Day 5: Approaches for Urban Drainage for Retrofitting, Redevelopment, and New Development

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Photo by Lovena, Harrisburg, PA

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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.

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Conservation Design Approach for New Development

- **Better site planning to maximize soil and water resources and topography of site**
- **Emphasize water conservation and beneficial uses of stormwater on site**
- **Encourage infiltration of runoff at site**
- **Treat water at critical source areas**
- **Treat runoff that cannot be infiltrated at site**

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Water Supply and Water Quality

- Conservation easiest to develop and cheapest new water source
- Water quality problems becoming better understood
- Habitat destruction becoming recognized as serious issue

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In El Paso, Texas, pricing and educational efforts are credited with a substantial reduction in water use. Conservation meets about 15 to 17% of the city's future water needs. Besides slowing the rate of depletion of the groundwater supply, the conservation measures cost about 8% less than the cost of existing water supplies (about \$135 per 1,000 m^3).

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Water Factory 21, Orange County, California, was the US's large-scale example to highly purify sanitary sewage for groundwater injection and reuse (operated from 1975 to 2004, replaced with new facility in 2007, the Groundwater Replenishment System that utilizes microfiltration, RO, and UV disinfection. There are about 15 large reuse treatment facilities in the US now).

Facilities of **Water Factory 21** include: a 15 million gallon per day (MGD) (56,775 m^3/d) advanced wastewater reclamation plant that provides chemical clarification, air stripping, recarbonation, multimedia filtration, carbon adsorption and chlorination; and a 5 MGD (18,925 m^3/d) reverse osmosis (RO) demineralization plant. Twenty-three multiple-point wells inject the water into the underground aquifers, creating a coastal barrier to prevent seawater intrusion.

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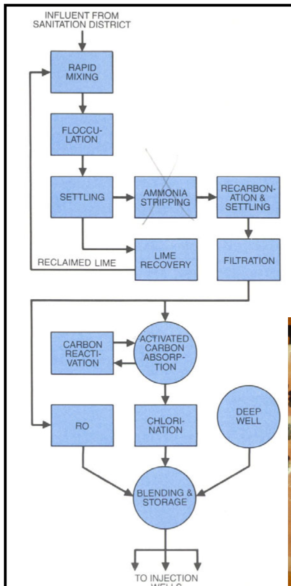

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OCWD's recharge channel in the Santa Ana River helps refill the groundwater basin.

The Orange County Water District also encourages infiltration in man-made meandering channels in the Santa Ana River.

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Water Use Calculations in WinSLAMM

WinSLAMM conducts a continuous water mass balance for every storm in the study period.

For rain barrels/tanks, the model fills the tanks during rains (up to the maximum amount of runoff from the roofs, or to the maximum available volume of the tank).

Between rains, the tank is drained according to the water demand rate. If the tank is almost full from a recent rain (and not enough time was available to use all of the water in the tank), excess water from the event could be discharged to the ground or rain gardens after the tank fills.

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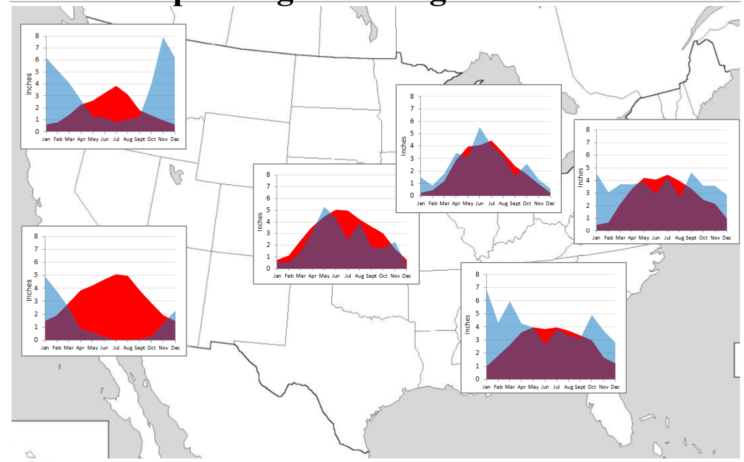
Stormwater as an irrigation water source highly variable depending on timing of demand and rain



Blue=rainfall; red=irrigation demand

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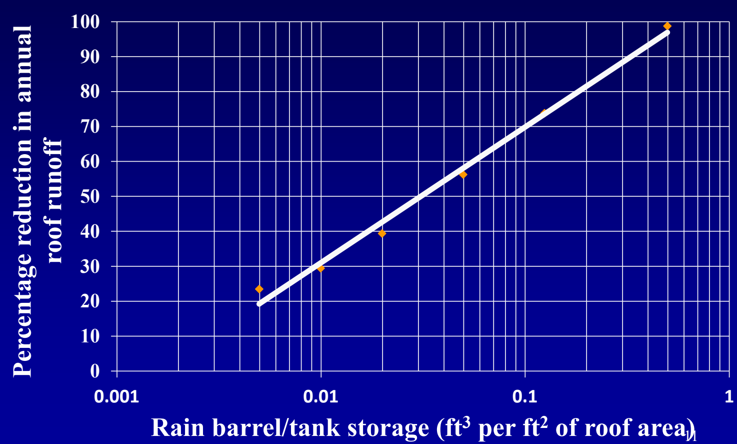
Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Barrels and Water Tanks (Kansas City CSO Study Area)



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0.125 ft of storage is needed for use of 75% of the total annual runoff from these roofs for irrigation. With 945 ft^2 roofs, the total storage is therefore 118 ft^3, which would require 25 typical rain barrels, way too many! However, a relatively small water tank (5 ft D and 6 ft H) can be used instead.

rain barrel/tank storage per house (ft^3)	percentage reduction in annual roof runoff	# of 35 gallon rain barrels per house	tank height size required if 5 ft D (ft)	tank height size required if 10 ft D (ft)
0	0	0	0	0
4.7	20	1	0.24	0.060
9.4	31	2	0.45	0.12
19	43	4	0.96	0.24
47	58	10	2.4	0.60
118	75	25	6.0	1.5
470	98	100	24	6.0

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Interactions of "Green Infrastructure" Controls Evaluated in the Kansas City CSO Demonstration Project

- When evaluated together, rain barrels/tanks collect the roof runoff first (for later irrigation use); the excess water can be discharged to the rain gardens. Overflow from the rain gardens is directed to the curb-side drainage system and biofilters.
- All of the site water (from the excess from the roof treatment systems or other upland controls and all other areas) is collected in the curb-side drainage system. The curb-cut biofilters are a cascading swale system where the site runoff is filtered and allowed to infiltrate. If the runoff volume is greater than the capacity of the biofilters, the excessive water is discharged into the combined sewer.
- As noted, the continuous simulations drain the devices between the runoff events, depending on the interevent conditions and water demand.

