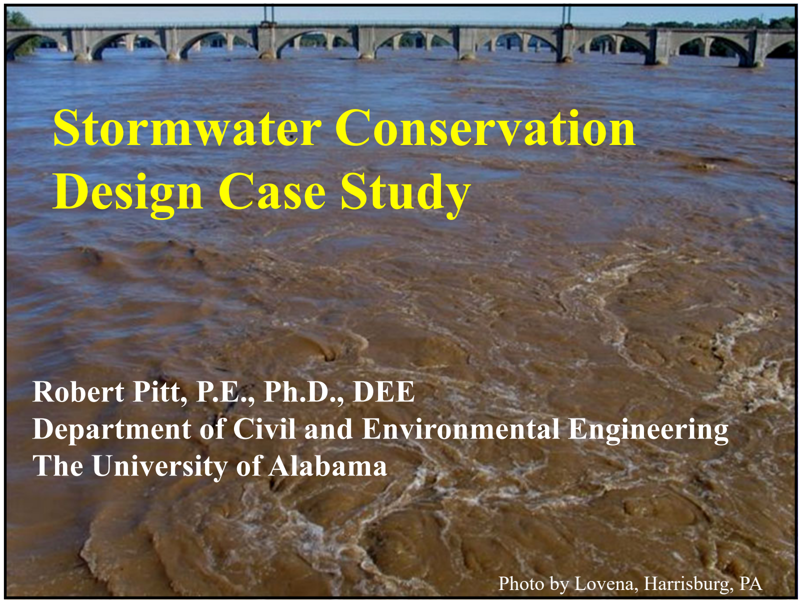


Stormwater Conservation Design Case Study

Robert Pitt, P.E., Ph.D., DEE
Department of Civil and Environmental Engineering
The University of Alabama

Photo by Lovena, Harrisburg, PA

1

Receiving Water Effects of Water Pollutant Discharges

- Sediment (amount and quality)
- Habitat destruction (mostly through high flows [energy] and sedimentation)
- Eutrophication (nutrient enrichment)
- Low dissolved oxygen (from organic materials)
- Pathogens (mostly from municipal wastewater and agricultural runoff)
- Toxicants (heavy metals and organic toxicants)
- Temperature
- Debris and unsafe conditions
- etc.

2

Historical concerns focused on increased flows during rains and associated flooding. However, decreased flows during dry periods are now seen to also cause receiving water problems.

WI DNR photo

3

WI DNR photo

Bank instability and habitat destruction due to increased flows

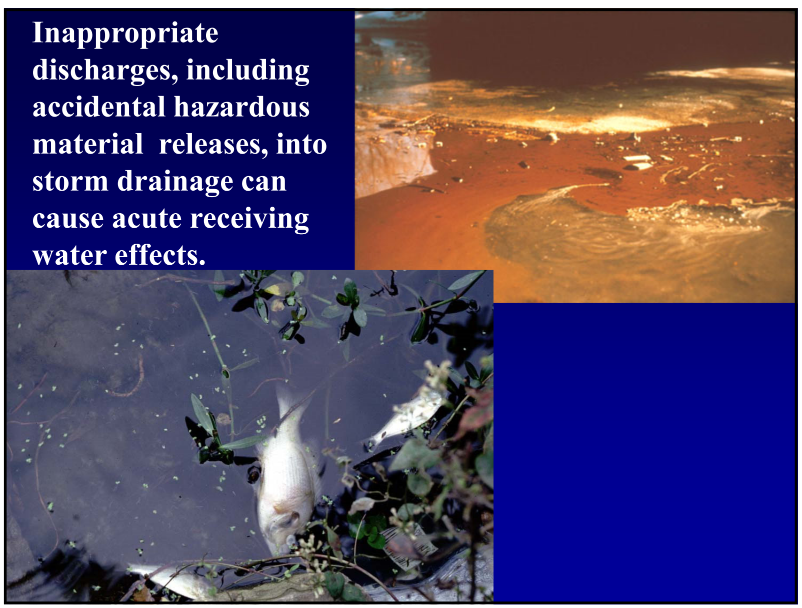
4


Sediment transported in stormwater causes significant receiving water impacts.
WI DNR photo
R. Bannerman photo

5


Gross floatables most important wet weather flow pollutant in many urban areas.

6


Inappropriate discharges, including accidental hazardous material releases, into storm drainage can cause acute receiving water effects.

7


Water contact warning sign, Orange County, CA, beach.
WARNING
RUNOFF/STORM DRAIN WATER MAY CAUSE ILLNESS
AVOID CONTACT WITH PONDED OR FLOWING RUNOFF AND THE AREA WHERE RUNOFF ENTERS THE OCEAN
AVISO

8

Fishing in urban waters also occurs, both for recreation and for food.

