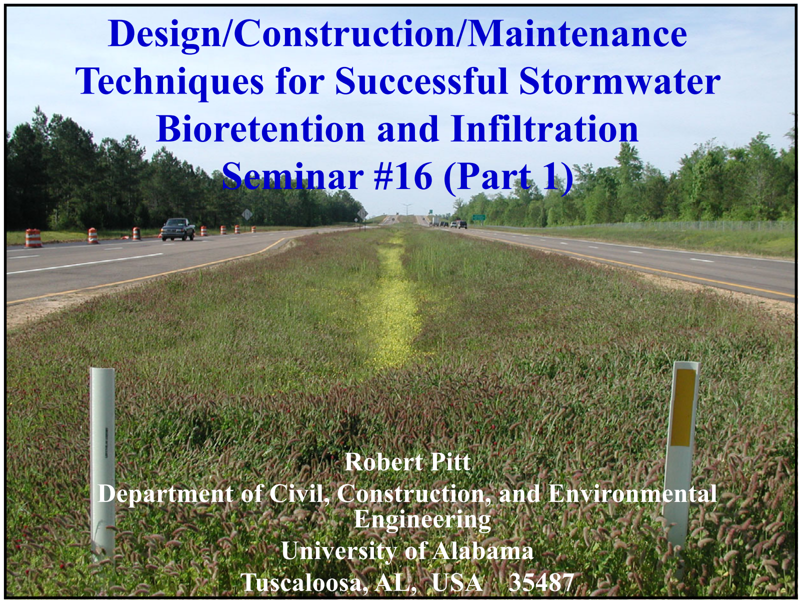
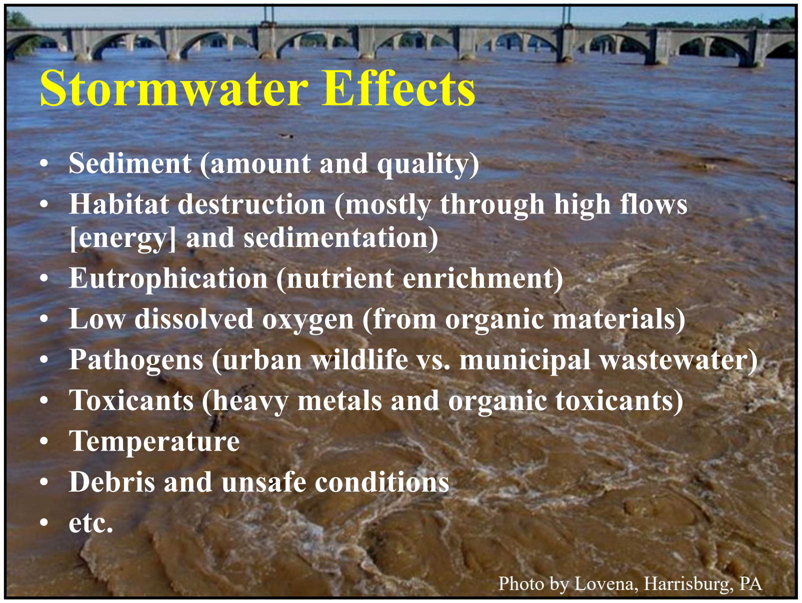


Design/Construction/Maintenance Techniques for Successful Stormwater Bioretention and Infiltration Seminar #16 (Part 1)

Robert Pitt
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

- Conservation design approach
- Site hydrology and application of controls
- Examples of bioretention and infiltration controls
- Site evaluations
- Soil compaction and soil restoration



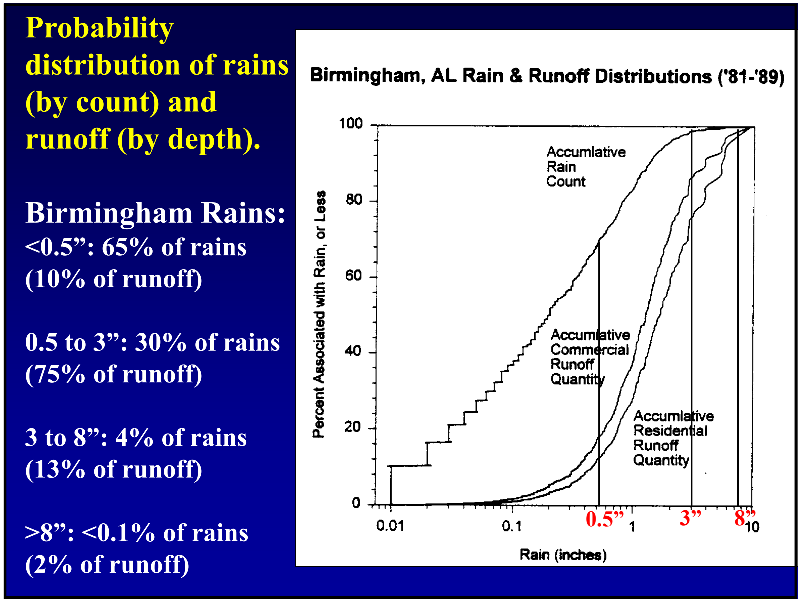
Stormwater Effects

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

Photo by Lovena, Harrisburg, PA

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 but prevent groundwater contamination
- Treat water at critical source areas and encourage pollution prevention (no zinc coatings and copper, for example)
- Treat runoff that cannot be infiltrated at site



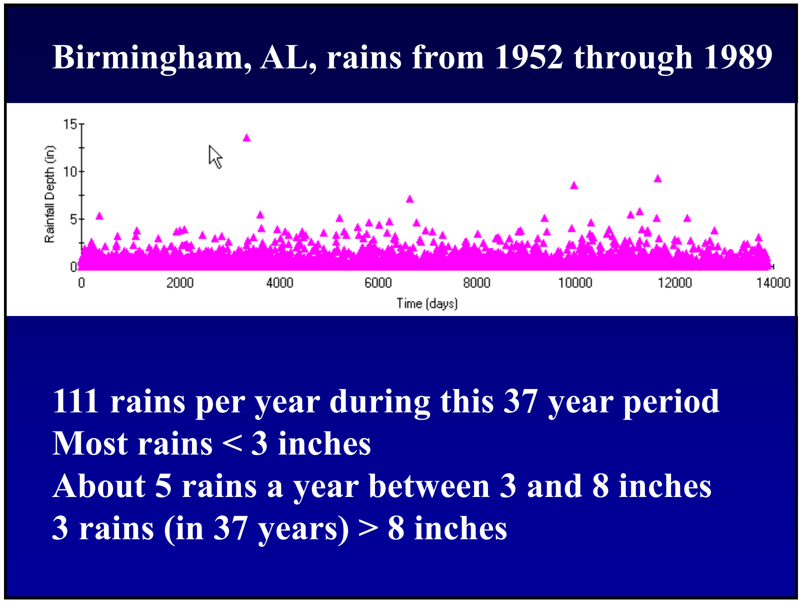
Probability distribution of rains (by count) and runoff (by depth).