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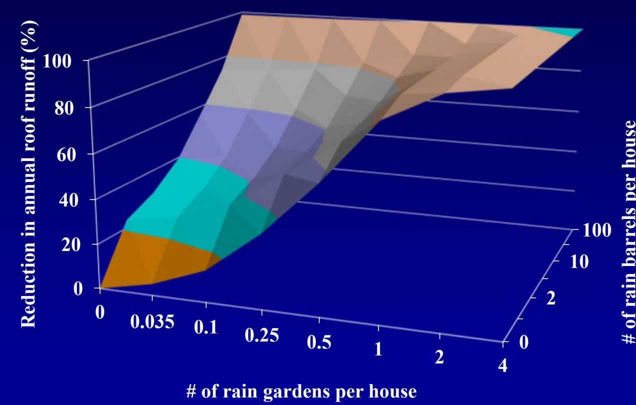
Interaction Benefits of Rain Barrels and Rain Gardens in the Kansas City CSO Study Area



Two 35 gal. rain barrels, plus one 160 ft^2 rain garden, per house can reduce the total annual runoff quantity from directly connected roofs by about 90%

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Roof Runoff Control Options

- Downspout disconnections
- Rain gardens
- Green roofs
- Beneficial use of roof runoff

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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. annual rain)	Seattle, Wash. (33.4 in.)	Phoenix, Arizona (9.6 in.)
Flat roofs instead of pitched roofs	13%	21%	25%
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

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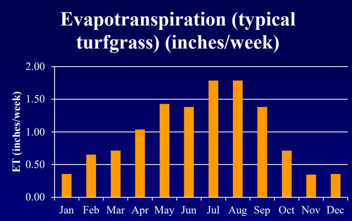
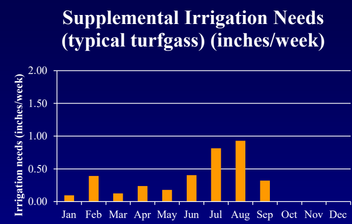
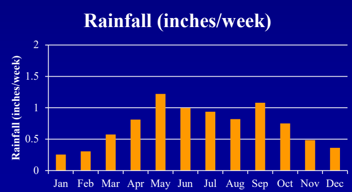
Water Harvesting Potential of Roof Runoff







Irrigation needs for the landscaped areas surrounding the homes were calculated by subtracting long-term rainfall from the regional evapotranspiration demands for turf grass.

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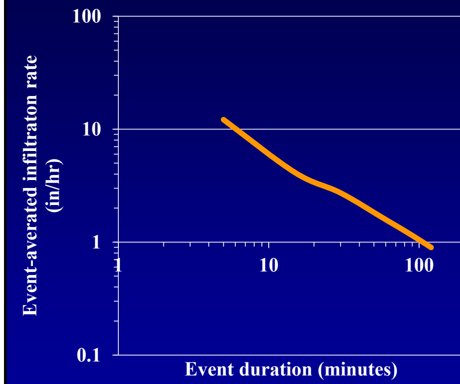
Long-duration Site Infiltration Rates



Clusters of three small Turf-Tec infiltrometers were used at each monitored location to obtain site infiltration rates in the disturbed urban soils.

The surface infiltration rates are less than 1 in/hr for rains about 2 hrs in duration and longer, but can be quite large for short duration (small) events.

Additional site measurements and deep soil profiles have indicated that infiltration rates are quite low for most of the area. Therefore, 0.2 in/hr was used during these evaluations for critical long-duration rains.

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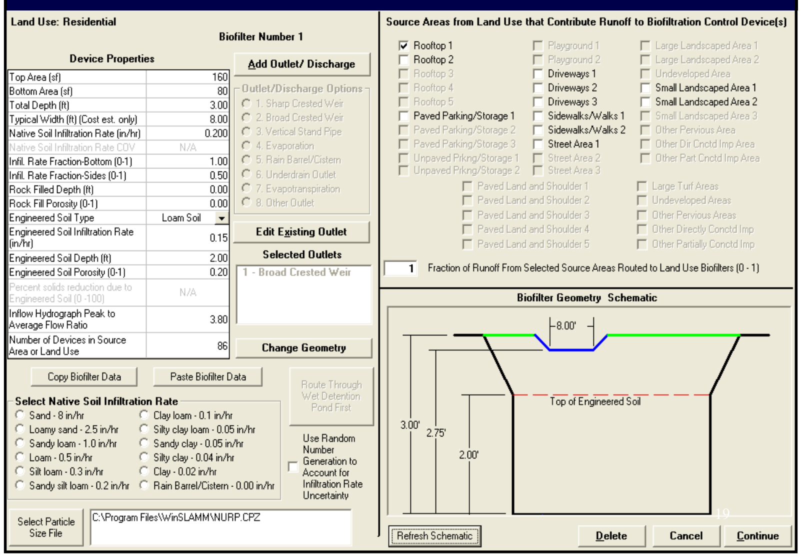
Basic Rain Garden Input Screen in WinSLAMM



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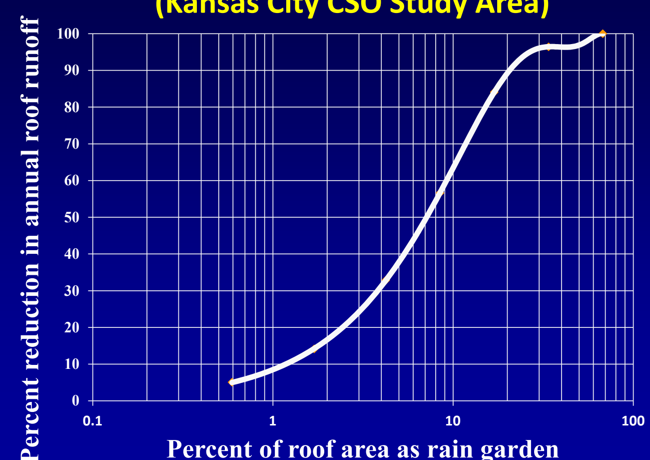
Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Gardens (Kansas City CSO Study Area)



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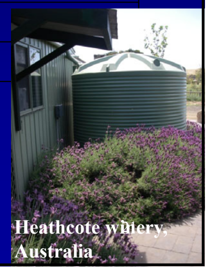
Household water use (gallons/day/house) from rain barrels or water tanks for outside irrigation to meet ET requirements in Kansas City:

January	42	July	357
February	172	August	408
March	55	September	140
April	104	October	0
May	78	November	0
June	177	December	0


Warrabungles National Park, Australia


Siding Springs Observatory, Australia


Heathcote winery, Australia

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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

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Roof drain direct connections and disconnections

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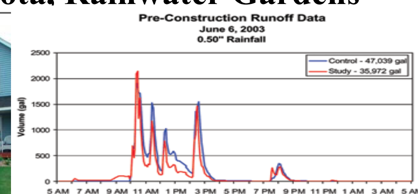
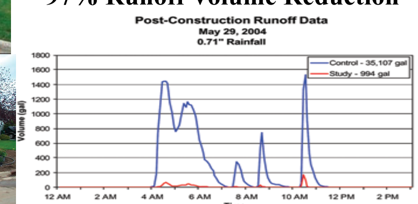
Burnsville, Minnesota, Rainwater Gardens



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

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Rain Garden Designed for Complete Infiltration of Roof Runoff

Green Roofing

Extensive Green Roof
- Lighter
- ≤6” media depth
- Planted with sedums or native plant species
- Saturated weights from 12-50lbs/sq.ft.

Intensive Green Roof
- Heavier
- ≥12” media depth
- Wider variety of plants which need more care and irrigation
- Saturated weights from 80-100lbs/sq.ft.