9

Children frequently play in urban creeks, irrespective of their designation as water contact recreation waters

10

A lot of stormwater flow and quality data has been collected during past several decades

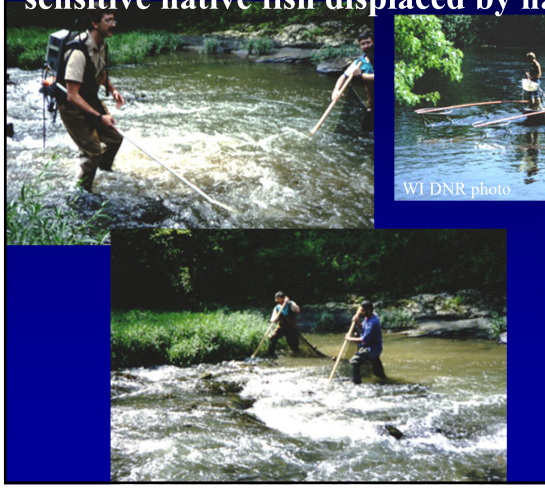
It is straight-forward and important to compare these observations with model assumptions

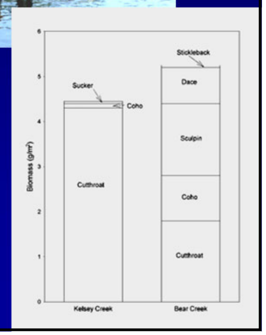
11

Contaminated sediments in urban receiving waters likely much more responsible for biological impacts than contaminated water.

12

Fish surveys in urban streams typically find similar biomass as in control streams, but sensitive native fish displaced by hardy exotics





13

Conservation Design Approach for New Development

- Better site planning to maximize resources of site
- Emphasize water conservation and water reuse on site
- Encourage infiltration of runoff at site
- Treat water at critical source areas
- Treat runoff that cannot be infiltrated at site

14

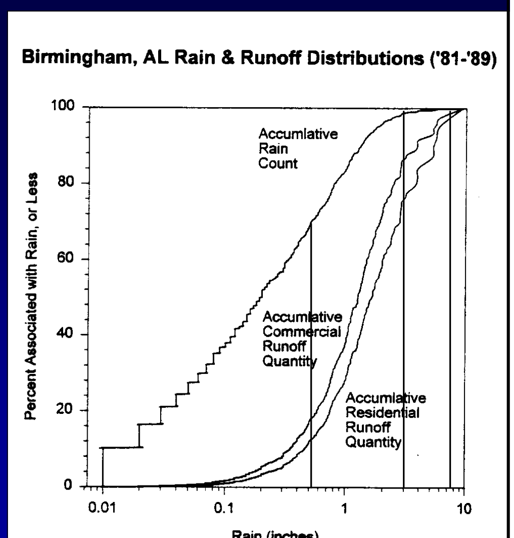
Probability distribution of rains (by count) and runoff (by depth).

<0.5”: 65% of rains (10% of runoff)

0.5 to 3”: 30% of rains (75% of runoff)

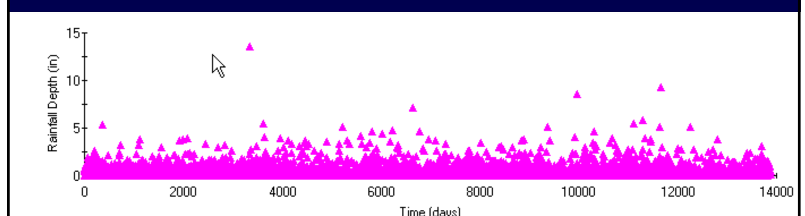
3 to 8”: 4% of rains (13% of runoff)

>8”: <0.1% or rains (2% or runoff)



15

Birmingham, AL, rains from 1952 through 1989



111 rains per year during this 37 year period
Most rains < 3 inches
About 5 rains a year between 3 and 8 inches
3 rains (in 37 years) > 8 inches

16

Design Issues (<0.5 inches)

- 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 limits (especially for bacteria and total recoverable heavy metals) for each event

17

Suitable Controls for Almost Complete Elimination of Runoff Associated with Small Rains (<0.5 in.)

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

18

Roof drain disconnections

19

Grass-Lined Swales

20

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

21

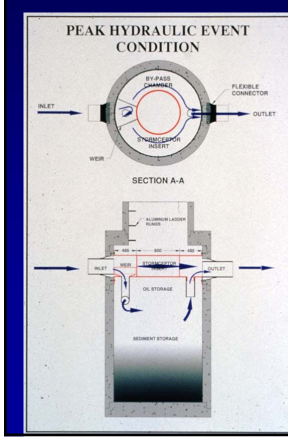
Green roof, Portland, OR

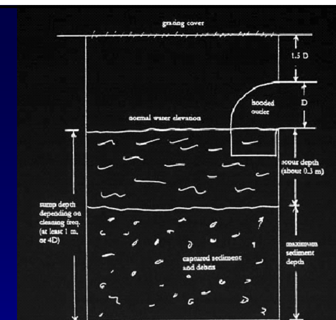
22

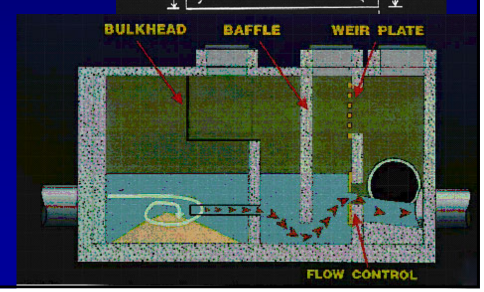
Street and catchbasin cleaning, and inlet controls most effective for smaller rains in heavily paved areas.

23

Hydrodynamic devices limited by site hydraulics to small paved areas and small rains.







24

Design Issues (0.5 to 3 inches)

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

25

Suitable Controls for Treatment of Runoff from Intermediate-Sized Rains (0.5 to 3 in.)

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

26

Rain Garden Designed for Complete Infiltration of Roof Runoff

27

Soil Modifications for rain gardens and other biofiltration areas can significantly increase treatment and infiltration capacity compared to native soils.