Birmingham Rains:
<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% of rains (2% of runoff)



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

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 for local reuse

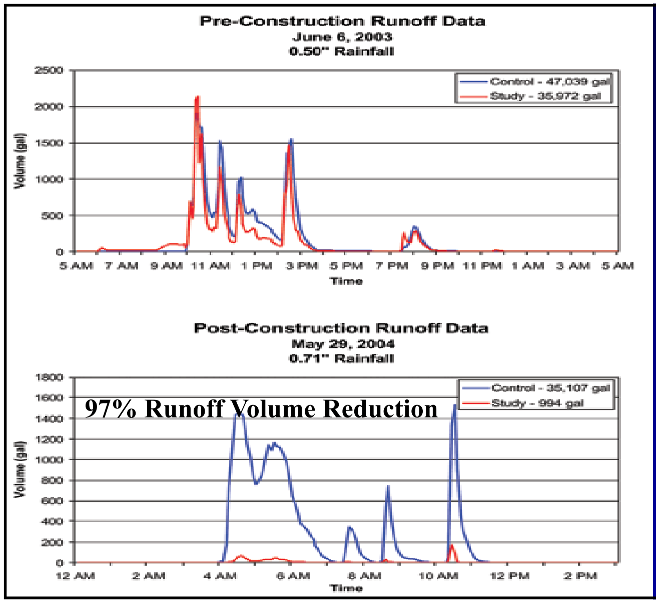
Suitable Controls for Treatment of Runoff from Intermediate-Sized Rains (0.5 to 3 in.)

- Initial portions of these rains will be captured/infiltrated by on-site controls or grass swales, but seldom can infiltrate all of these rains
- Remaining portion of runoff should be treated to remove particulate-bound pollutants

Roof drain disconnections

Not this!

Rain Garden Designed for Complete Infiltration of Roof Runoff

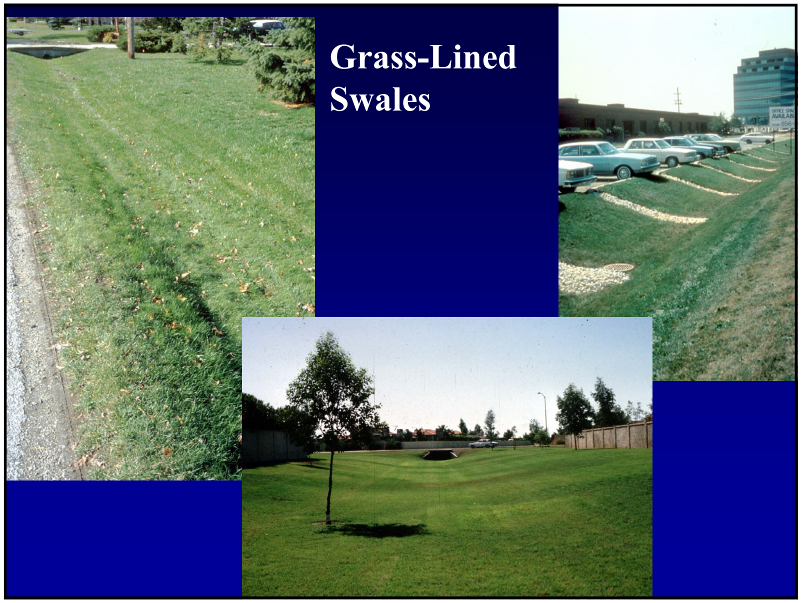


97% Runoff Volume Reduction

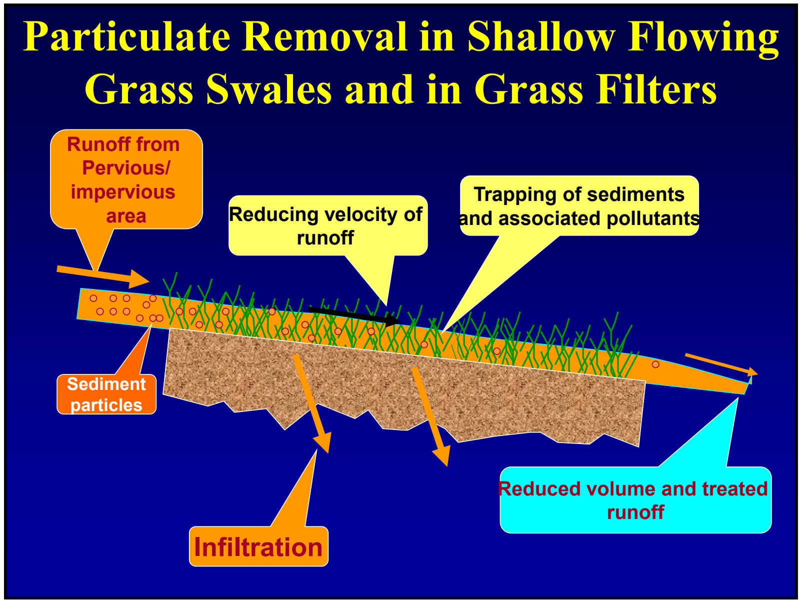
Land and Water, Sept/Oct. 2004

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.)
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%



Grass-Lined Swales



Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters

Runoff from Pervious/ impervious area

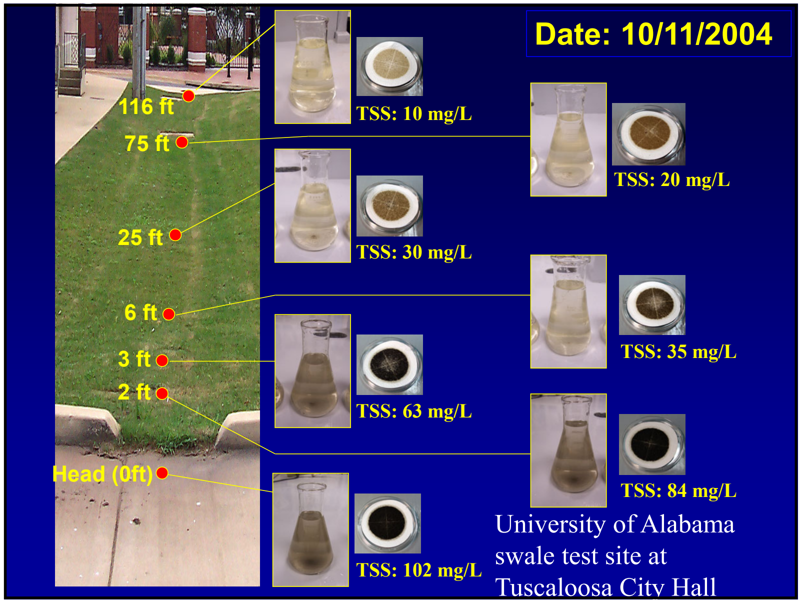
Reducing velocity of runoff

Trapping of sediments and associated pollutants

Sediment particles

Reduced volume and treated runoff

Infiltration



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

Conventional curbs with inlets directed to site swales

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

Also incorporate grass filtering before infiltration

Porous paver blocks have been used in many locations to reduce runoff to combined systems, 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 heavy salt applications instead of sand for ice control).

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

Bioretention and biofiltration areas having moderate capacity

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

Stormwater Infiltration Controls in Urban Areas

- Bioretention areas
- Rain gardens
- Porous pavement
- Grass swales
- Infiltration Basins
- Infiltration Trenches
- Subsurface Dispersal

Seattle, WA

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

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)

Site Evaluation Tests

- Needed to characterize and quantify:
  - Site soil conditions (infiltration capacity, soil texture, cation exchange capacity, sodium adsorption capacity, etc.)
  - Groundwater conditions (depth and movement)

Measure Soil Characteristics to Predict Infiltration Problems (Before and After Construction)

- Infiltration Tests (bulk density)
- Evaluate soil texture with cores
- Estimate depth to groundwater
- Estimate potential for mounding

Subsurface Exploration Needed for Most Infiltration Systems

- **Backhoe Test Pits**
- **Test Borings**
- **Monitoring Wells**

Number of Pits and Borings Needed

Infiltration Device	***Tests Required***	***Minimum Number of Pits or Borings***	***Minimum Drill/Test Depth***
Bioretention	Pits or Borings; Mounding	1 test/50 linear feet of device with a Minimum of 2	5 Feet or Depth to Limiting Layer
Infiltration Basin	Pits or Borings; Mounding	2 Pits per Area; With 1 Pit or Boring for Every 10,000 sq. ft.	Pits to 10 Ft. or Borings to 20 Ft.