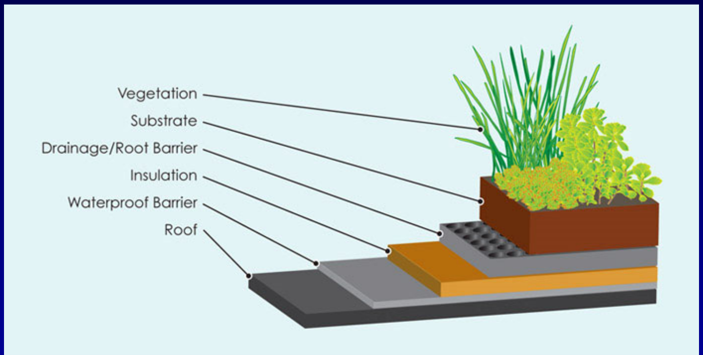
Benefits of Green Roofing

- Reduce Heat Island Effect
- Reduce Air Pollution and Greenhouse Gas Emission
- Improved human health and comfort
- Enhanced Stormwater Management and Water Quality
- Improved Quality of Life

Information courtesy of the Environmental Protect Agency – http://www.epa.gov/heatisland/mitigation/greenroofs.htm

http://www.coolflatroof.com/pics/green-roof-blocks.jpg

Green Roof Design



Cross-section of a typical green roof illustrating the key components

http://www.greensulate.com/green_roofs_intensive.php

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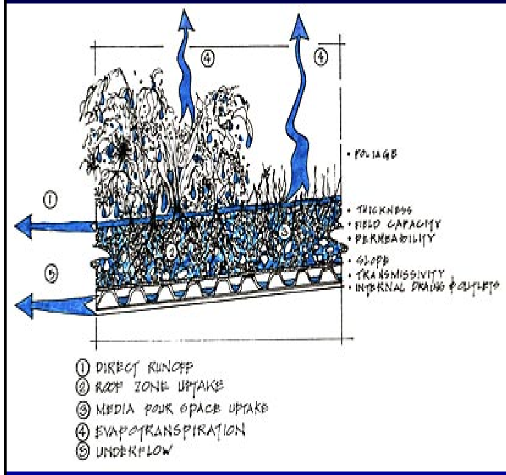
Function of a Green Roof



- The storage of water in the substrate
- Absorbing water in the root zone
- Capturing and holding precipitation in the plant foliage where it is returned to the atmosphere through transpiration and evaporation
- Slowing the velocity of direct runoff as it infiltrates through layers of vegetated cover

http://www.lid-stormwater.net/greenroofs_benefits.htm

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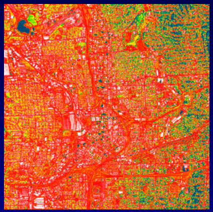
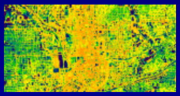
Urban Heat Island Effect – Atlanta, GA



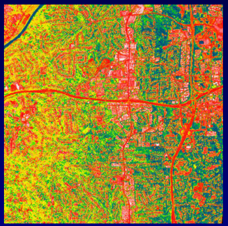
Urban Temp. - Day



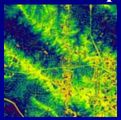
Urban Temp. - Night

Can a green roof make an urban area look like a suburban area?

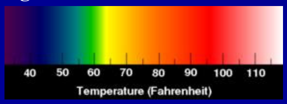
→



Suburban Temp. - Day



Suburban Temp. - Night



Images Courtesy of NASA

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Evapotranspiration (ET) is the major rain abstraction mechanism available for green roofs, besides some detention storage and evaporation.

Plant	Crop Coefficient Factor (Kc)	Root Depth (ft)
Cool Season Grass (turfgrass)	0.80	1
Common Trees	0.70	3
Annuals	0.65	1
Common Shrubs	0.50	2
Warm Season Grass	0.55	1
Prairie Plants (deep rooted)	0.50	6

Central Alabama	Average daily ET_o reference conditions (inches/day) (irrigated alfalfa)
January	0.035
February	0.048
March	0.072
April	0.102
May	0.156
June	0.192
July	0.186
August	0.164
September	0.141
October	0.096
November	0.055
December	0.036

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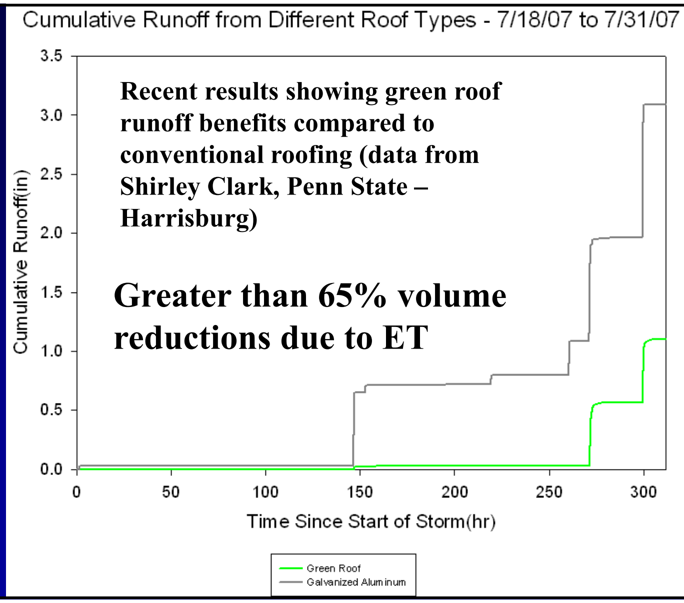

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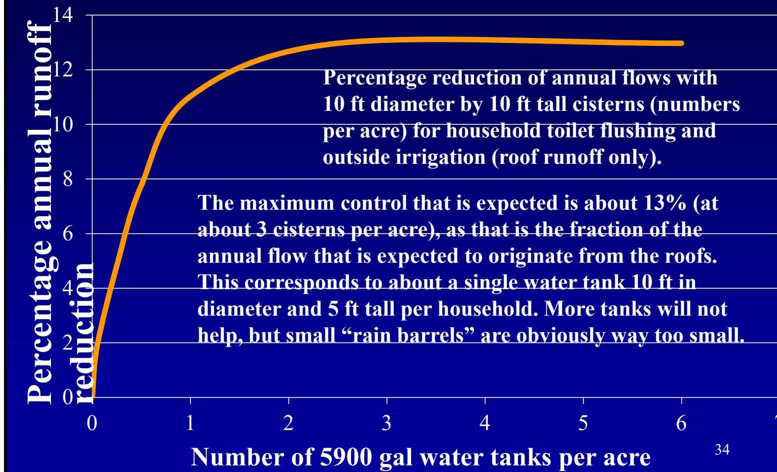
Number of water tanks and annual flow volume reductions for Kansas City test area



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Infiltration/Biofiltration

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

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- 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.