(King County, Washington, test plots)

28

Percolation areas or ponds, infiltration trenches, and French drains can be designed for larger rains due to storage capacity, or small drainage areas.

29

Bioretention and biofiltration areas having moderate capacity

30

Temporary parking or access roads supported by turf meshes, or paver blocks, and advanced porous paver systems designed for large capacity.

31

Large capacity grass swales and channels designed for both conveyance and water quality objectives.

32

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

33

Design Issues (3 to 8 inches)

- These events can be 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 (three 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

34

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

WI DNR photos

35

High flows surcharge drainage system and exceed capacity of road crossing culverts.

MD photo

36

Controls for Treatment of Runoff from Drainage Events (3 to 8 in.)

- 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

37

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

Golf courses can provide large volumes of storage.

38

Design Issues (> 8 inches)

- Occur rarely (once every several years to once every several decades, or less frequently) Three rains were recorded that were >8 inches in Birmingham during the 37 years between 1952 and 1989
- 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)

39

WI DNR photo

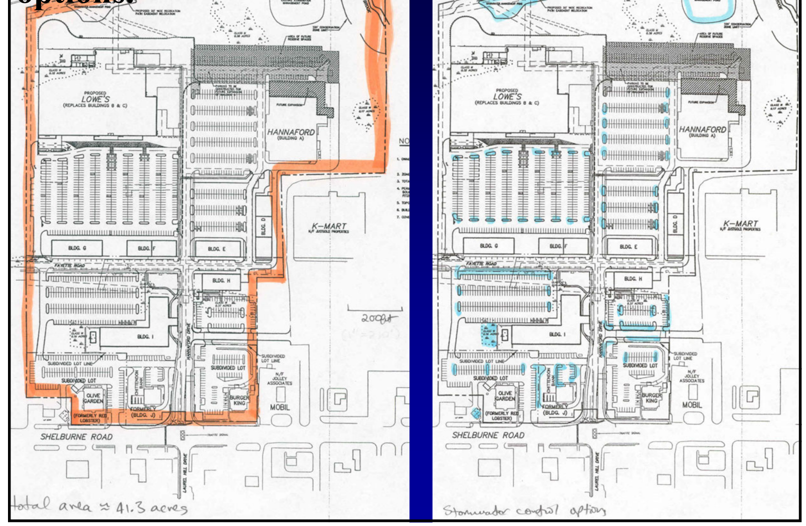
40

Controls for Treatment of Runoff from Very Large Events (> 8 in.)

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

41

Big box development stormwater management options.



42

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

43

Stormwater Controls

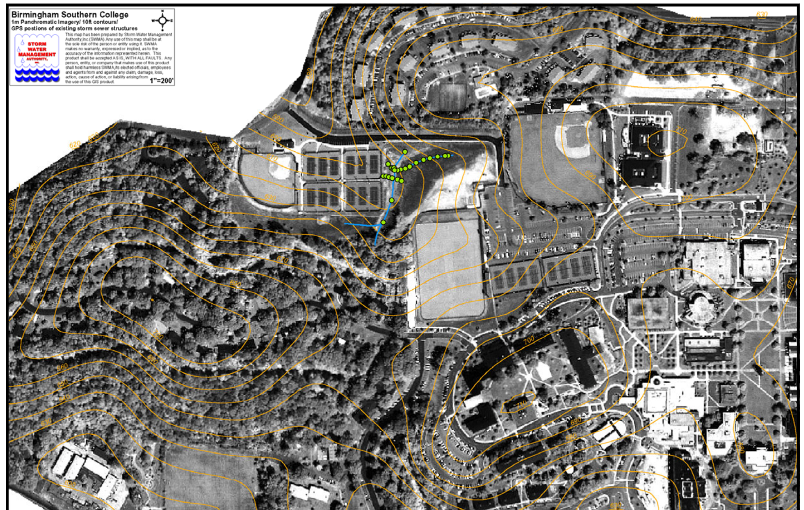
- Biofiltration areas (parking lot islands)
  - 52 units of 40 ft by 8 ft
  - Surface area: 320 ft^2
  - Bottom area: 300 ft^2
  - Depth: 1 ft
  - Vertical stand pipe: 0.5 ft. dia. 0.75 ft high
  - Broad-crested weir overflow: 8 ft long, 0.25 ft wide and 0.9 ft high
  - Amended soil: sandy loam
- Also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

44

Runoff Volume Changes

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

45



Birmingham Southern College Campus (map by Jefferson County Stormwater Management Authority)

46

Birmingham Southern College Fraternity Row

	Acres	% of Total
Roadways	0.24	6.6%
Parking	0.89	24.5
Walks	0.25	6.9
Roofs	0.58	16.0
Landscaping	1.67	46.0
Total:	3.63	100.0

47

Supplemental Irrigation

	Inches per month (example)	Average Use for 1/2 acre (gal/day)
Late Fall and Winter (Nov-March)	1 to 1-1/2	230 - 340
Spring (April-May)	2 to 3	460 - 680
Summer (June-August)	4	910
Fall (Sept-Oct)	2 to 3	460 - 680
Total:	28 (added to 54 inches of rain)	

48

Capture and Reuse of Roof Runoff for Supplemental Irrigation

Tankage Volume (ft^3) per 4,000 ft^2 Building	Percentage of Annual Roof Runoff used for Irrigation
1,000	56%
2,000	56
4,000	74
8,000	90
16,000	98