Site Characterization Costs

typical unit costs (2000 costs)

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

Backhoe Test Pits

- Essential for identifying stratification
- Safety (slopes, water table, etc.)
- Ideal for collecting samples for testing

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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

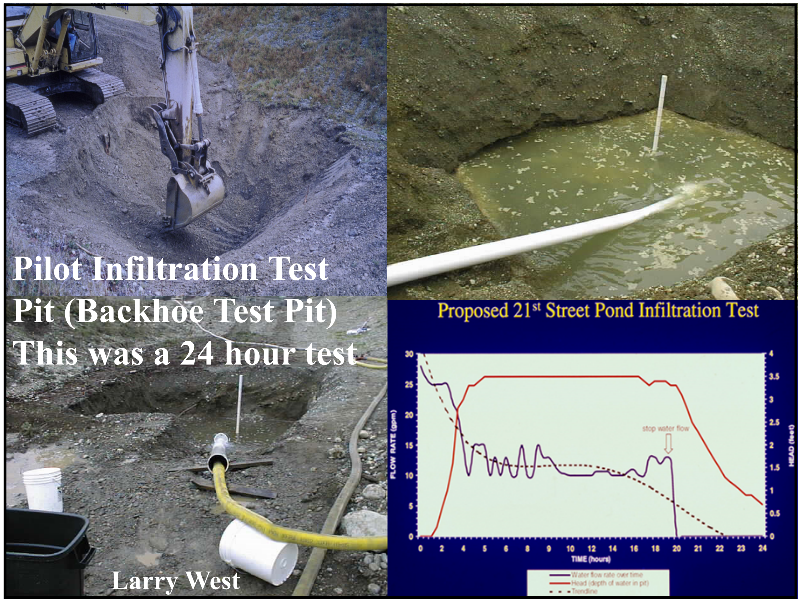
** Not recommended for treatment

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

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



Pilot Infiltration Test Pit (Backhoe Test Pit) This was a 24 hour test

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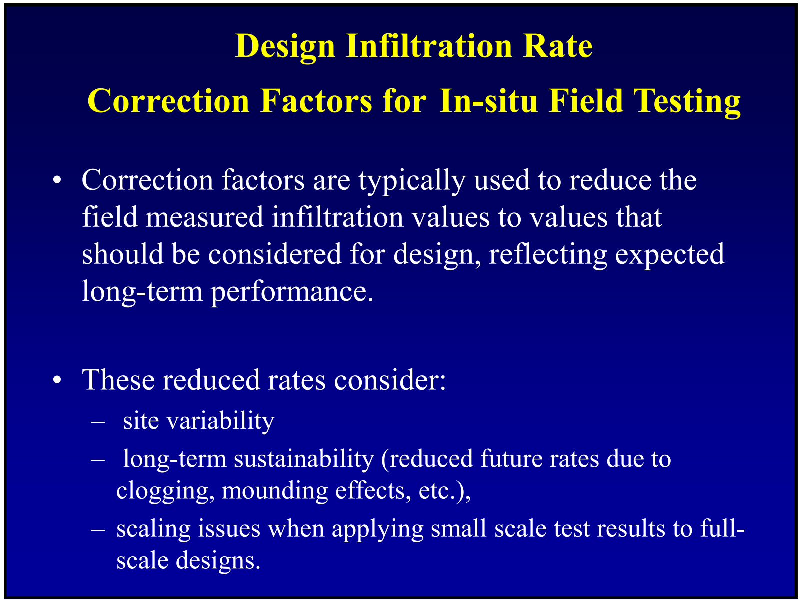
Proposed 21st Street Pond Infiltration Test

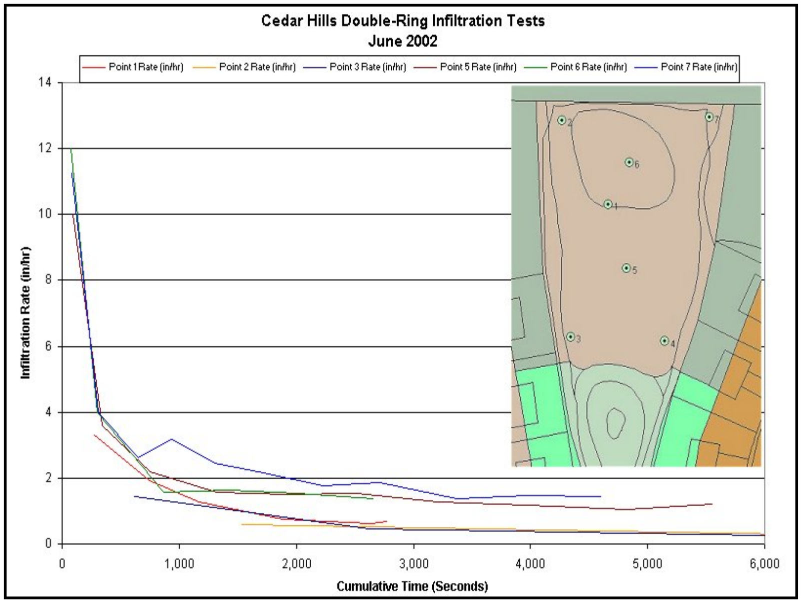


Design Infiltration Rate

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.



Cedar Hills Double-Ring Infiltration Tests
June 2002

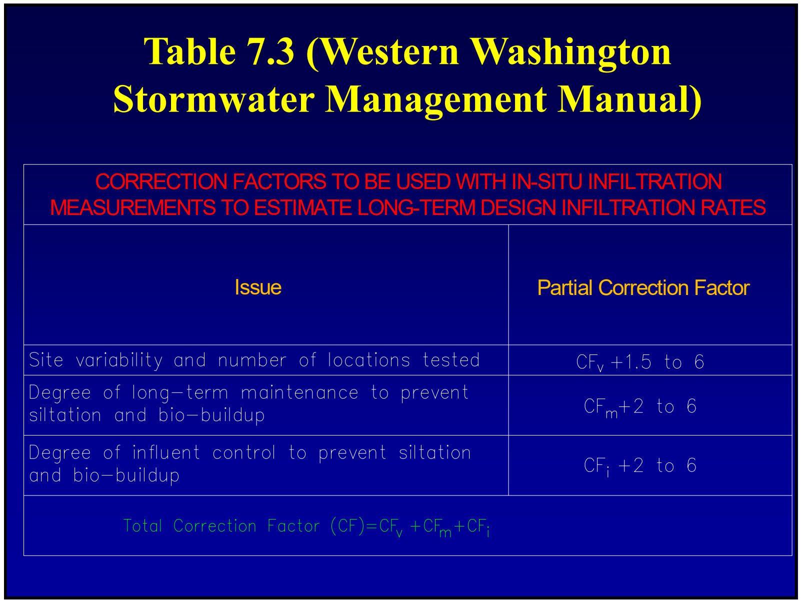


Table 7.3 (Western Washington Stormwater Management Manual)