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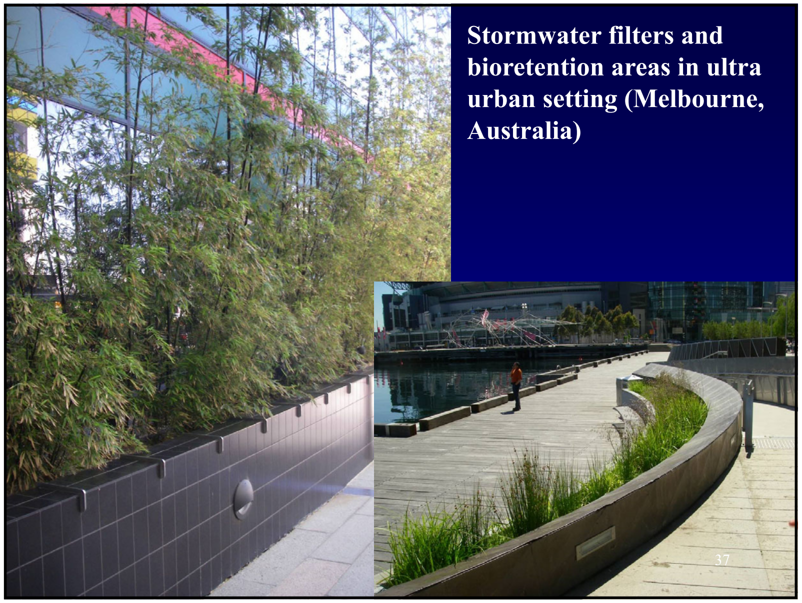
Stormwater filters and bioretention areas in ultra urban setting (Melbourne, Australia)
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Street-side tree biofilters in downtown area (Melbourne, Australia)
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Small depressions graded near parking lots or buildings for infiltration (older method, using regular turf grass) (MD and WI).
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Portland, Oregon, bioretention areas to capture and treat parking lot runoff.
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Parking lot medians easily modified for bioretention (OR and MD).
Larry Coffman
41
Larry Coffman

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

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Neenah Foundry Employee Parking Lot Grass Filter/Biofilter, Neenah, Wisconsin
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Bioretention and biofiltration areas having moderate capacity
Surface overflow
Portland, Oregon

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Many examples given in the "San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook"
http://www.flowstobay.org/ms_sustainable_streets.php
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Porous paver blocks have been used in many locations to reduce runoff to combined sewer systems, thereby reducing overflow frequency and volumes (Sweden, Germany, and WI).
Not recommended in areas of heavy automobile use due to groundwater contamination (provide little capture of critical pollutants, plus most manufactures recommend use of salt applications instead of sand for ice control).
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Wolfgang Geiger's Porous Paver Test Rig, Essen, Germany
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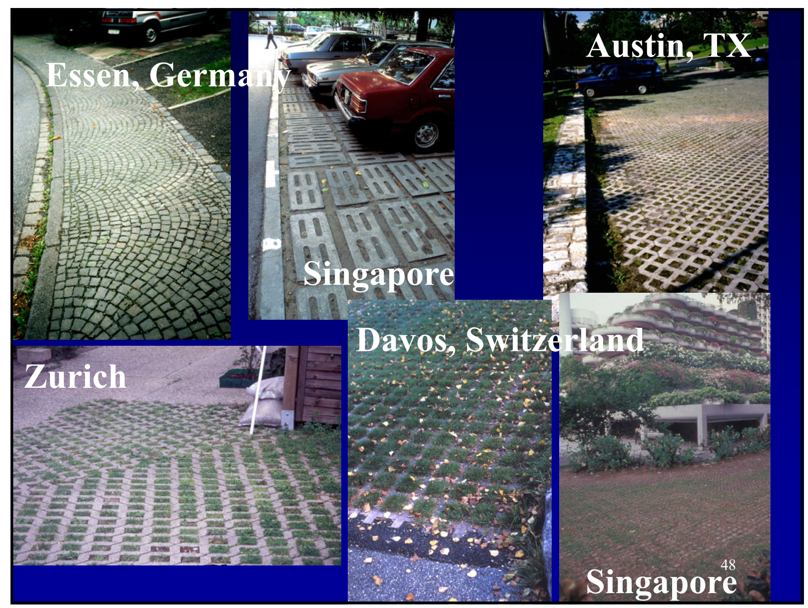
Essen, Germany
Singapore
Austin, TX
Zurich
Davos, Switzerland
Singapore
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Temporary parking or access roads supported by turf meshes, or paver blocks, and advanced porous paver systems designed for large capacity.

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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)

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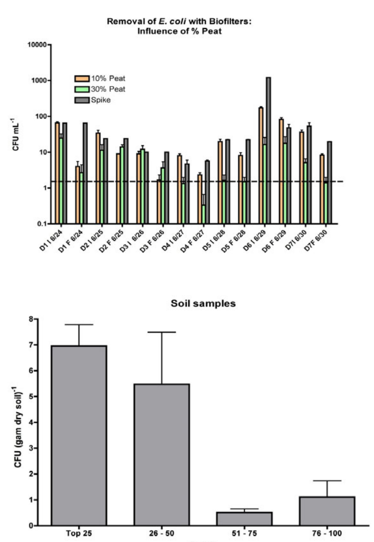
Biofilters: Peat



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

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Preliminary data, Penn State - Harrisburg

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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)

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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).

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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

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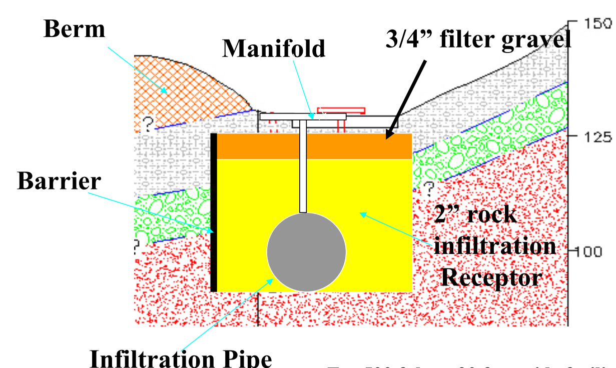
Large-Scale Infiltration Bench for Verification Testing in Washington

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 for Large-Scale Infiltration Testing

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Discharge Flow Dissipater during Large-Scale Infiltration Test

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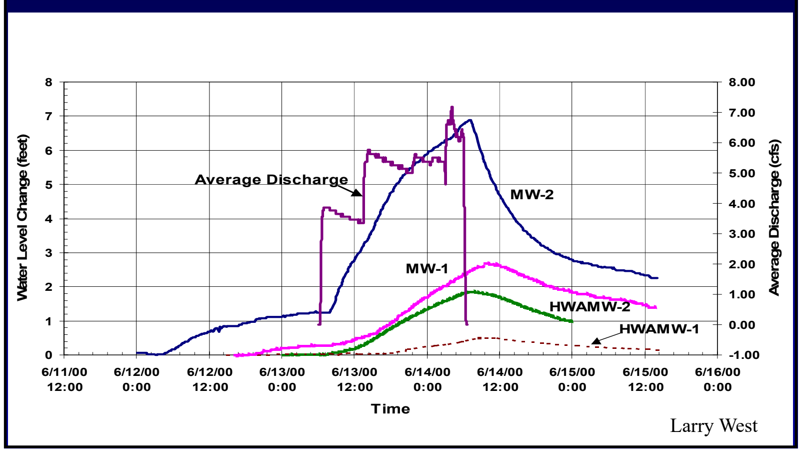
Full-scale 24-hr Infiltration Test
Ground Water Levels and Average Flow Discharge