49

Combinations of Controls to Reduce Runoff Volume

	Total Annual Runoff (ft^3/year)	Increase Compared to Undeveloped Conditions
Undeveloped	46,000	--
Conventional development	380,000	8.3X
Grass swales and walkway porous pavers	260,000	5.7
Grass swales and walkway porous pavers, plus roof runoff disconnections	170,000	3.7
Grass swales and walkway porous pavers, plus bioretention for roof and parking area runoff	66,000	1.4

50

Elements of Conservation Design for Cedar Hills Development

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

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

51

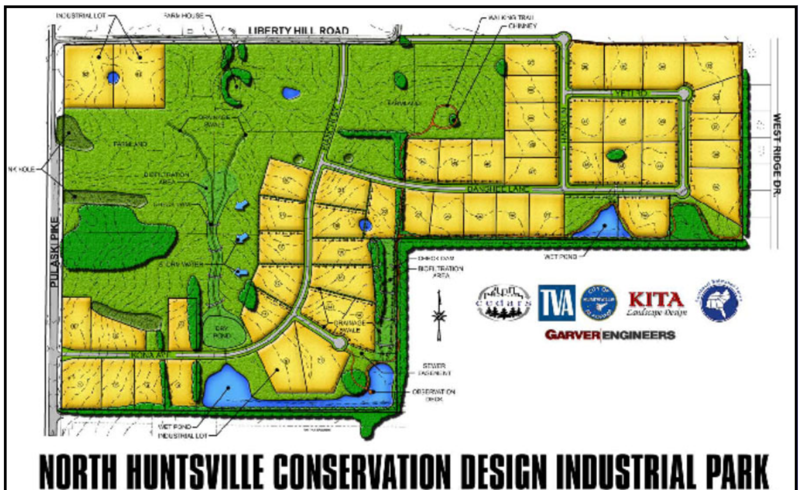
52

53

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

54



55

Conservation Design Elements for North Huntsville, AL, Industrial Park

- Grass filtering and swale drainages
- Modified soils to protect groundwater
- Wet detention ponds
- Bioretention and site infiltration devices
- Critical source area controls at loading docks, etc.
- Pollution prevention through material selection (no exposed galvanized metal, for example) and no exposure of materials and products.

56

A new industrial site in Huntsville, AL, has 52 approximately two acre individual building sites. Each of the sites will be served with a grass-lined bioretention channel that will carry site water to a larger swale system. The slopes of the channels vary from about 1 to 6.5%. The peak flow from each construction site was calculated to be about 16 ft^3/sec (corresponding to the Huntsville, AL, 25 yr design storm of 6.3 inches for 24 hours). The on-site swales will also have modified soils to increase the CEC and organic matter content to protect groundwater resources.

57

The bare swale soil has an allowable shear stress of about 0.05 lb/ft^2. The calculated values for unprotected conditions are all much larger. Therefore, a North American Green S75 mat was selected, having an allowable shear stress of 1.55 lb/ft^2 and a life of 12 months. Check dams are needed when slopes are >5% due to high velocities.

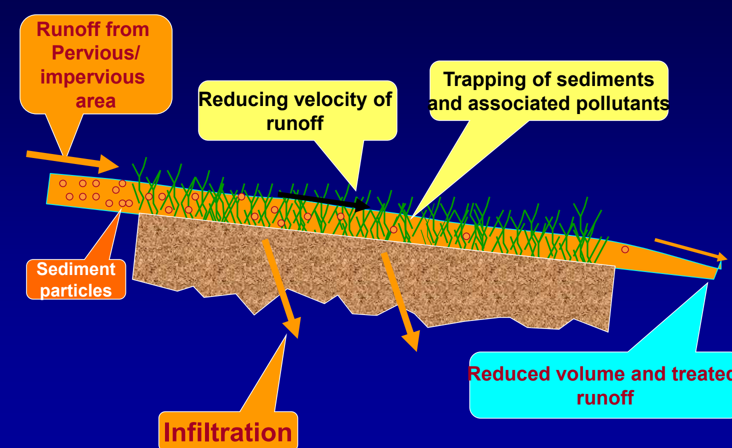
Slope	Bare soil shear stress (lb/ft^2)	Unvegetated mat shear stress, effect on soil (lb/ft^2)	Safety factor (allowable shear stress of 0.05 lb/ft^2)	Maximum velocity with mature vegetation (ft/sec)
1%	0.14	0.012	4.2	3.1
3%	0.28	0.023	2.2	4.8
5%	0.42	0.035	1.4	5.5
6.5%	0.46	0.039	1.3	6.4

58

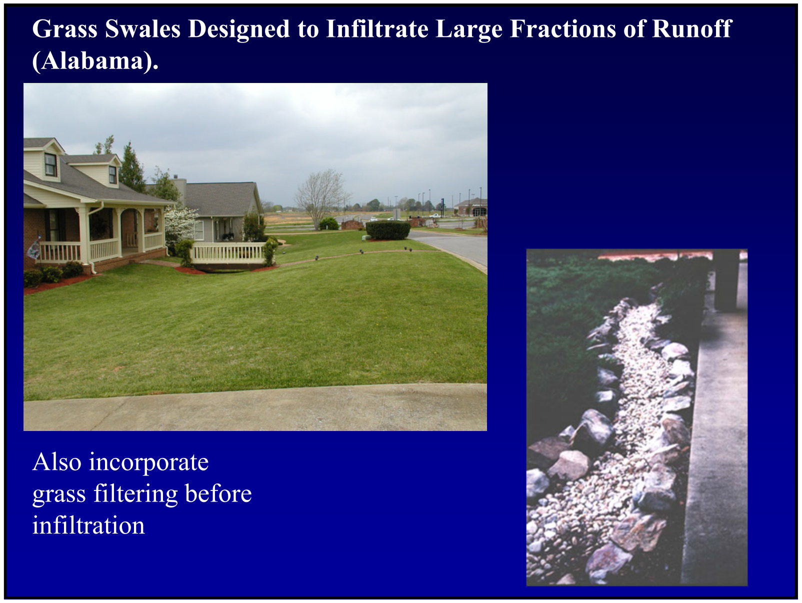
Grass Filtering of Stormwater Sediment

59

Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters



60


Grass Swales Designed to Infiltrate Large Fractions of Runoff (Alabama).
Also incorporate grass filtering before infiltration