CORRECTION FACTORS TO BE USED WITH IN-SITU INFILTRATION MEASUREMENTS TO ESTIMATE LONG-TERM DESIGN INFILTRATION RATES

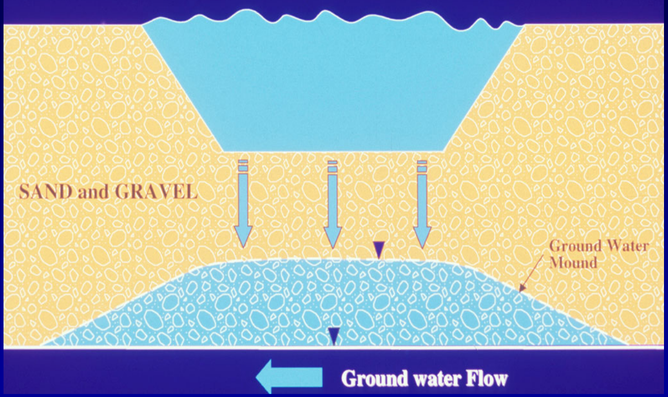
Issue	Partial Correction Factor
Site variability and number of locations tested	CF_v +1.5 to 6
Degree of long-term maintenance to prevent siltation and bio-buildup	CF_m+2 to 6
Degree of influent control to prevent siltation and bio-buildup	CF_i +2 to 6
Total Correction Factor (CF)=CF_v +CF_m+CF_i	

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	Buried Gallery	6
Pre-Treatment	2 - 6	Excellent 2 Ponds	2
Total Correction Factor	5.5 - 18		12

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

Ground Water Mounding



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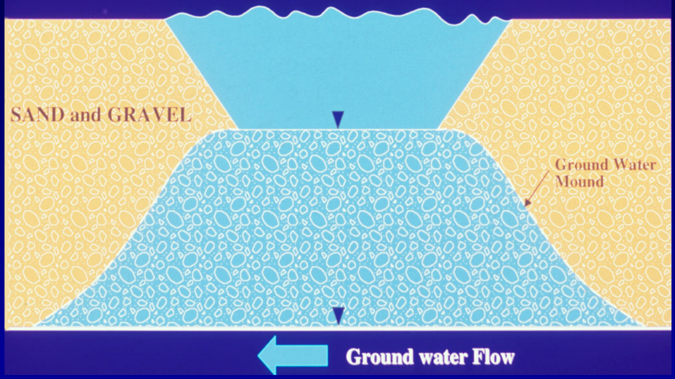
Ground Water Mounding

Cont.



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Ground Water Mounding “Rules of Thumb”

- Mounding reduces infiltration rate to saturated permeability of soil, often 2 to 3 orders of magnitude lower than infiltration rate.
- Long narrow system (i.e. trenches) don't mound as much as broad, square/round systems

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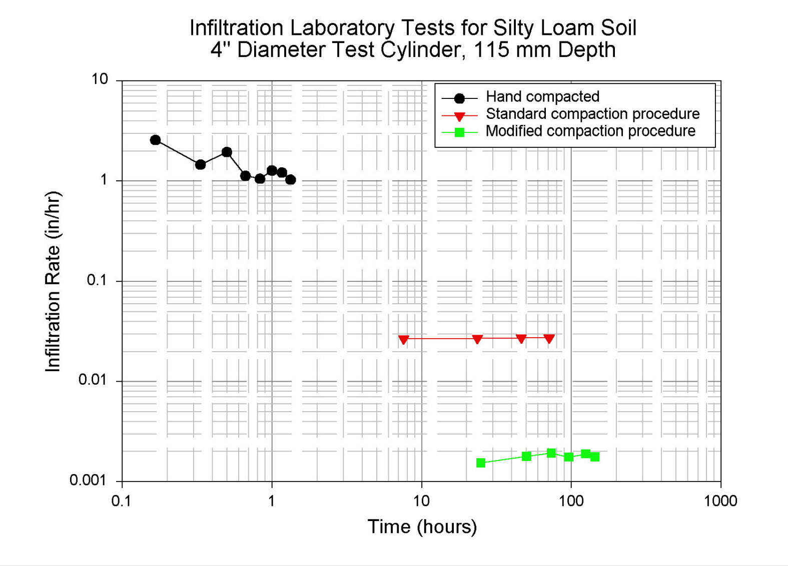
Soil Compaction and Recovery of Infiltration Rates

- 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



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	1.595	35
	Standard	1.653	9
	Modified	1.992	1.5
Silt Loam	Hand	1.504	1.3
	Standard	1.593	0.027
	Modified	1.690	0.0017
Clay Loam	Hand	1.502	0.29
	Standard	1.703	0.015
	Modified	1.911	<0.001

Compaction, especially when a small amount of clay is present, causes a large loss in infiltration capacity.

Compaction Measurements

Soil Density Measurements

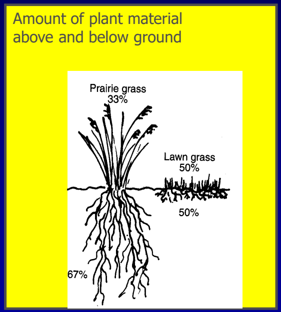
Types of Solutions to Infiltration Problems

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

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

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

Value of Using Native Plants



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

Infiltration Basin with Compacted Soils

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

Working Infiltration Basin (West Bend, WI)

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

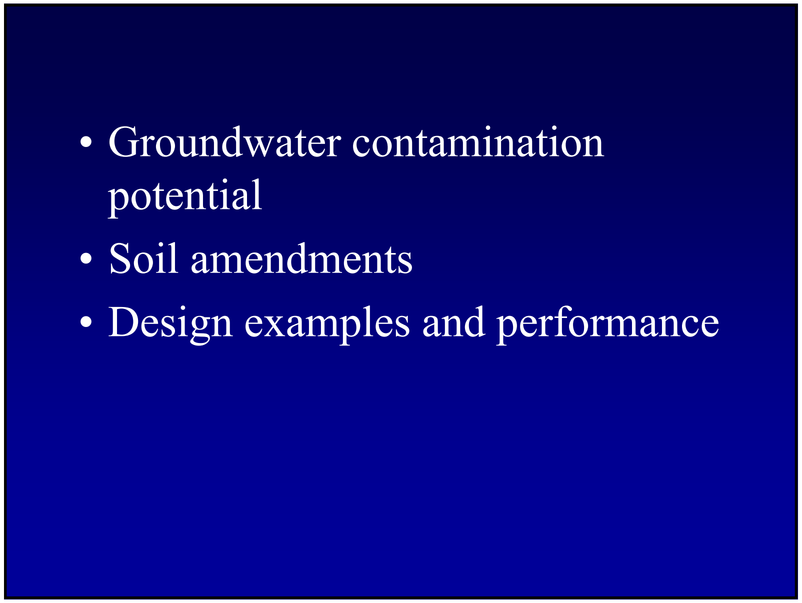
Conclusions

- Many bioretention and infiltration types of controls are available that can be used in a variety of applications.
- They must be designed to consider site soil and rainfall conditions.
- Intermediate-sized rains should be the focus of control programs, but these devices are generally limited to the lower range of these critical rains, unless large areas are dedicated to infiltration or have outstanding soils available.
- Infiltration controls work very well in conjunction with other types of complementary stormwater controls.