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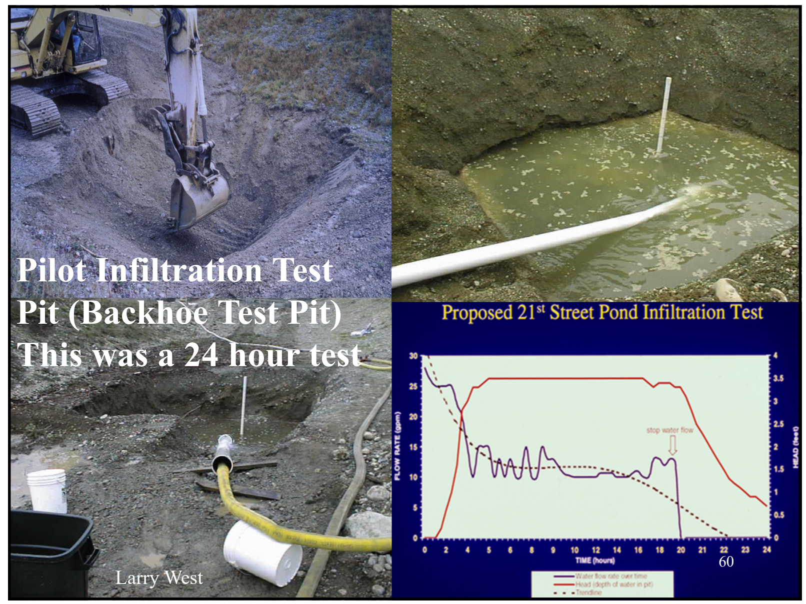

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Number of Pits and Borings Needed

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.

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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
- Groundwater mounding analysis - $2,000 to $5,000
- Conduct site characterization during geotech study

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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

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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

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New Wisconsin infiltration standards

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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.

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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

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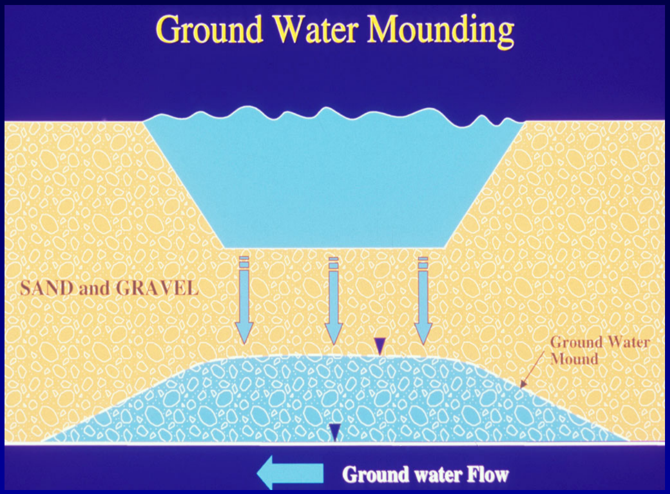

Larry West

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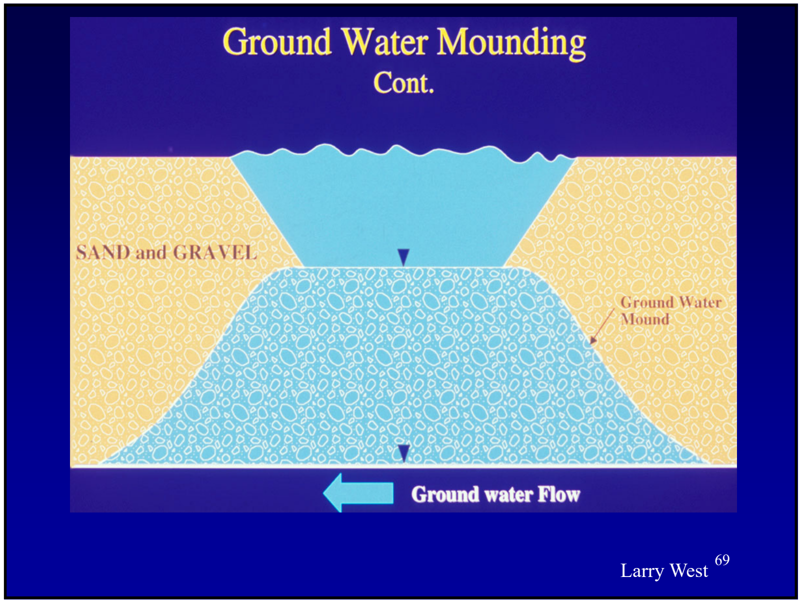

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Ground Water Mounding "Rules of Thumb"

- 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

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Grass Filtering of Stormwater Sediment

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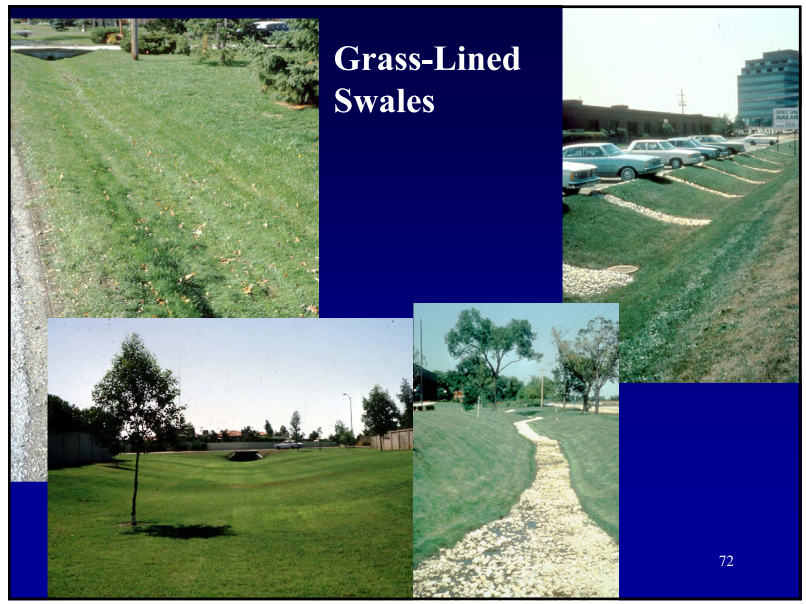
Grass-Lined Swales



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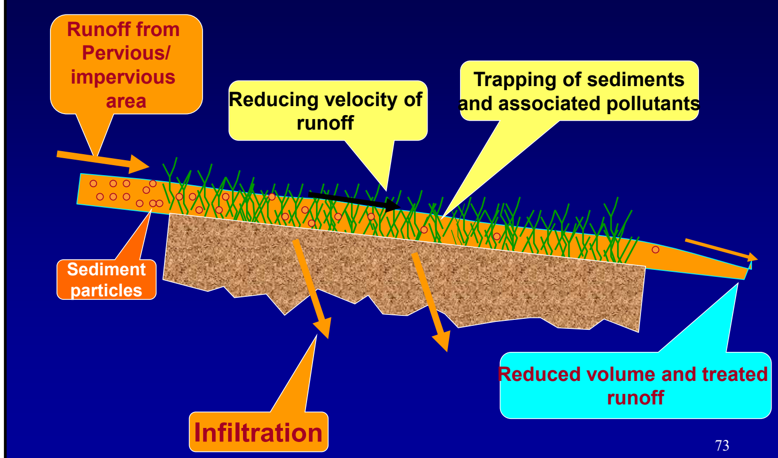
Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters



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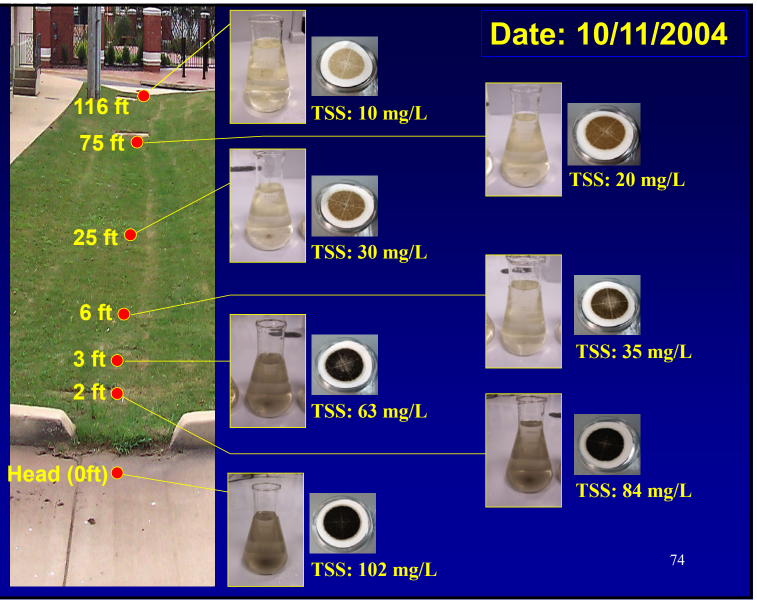

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Runoff Heavy Metals Retained and Released during Indoor Swale Experiments

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.

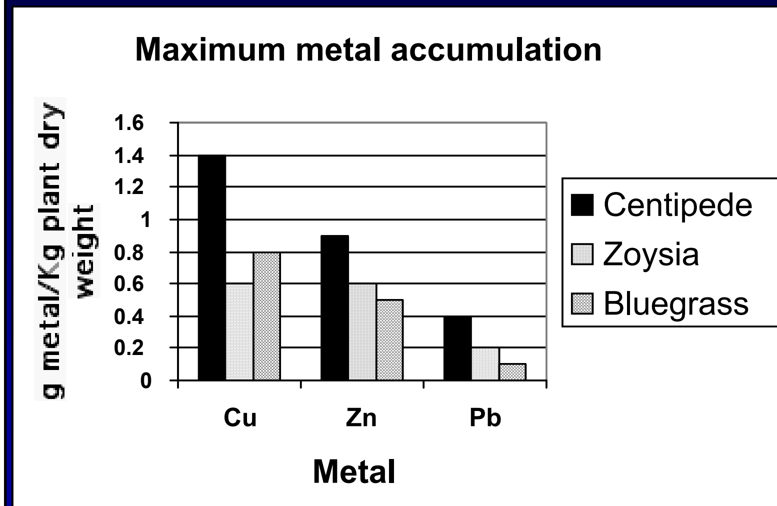
Major ions released, % (these are soil constituents)

	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%.

75

Phytoremediation



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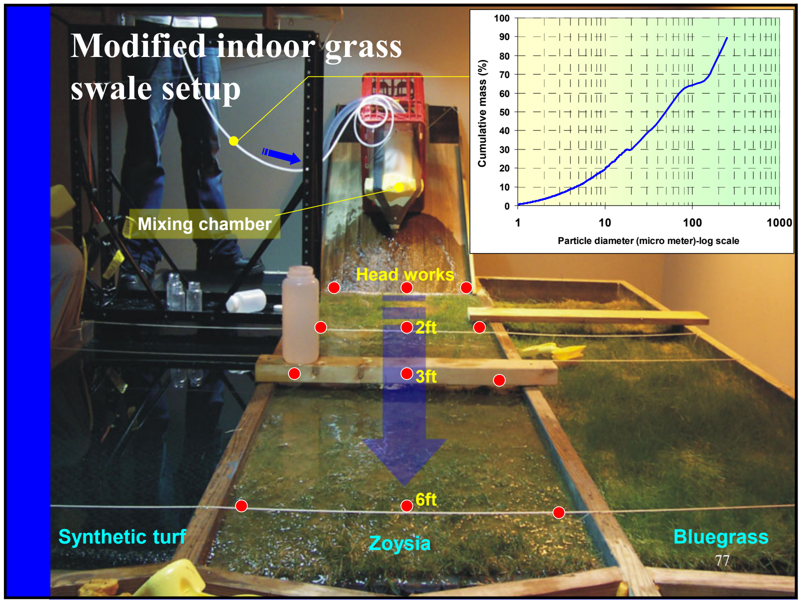
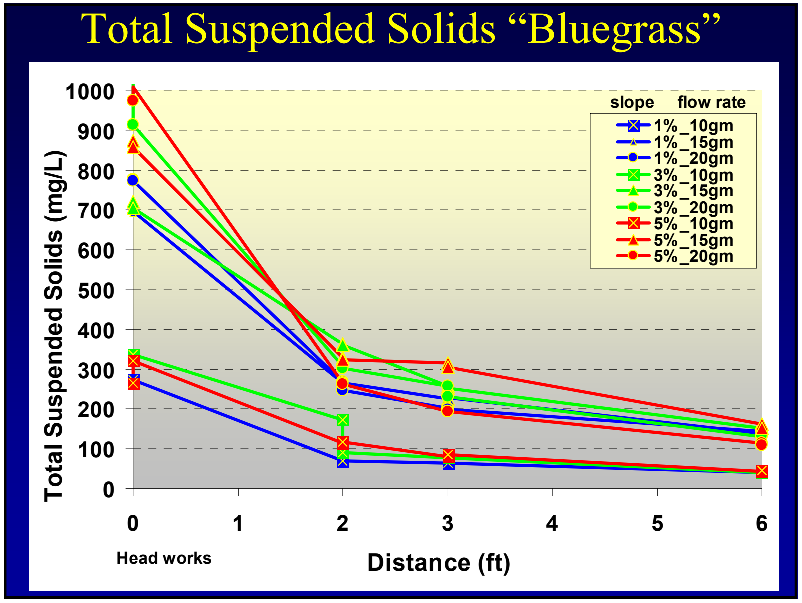
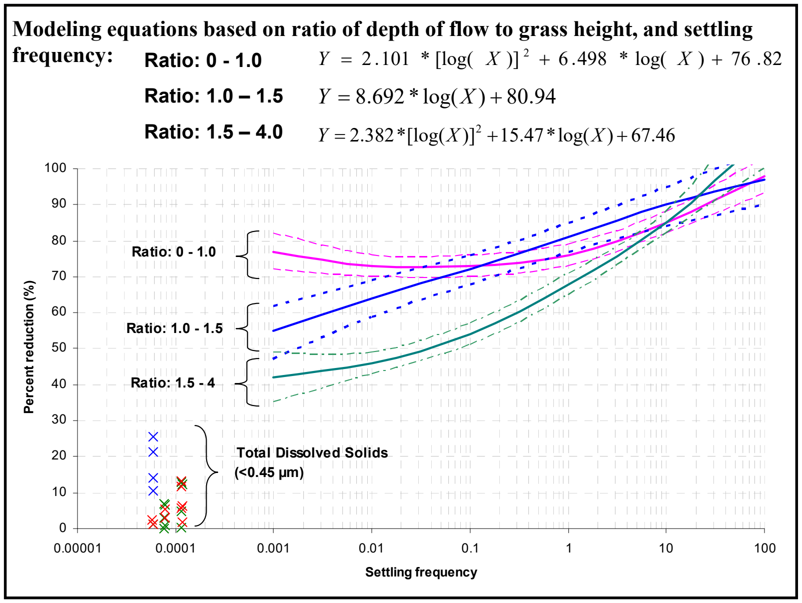