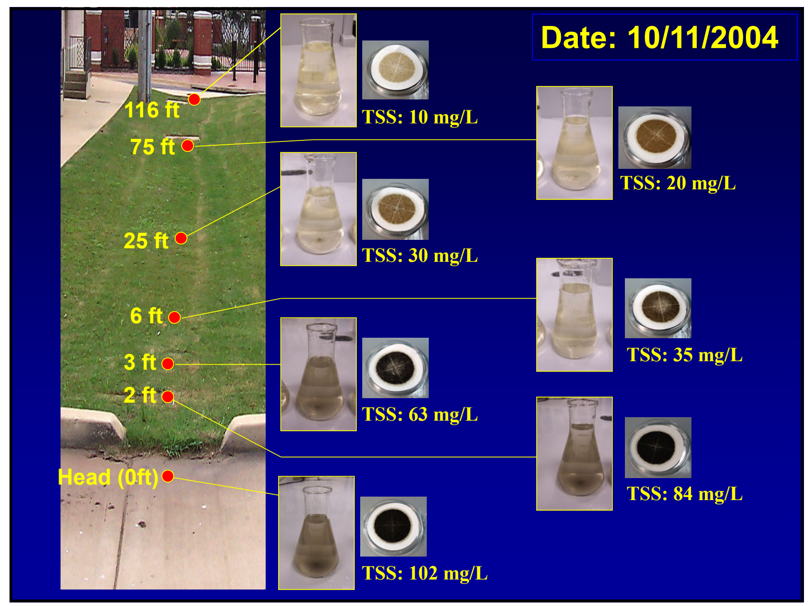
61


Swales can be both interesting and fit site development objectives.

62


Conventional curbs with inlets directed to site swales

63


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

64

On-site bioretention swales:

These small drainages collect the on-site water from the paved parking and roofs and direct it to the large natural swales. These were assumed to have the following general characteristics: 200 ft long, with 10 ft bottom widths, 3 to 1 (H to V) side slopes (or less), and 2 inches per hour infiltration rates. One of these will be used at each of the 6 sites on the eastern edge of this subarea. These swales will end at the back property lines with level spreaders (broad crested weirs) to create sheetflow towards the large drainage swale, if possible.

65

Large regional drainage swale:

There is one long regional drainage swale in this subarea that collects the sheetflows from the bioretention swales from each site and directs the excess water to the ponds on the southern property edge. This swale is about 1700 feet long, on about a 2.6% slope, and will be 50 ft wide. It will also have 3 to 1 (H to V) side slopes, or less, and have 1 inch per hour infiltration rates. The bottom of the swale will be deep vibratory cultivated during proper moisture conditions to increase the infiltration rate, if compacted. This swale will also have limestone check dams every 100 ft to add alkalinity to the water and to encourage infiltration. The vegetation in the drainage should be native grasses having deep roots and be mowed to a height of about 6 inches, or longer. Any cut grass should be left in place to act as a mulch which will help preserve infiltration rates. The swale should have a natural buffer on each side at least 50 ft wide. Any road or walkway crossings over the grassed waterway areas should be on confined to a narrow width.

66

Wet Detention Ponds

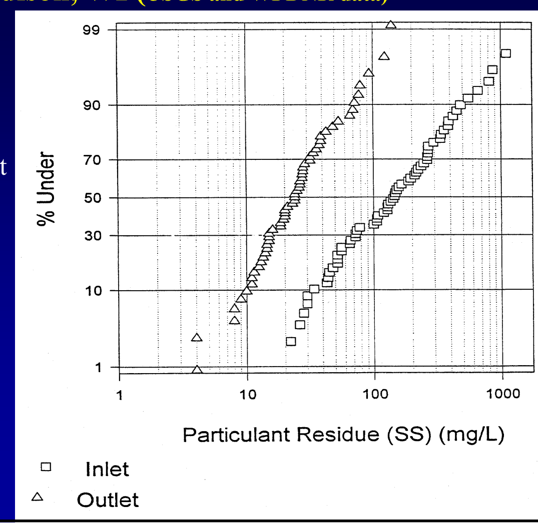
Typical Wet Pond Performance Reported in Literature

- Suspended solids: 70-95%
- COD: 60-70%
- BOD5: 35-70%
- Total Kjeldahl Nitrogen: 25-60%
- Total Phosphorus: 35-85%
- Bacteria: 50-95%
- Copper: 60-95%
- Lead: 60-95%
- Zinc: 60-95%

67

Suspended Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)

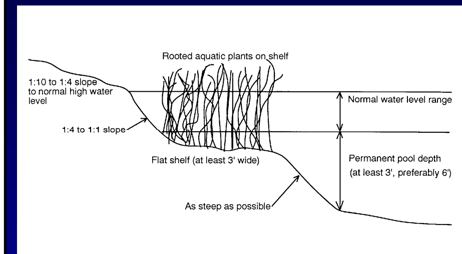
Consistently high TSS removals for all influent concentrations (but better at higher concentrations, as expected)



68

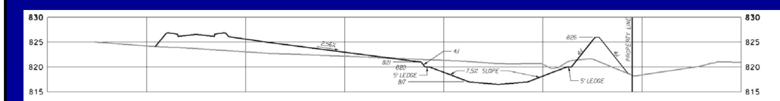
Wet detention ponds

The regional swales will direct excess water into the 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 3 ft. of standing water above 2 ft. of sacrificial storage. The live storage volume provides necessary peak flow control.