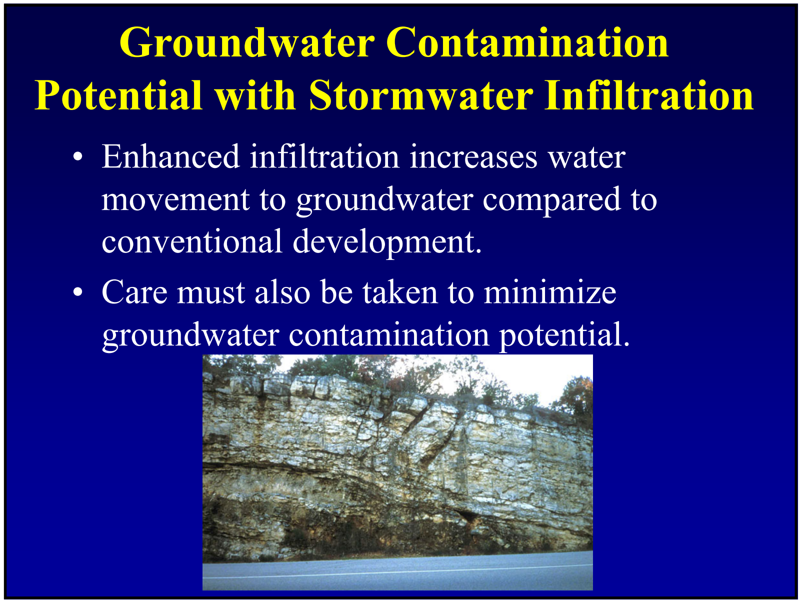
Design/Construction/Maintenance Techniques for Successful Stormwater Bioretention and Infiltration

Seminar #18 (Part 2)

Robert Pitt
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

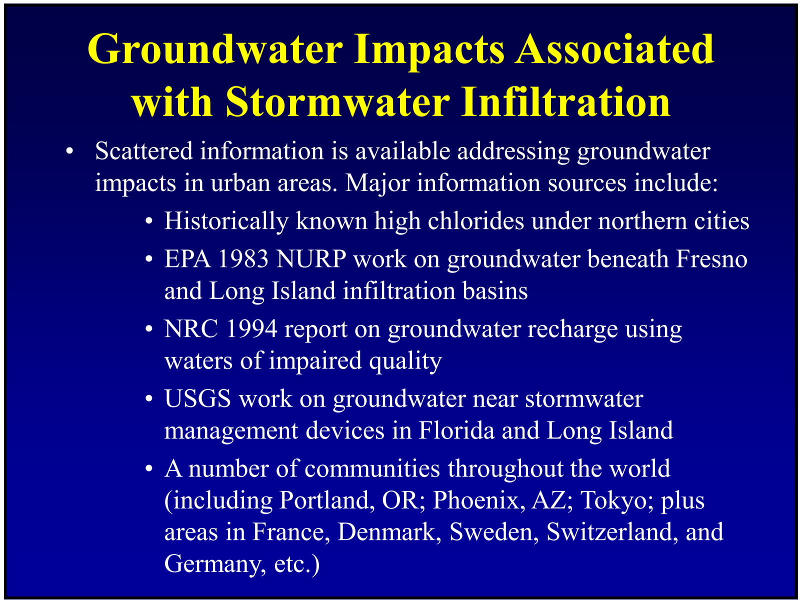


- Groundwater contamination potential
- Soil amendments
- Design examples and performance



Groundwater Contamination Potential with Stormwater Infiltration

- Enhanced infiltration increases water movement to groundwater compared to conventional development.
- Care must also be taken to minimize groundwater contamination potential.

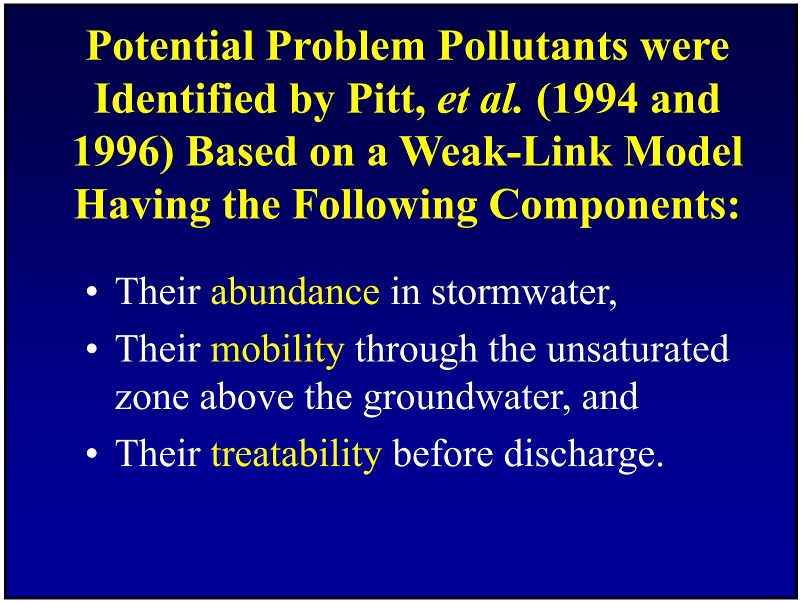


Groundwater Impacts Associated with Stormwater Infiltration

- Scattered information is available addressing groundwater impacts in urban areas. Major information sources include:
  - Historically known high chlorides under northern cities
  - EPA 1983 NURP work on groundwater beneath Fresno and Long Island infiltration basins
  - NRC 1994 report on groundwater recharge using waters of impaired quality
  - USGS work on groundwater near stormwater management devices in Florida and Long Island
  - A number of communities throughout the world (including Portland, OR; Phoenix, AZ; Tokyo; plus areas in France, Denmark, Sweden, Switzerland, and Germany, etc.)

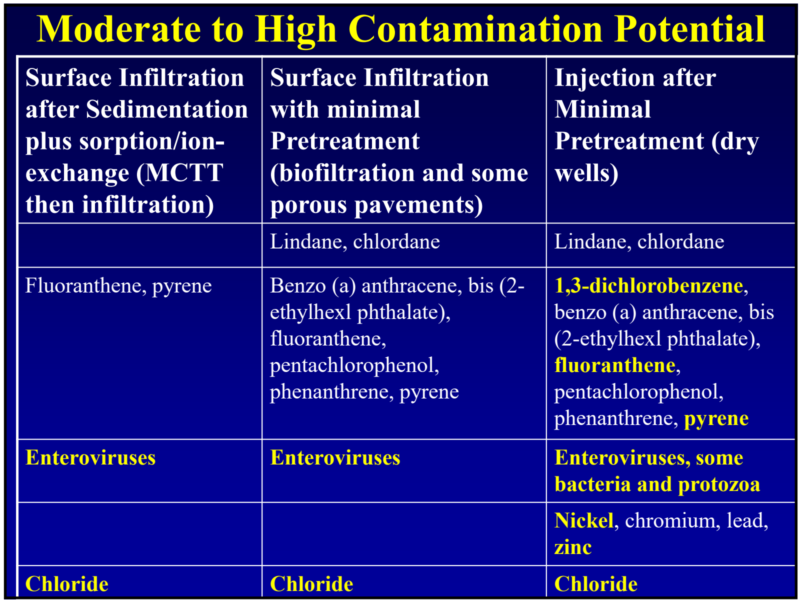
Minimal Pre-treatment before Infiltration Leads to Greater Groundwater Contamination Potential