Modified indoor grass swale setup
Mixing chamber
Head works
2ft
3ft
6ft
Synthetic turf
Zoysia
Bluegrass
Cumulative mass (%)
Particle diameter (micro meter)-log scale
77

77


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)

78


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

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Grass-Lined Swales
80

80


Swales can be both interesting and fit site development objectives.
Tuscaloosa, AL
Street Edge Alternative (SEA St)
Seattle, WA
81

81


Swale Problems
Blocked with Fill
Shallow Groundwater
Erosive Channel
Under -Sized
82

82


Conventional curbs with inlets directed to site swales
WI
MS
83

83


Treatment of Flows in Excess of Infiltration Capacity
• Wet detention ponds, stormwater filters, or correctly-sized critical source area controls needed to treat runoff that cannot be infiltrated.
84

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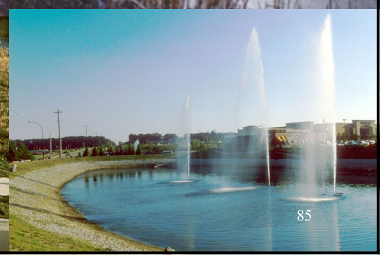
Wet Detention Ponds

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%





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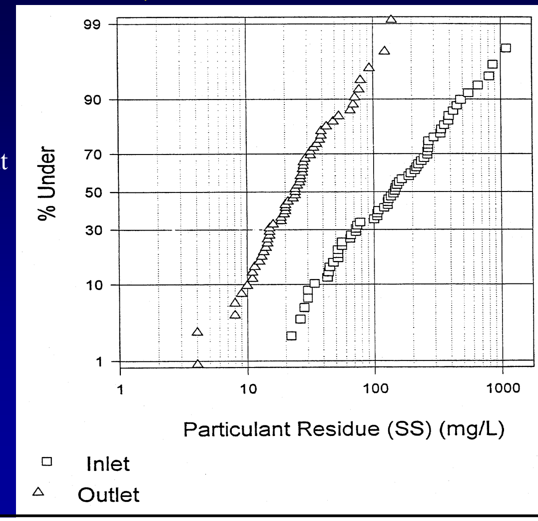
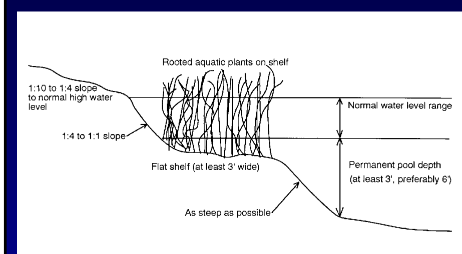
Suspended Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)

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



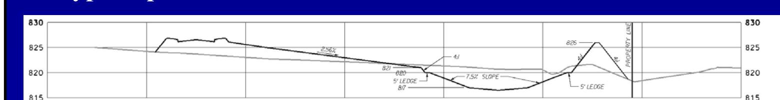
Wet detention ponds

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:



Percolation areas or ponds can be designed for larger rains due to storage capacity, or small drainage areas.

Water table percolation pond in Berlin

88

Treatment of Runoff from Critical Source Areas

- Flow diversion
- Treatment trains having combinations of effective unit processes targeted to pollutants of interest
- Pollution prevention through the use of non-contaminating exposed materials

89

89

Critical Source Area Control

Covering fueling area

Berm around storage tanks

90

90

correctly-sized critical source area controls needed to treat runoff originating from heavily contaminated areas

Austin sand filter

MCTT

91

91

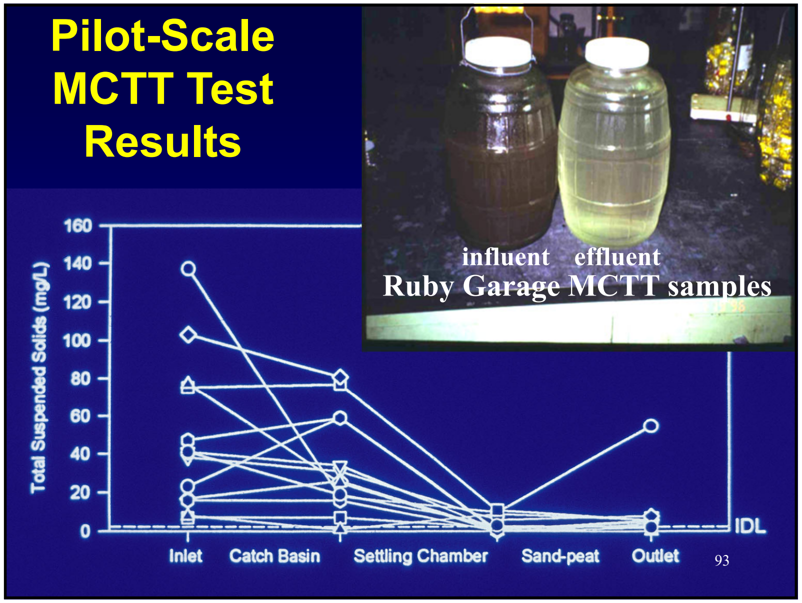
Multi-Chambered Treatment Train (MCTT) for stormwater control at large critical source areas

Milwaukee, WI,
Ruby Garage
Maintenance Yard
MCTT Installation

92

92

Pilot-Scale MCTT Test Results



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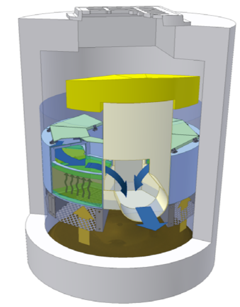
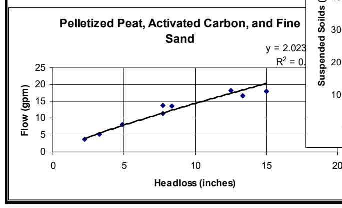
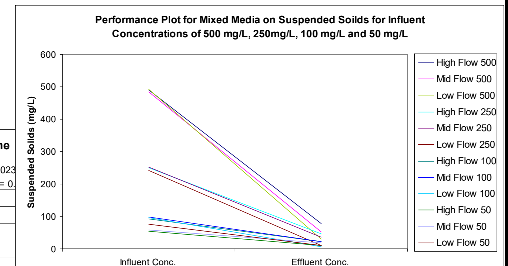
Upflow Filter™

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.