Typical pond section:

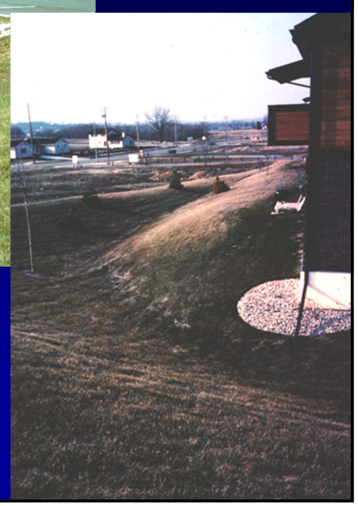


69

Infiltration/Biofiltration

- Infiltration trenches
- Infiltrating swales
- Infiltration ponds
- Porous pavement
- Percolation ponds
- Biofiltration areas (rain gardens, etc.)

70

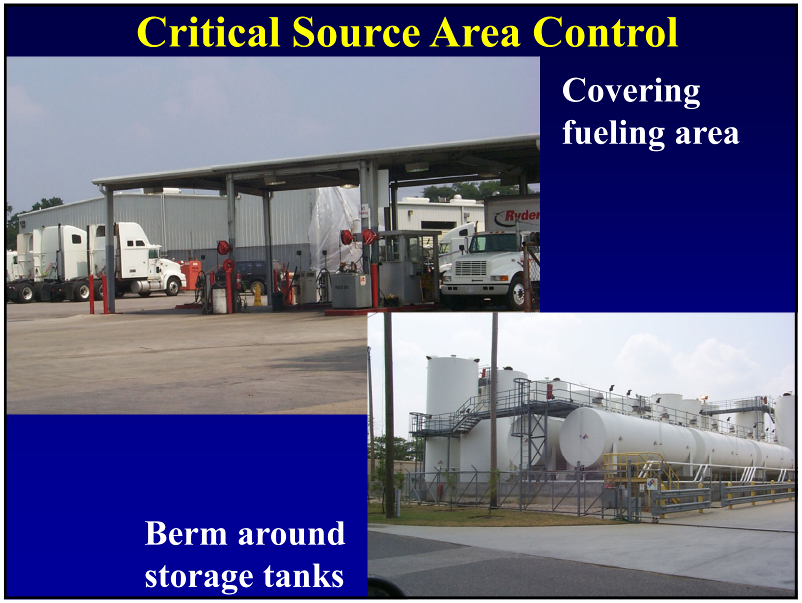


Small depressions graded near parking lots or buildings for infiltration (older method, using regular turf grass) (MD and WI).

71

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

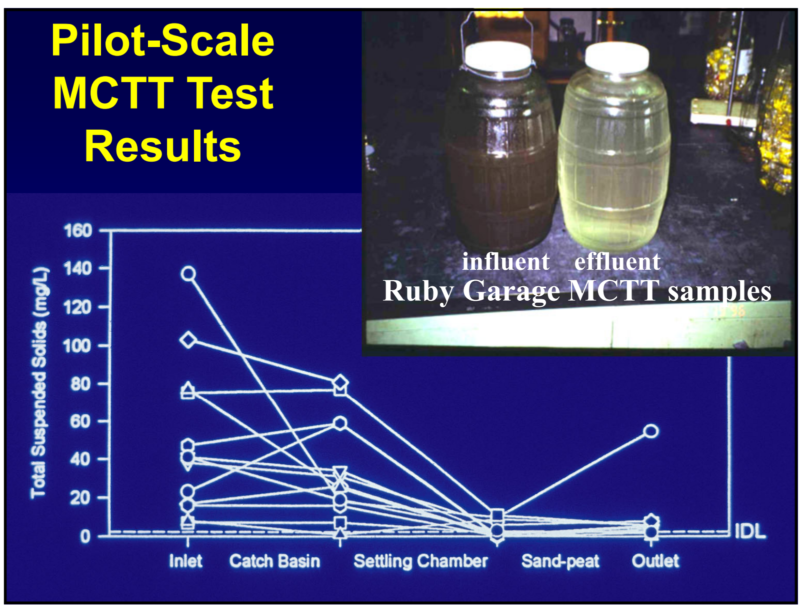
72


Critical Source Area Control
Covering fueling area
Ryder
Berm around storage tanks