(also, filter fabric liners are usually not recommended anymore as many have failed due to clogging from silts)



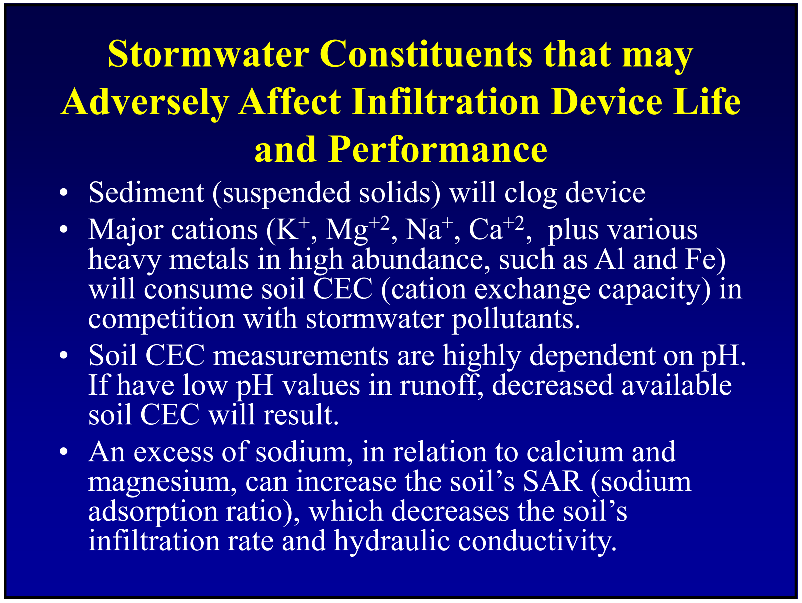
Potential Problem Pollutants were Identified by Pitt, *et al.* (1994 and 1996) Based on a Weak-Link Model Having the Following Components:

- Their abundance in stormwater,
- Their mobility through the unsaturated zone above the groundwater, and
- Their treatability before discharge.



Moderate to High Contamination Potential

Surface Infiltration after Sedimentation plus sorption/ion-exchange (MCTT then infiltration)	Surface Infiltration with minimal Pretreatment (biofiltration and some porous pavements)	Injection after Minimal Pretreatment (dry wells)
	Lindane, chlordane	Lindane, chlordane
Fluoranthene, pyrene	Benzo (a) anthracene, bis (2-ethylhexl phthalate), fluoranthene, pentachlorophenol, phenanthrene, pyrene	**1,3-dichlorobenzene**, benzo (a) anthracene, bis (2-ethylhexl phthalate), **fluoranthene**, pentachlorophenol, phenanthrene, **pyrene**
Enteroviruses	**Enteroviruses**	**Enteroviruses, some bacteria and protozoa**
		Nickel, chromium, lead, **zinc**
Chloride	**Chloride**	**Chloride**



Stormwater Constituents that may Adversely Affect Infiltration Device Life and Performance

- Sediment (suspended solids) will clog device
- Major cations (K^+, Mg^{+2}, Na^+, Ca^{+2}, plus various heavy metals in high abundance, such as Al and Fe) will consume soil CEC (cation exchange capacity) in competition with stormwater pollutants.
- Soil CEC measurements are highly dependent on pH. If have low pH values in runoff, decreased available soil CEC will result.
- An excess of sodium, in relation to calcium and magnesium, can increase the soil's SAR (sodium adsorption ratio), which decreases the soil's infiltration rate and hydraulic conductivity.

Enhanced Infiltration and Groundwater Protection with Soil Amendments

- Modifying soil in biofiltration and bioretention devices can improve their performance, while offering groundwater protection.

Many soil processes reduce the mobility of stormwater pollutants

- Ion exchange, sorption, precipitation, surface complex ion formation, chelation, volatilization, microbial processes, lattice penetration, etc.
- If soil is lacking in these properties, then soil amendments can be added to improve the soil characteristics.
- Cation exchange capacity (CEC) and sodium adsorption ratio (SAR) are two soil factors that can be directly measured and water characteristics compared. Other soil processes (especially in complex mixtures) need to be evaluated using controlled experiments.

Effects of Compost-Amendments on Runoff Properties

- Rob Harrison ,Univ. of Wash., and Bob Pitt, Univ. of Alabama examined the benefits of adding large amounts of compost to glacial till soils at the time of land development (4” of compost for 8” of soil)

Enhanced Infiltration with Amendments

	Average Infiltration Rate (in/h)
UW test plot 1 Alderwood soil alone	**0.5**
UW test plot 2 Alderwood soil with Ceder Grove compost (old site)	**3.0**
UW test plot 5 Alderwood soil alone	**0.3**
UW test plot 6 Alderwood soil with GroCo compost (old site)	**3.3**

Six to eleven times increased infiltration rates using compost-amended soils measured during long-term tests using large test plots and actual rains (these plots were 3 years old).

Changes in Mass Discharges for Plots having Amended Soil Compared to Unamended Soil

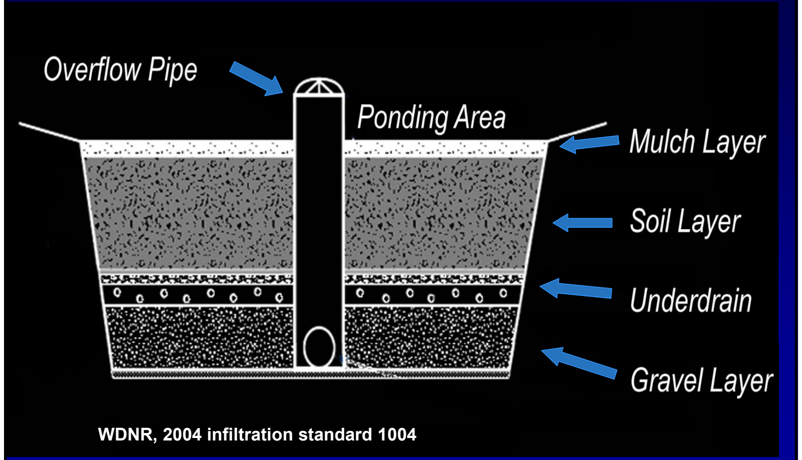
Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09	0.29 (due to ET)
Phosphate	0.62	3.0
Ammonia	0.56	4.4
Nitrate	0.28	1.5
Copper	0.33	1.2
Zinc	0.061	0.18

Increased mass discharges in subsurface water pollutants observed for many constituents (new plots).

Water Quality and Quantity Effects of Amending Urban Soils with Compost

- Surface runoff rates and volumes decreased by six to ten eleven after amending the soils with compost, compared to unamended sites.
- Unfortunately, the concentrations of many pollutants increased in surface runoff from amended soil plots, especially nutrients which were leached from the fresh compost.
- However, the several year old test sites had less, but still elevated concentrations, compared to unamended soil-only test plots.