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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.

95

95

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

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Examples Utilizing these Concepts

- Retrofitted bioretention and wet ponds at big box commercial development in VT
- Beneficial use of stormwater at university in AL
- Multi-faceted conservation design at residential development in WI
- Multi-faceted conservation design at industrial site in AL
- Large rain garden at transportation corridor in WI
- Green infrastructure retrofitted in combined sewer area in MO
- Groundwater effects with dry wells in NJ

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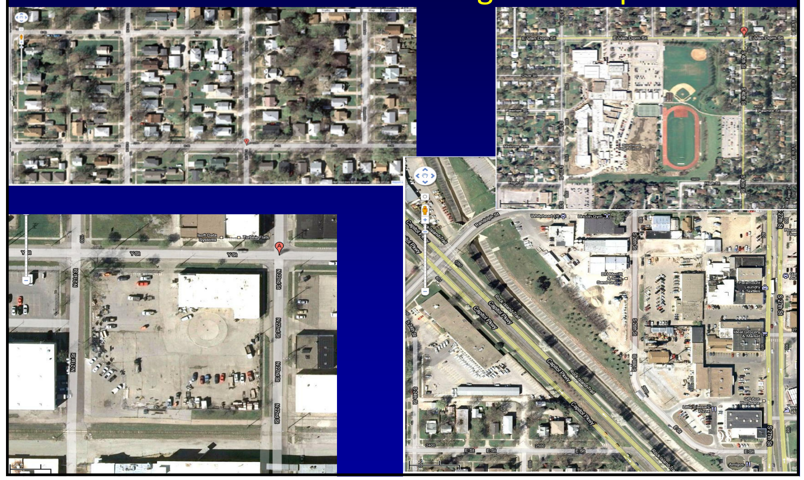
Lincoln, Nebraska

Retrofit Stormwater Management Options



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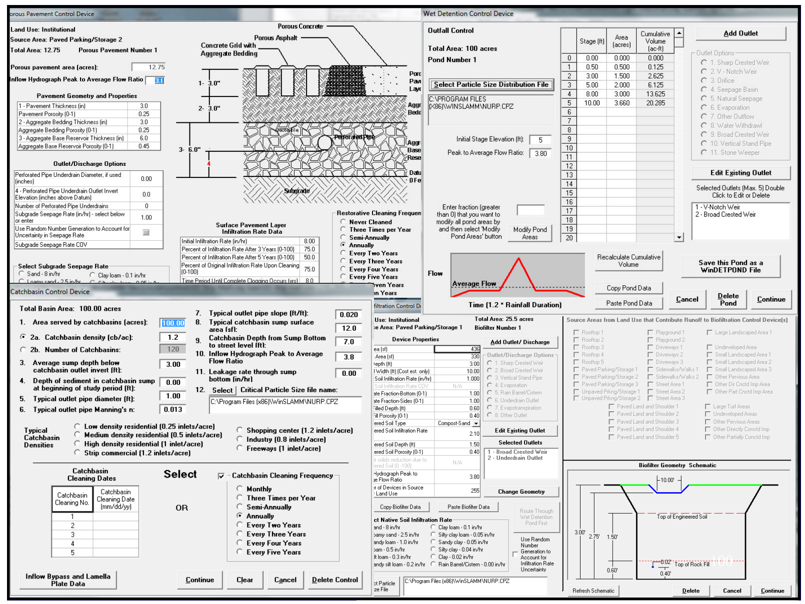
Stormwater Controls Examined

- **Roof runoff controls: rain gardens, disconnections, rain barrels and larger water tanks**
- **Pavement controls: disconnections, biofiltration, and porous pavement**
- **Street side drainage controls: grass swales and curb-cut biofilters**
- **Public works practices: street cleaning and catchbasin cleaning**
- **Outfall controls: wet detention ponds**

And combinations of the above

99

99



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Control Program for Commercial Strip Mall Land Use	Volume Reduction (% reduction compared to base conditions for clay loam conditions in the biofilters)	Volume Reduction (% reduction compared to base conditions for sandy loam conditions in the biofilters)	Total Annual Costs ($/100 acres/yr)
Porous pavement (in half of the parking areas)	25%	25%	$180,400
Curb-cut biofilters (along 80% of the curbs)	29	67	$166,500
Biofilters in parking areas (10 percent of the source area)	29	47	$314,000
Small wet pond plus biofilters in parking areas (10 percent of the source area)	29	47	$341,800
Biofilters in parking areas (25 percent of the source area)	40	not analyzed for sandy loam conditions	$785,000
Small wet pond plus biofilters in parking areas (10 percent of the source area) and curb-cut biofilters (along 40% of the curbs)	43	80	$424,600

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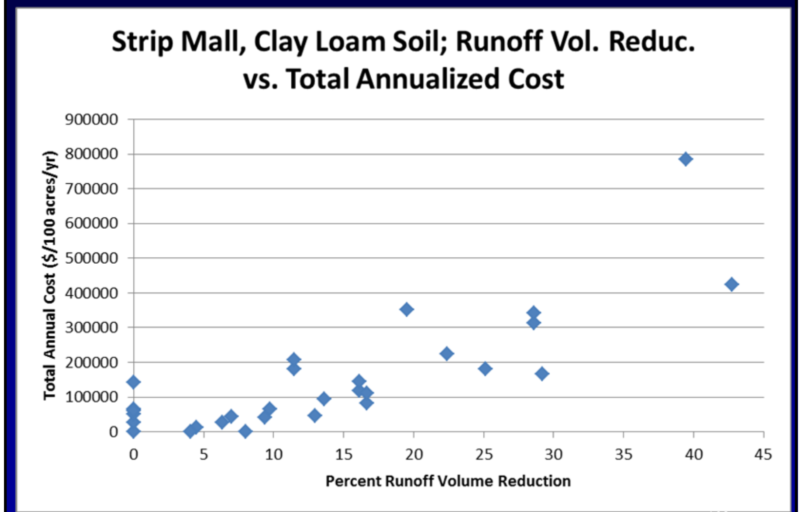

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The controls are listed with the first having the lowest level of maximum control, but the highest unit cost-effectiveness; and the last control listed having the highest level of maximum control, but the lowest unit cost-effectiveness. Therefore, if low to moderate levels of control are suitable, the first control option may be best, but if maximum control levels are needed, then the last control option listed would be needed:

- Strip mall and shopping center areas:
  - Porous pavement (in half of the parking areas)
  - Curb-cut biofilters (along 80% of the curbs) for strip malls or biofilters in parking areas (10 percent of the source area) for shopping centers
  - Biofilters in parking areas (10 percent of the source area) and curb-cut biofilters (along 40% of the curbs)
- Light industrial areas:
  - Curb-cut biofilters (along 40% of the curbs)
  - Roofs and parking areas half disconnected
  - Roofs and parking areas all disconnected

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Conclusions

- There are many options available to reduce stormwater discharges to combined sewers.
- The selection needs to be based on site specific development, soil, and rainfall conditions.
- Moderate runoff volume reductions are possible in retro-fitted applications, but the use of the controls need be extensive (and expensive).
- Much less costly and more effective to apply these controls to new development.
- Even with new development, there will still be degradation unless retrofitted controls are also used to compensate.

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