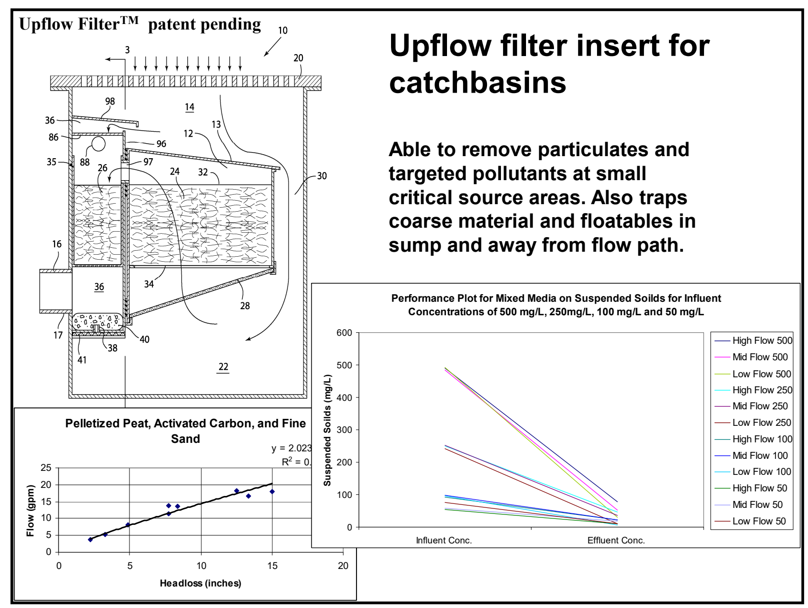
73


Multi-Chambered Treatment Train (MCTT) for stormwater control at large critical source areas
Milwaukee, WI,
Ruby Garage
Maintenance Yard
MCTT Installation

74


Pilot-Scale MCTT Test Results
influent effluent
Ruby Garage MCTT samples
Total Suspended Solids (mg/L)
160
140
120
100
80
60
40
20
0
IDL
Inlet
Catch Basin
Settling Chamber
Sand-peat
Outlet

75

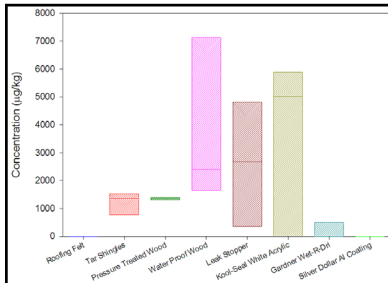

Upflow Filter™ patent pending
Upflow filter insert for catchbasins
Able to remove particulates and targeted pollutants at small critical source areas. Also traps coarse material and floatables in sump and away from flow path.
Pelletized Peat, Activated Carbon, and Fine Sand
Flow (gpm)
Headloss (inches)
Performance Plot for Mixed Media on Suspended Solids for Influent Concentrations of 500 mg/L, 250mg/L, 100 mg/L and 50 mg/L
Suspended Solids (mg/L)
Influent Conc.
Effluent Conc.
High Flow 500
Mid Flow 500
Low Flow 500
High Flow 250
Mid Flow 250
Low Flow 250
High Flow 100
Mid Flow 100
Low Flow 100
High Flow 50
Mid Flow 50
Low Flow 50

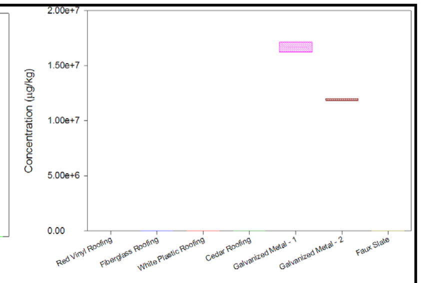
76

High Zinc Concentrations have been Found in Roof Runoff for Many Years at Many Locations

- Typical Zn in stormwater is about 100 µg/L, with industrial area runoff usually several times this level.
- Water quality criteria for Zn is as low as 100 µg/L for aquatic life protection in soft waters, up to about 5 mg/L for drinking waters.
- Zinc in runoff from galvanized roofs can be several mg/L
- Other pollutants and other materials also of potential concern.
- A cost-effective stormwater control strategy should include the use of materials that have reduced effects on runoff degradation.

77





2002 Laboratory-Scale Tests: Zinc

- Galvanized metal extremely high
- Water proofed wood, leak stopper, and while acrylic very high

78

2005: Testing Frame Set-Ups at Penn State-Harrisburg and the University of Alabama at Birmingham

Six frames and 12 panels being tested at each site

79

Different site subareas have different combinations of controls. Base conditions are for conventional development.

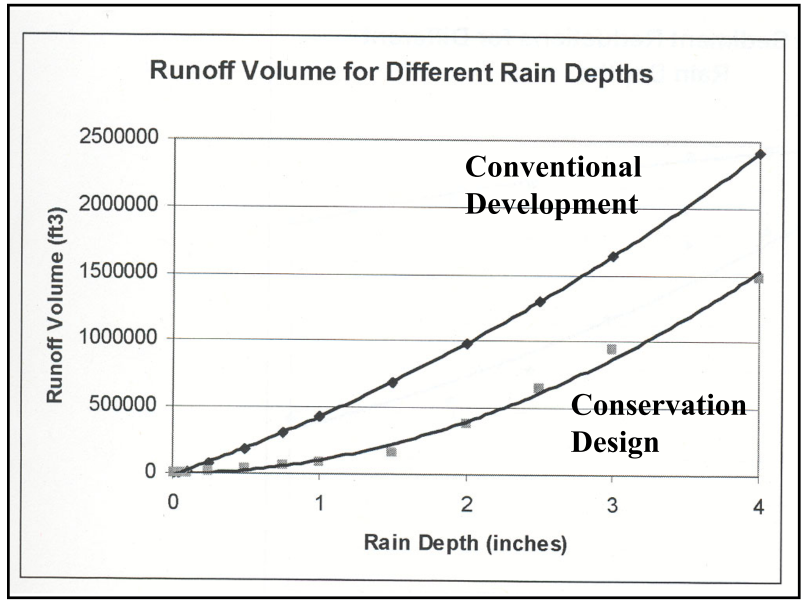
Drainage Area	Proposed Stormwater Components	Annual Runoff Volume (ft^3/year) Base Conditions	With Controls
A	Pond, swale, and site bioretention	6.3 x 10^6	2.5 x 10^6 (61%)
B	Small pond and swale	5.4 x 10^6	1.7 x 10^6 (69%)
C	Pond and swale	2.5 x 10^6	0.83 x 10^6 (68%)
D (including off-site area)	Off-site pond, swale, and site bioretention	11 x 10^6	5.8 x 10^6 (50%)
Total site		25 x 10^6	11 x 10^6 (56%)