Typical Biofiltration Facility

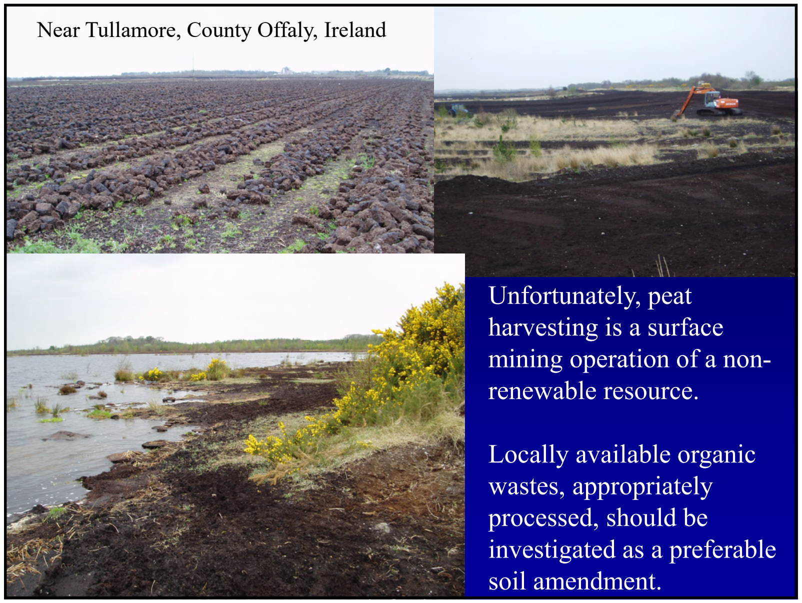


WDNR, 2004 infiltration standard 1004

Engineered Soil Mixture – WI Technical Standard 1004

- Mineral Sand (40%) – USDA Coarse Sand or ASTM C33 (Fine Aggregate Concrete Sand)
- Compost (30%) – Meet WDNR Spec. S100
- Topsoil (30%) – Sandy loam or loamy sand

Unfortunately, most compost specifications are not very clear and also allow many components that are not desirable (such as not fully stabilized materials and even some animal wastes). Need a material that will not be a pollutant source, while adding desirable soil properties. Fully composted garden wastes and some stabilized agricultural products are usually best (about 15 meq/100g). Peat is one of the best soil amendments, as it has a much greater CEC than other organic materials (about 300 meq/100g).



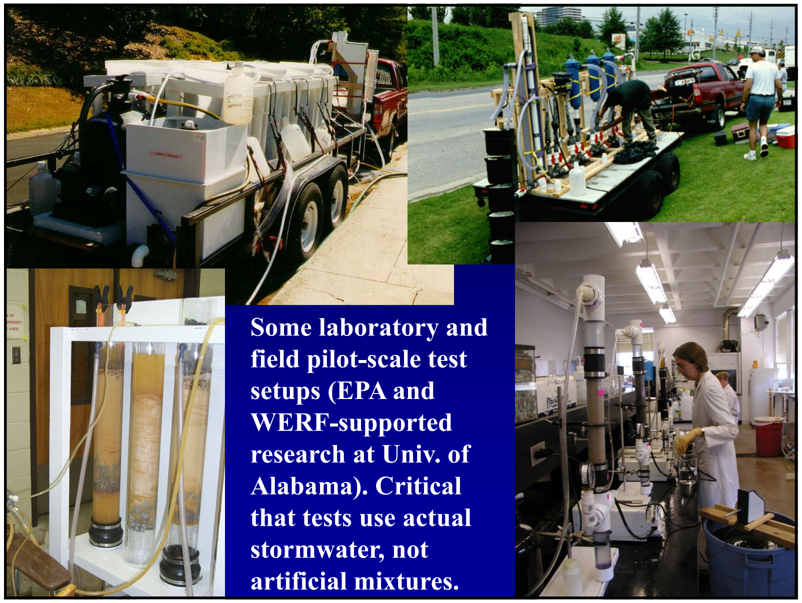
Near Tullamore, County Offaly, Ireland

Unfortunately, peat harvesting is a surface mining operation of a non-renewable resource.

Locally available organic wastes, appropriately processed, should be investigated as a preferable soil amendment.

Tests on Soil Amendments

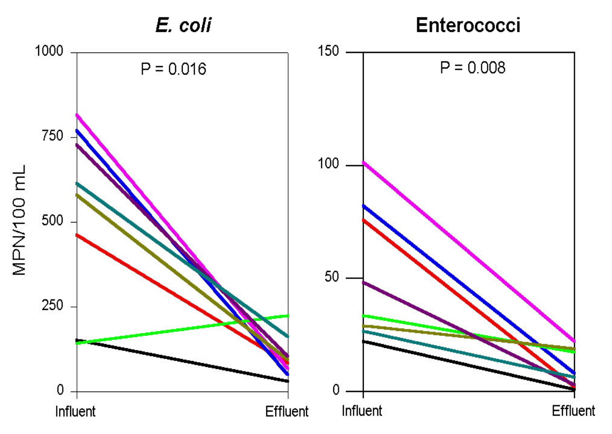
- Many tests have been conducted to investigate filtration/ion exchange/sorption properties of materials that can be potentially used as a soil amendment.



Some laboratory and field pilot-scale test setups (EPA and WERF-supported research at Univ. of Alabama). Critical that tests use actual stormwater, not artificial mixtures.

Capture of Stormwater Particulates by Different Soils and Amendments

	0.45 to 3µm	3 to 12µm	12 to 30µm	30 to 60µm	60 to 120µm	120 to 250µm	>250µm
Porous pavement surface (asphalt or concrete)	0%	0%	0%	10%	25%	50%	100%
Coarse gravel	0%	0%	0%	0%	0%	0%	10%
Fine sand	10%	33%	85%	90%	100%	100%	100%
Loam soil	0%	0%	0%	0%	25%	50%	100%
Activated carbon, peat, and sand	40%	45%	80%	100%	100%	100%	100%



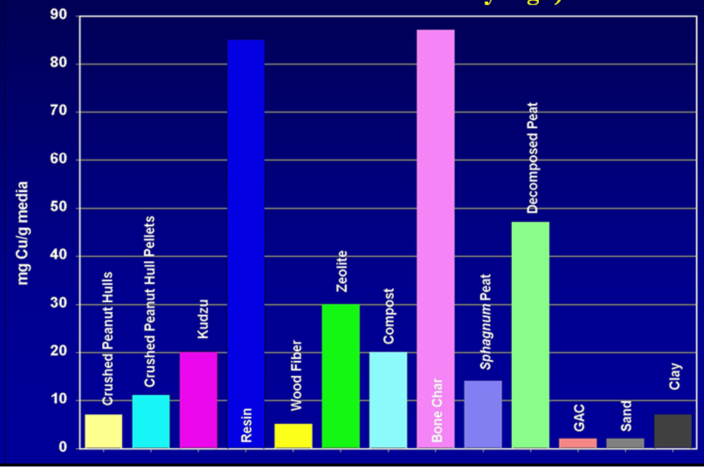
PEAT-SAND FILTER: Pilot-Scale Testing, Fall 1999