Calculated using WinSLAMM and 40 years of rain records

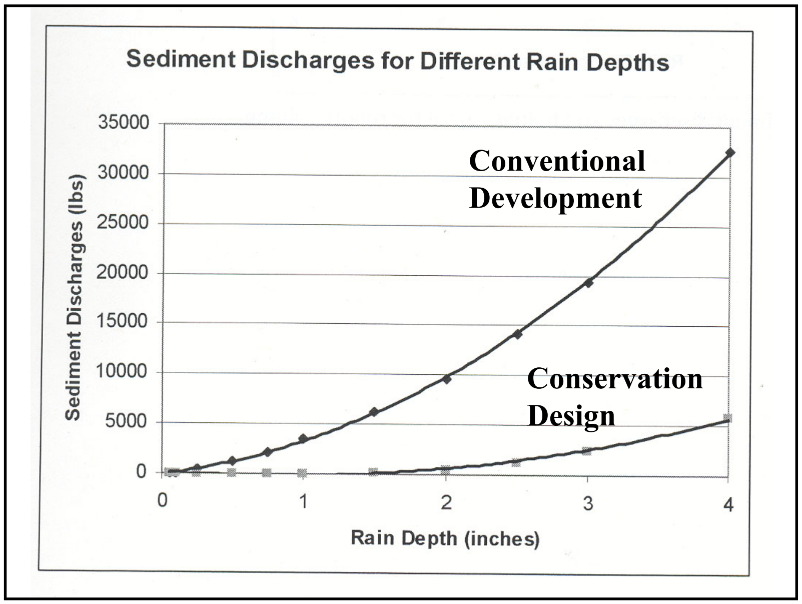
80

Drainage Area	Proposed Stormwater Components	Annual Particulate Solids Discharges (lb/year) Base Conditions	With Controls
A	Pond, swale, and site bioretention	98,000	4,400 (96%)
B	Small pond and swale	54,000	3,800 (93%)
C	Pond and swale	19,000	1,200 (94%)
D (including off site area)	Off-site pond, swale, and site bioretention	120,000	9,250 (92%)
Total site		290,000	19,000 (93%)

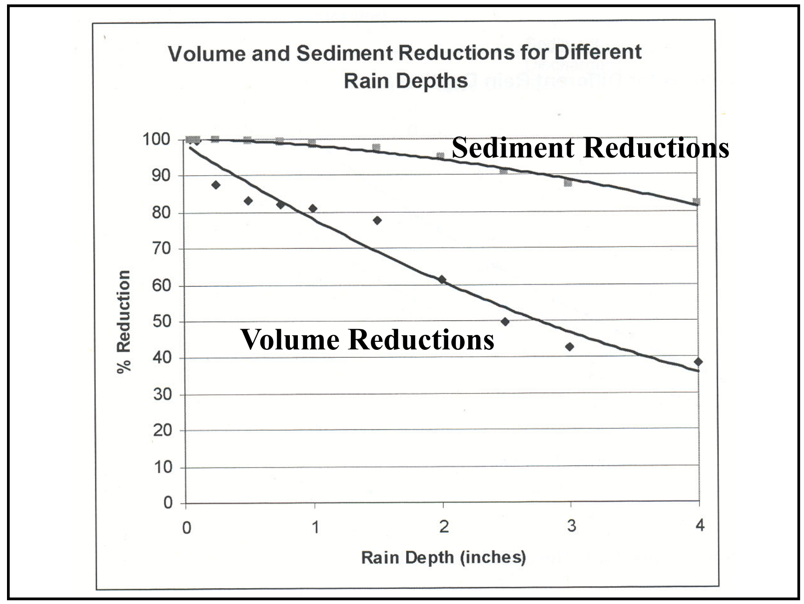
81



82



83



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Appropriate Combinations of Controls

- No single control is adequate for all problems
- Only infiltration reduces water flows, along with soluble and particulate pollutants. Only applicable in conditions having minimal groundwater contamination potential.
- Wet detention ponds reduce particulate pollutants and may help control dry weather flows. They do not consistently reduce concentrations of soluble pollutants, nor do they generally solve regional drainage and flooding problems.
- A combination of biofiltration and sedimentation practices is usually needed, at both critical source areas and at critical outfalls.

85

Combinations of Controls Needed to Meet Many Stormwater Management Objectives

- Smallest storms should be captured on-site for reuse, or infiltrated
- Design controls to treat runoff that cannot be infiltrated on site
- Provide controls to reduce energy of large events that would otherwise affect habitat
- Provide conventional flood and drainage controls

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