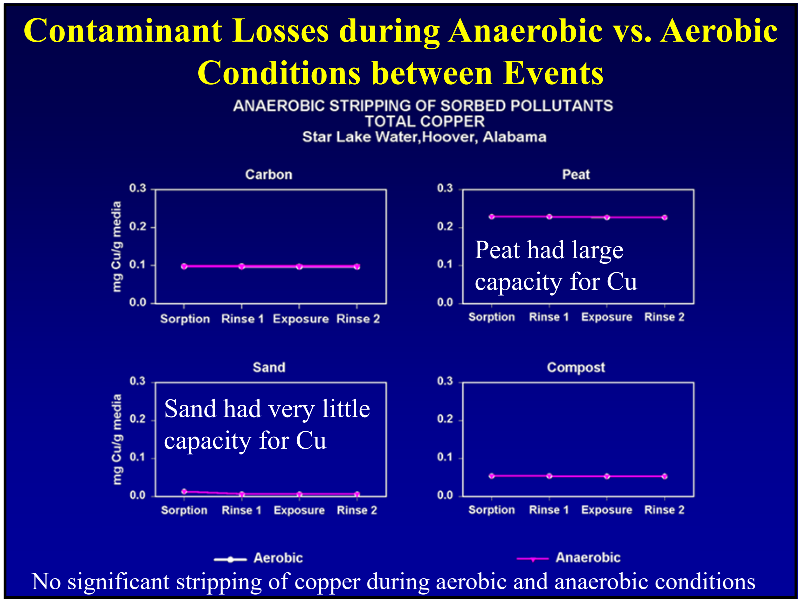
Laboratory Media Studies

- Rate and Extent of Metals Capture
  - Capacities (partitioning)
  - Kinetics (rate of uptake)
- Effect of pH & pH changes due to media, particle size, interfering ions, etc
- Packed bed filter studies
- Physical properties and surface area determinations

Example Media Capacities for Copper

(high concentration tests; much different for typical stormwaters; commercial resins much worse and peat and *bone char activated carbon very high*)





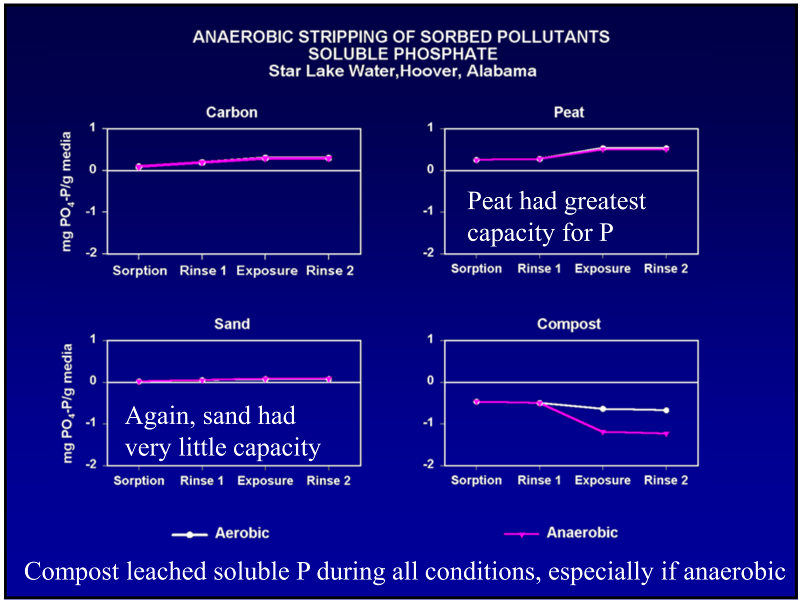
Contaminant Losses during Anaerobic vs. Aerobic Conditions between Events

ANAEROBIC STRIPPING OF SORBED POLLUTANTS
TOTAL COPPER
Star Lake Water,Hoover, Alabama

Peat had large capacity for Cu

Sand had very little capacity for Cu

No significant stripping of copper during aerobic and anaerobic conditions



ANAEROBIC STRIPPING OF SORBED POLLUTANTS
SOLUBLE PHOSPHATE
Star Lake Water,Hoover, Alabama

Peat had greatest capacity for P

Again, sand had very little capacity

Compost leached soluble P during all conditions, especially if anaerobic

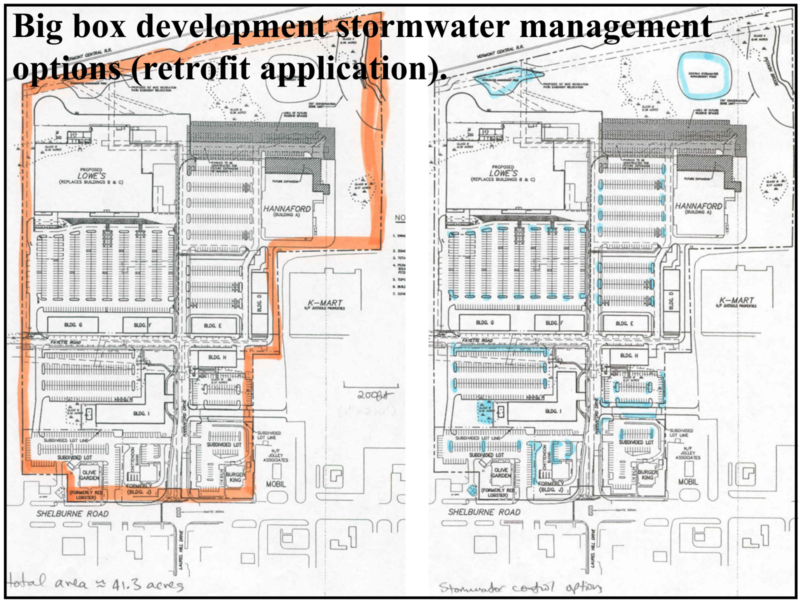
Cation Exchange Capacity (CEC)

Sands have low CEC values, typically ranging from about 1 to 3 meq/100g of material. As the organic content of the soil increases, so does its' CEC. Compost, for example, can have a CEC of between 15 and 20 meq/100 grams, while clays can have CEC values of 5 and 60 meq/100 grams. Natural soils can therefore vary widely in the CEC depending on their components. Silt loam soils can have a CEC between 10 and 30 meq per 100 gram for example. Soil amendments (usually organic material, such as compost or especially peat) can greatly increase the CEC of a soil that is naturally low in organic material.

Example Site Designs and Evaluations Emphasizing Bioretention

- Bioretention can be most effectively used at new development sites; site surveys can identify the best soils, and lead to recommended amendments.
- Bioretention can be used in retrofitted applications, though more costly and not as effective.
- Bioretention and infiltration should be used in conjunction with other stormwater controls, especially sedimentation (such as wet ponds) and energy controlling practices (such as dry ponds).

Big box development stormwater management options (retrofit application).



total area ≈ 41.3 acres

Stormwater control options

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

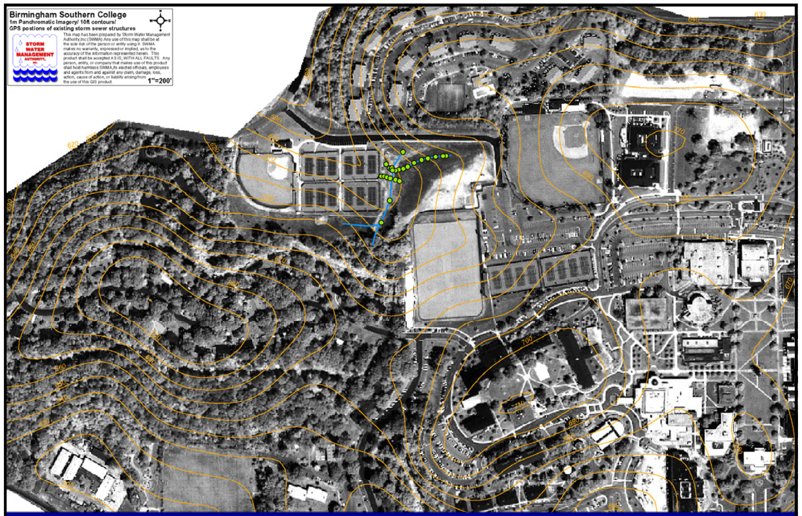
Stormwater Controls

- 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 soil: sandy loam

- 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%**



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

Birmingham Southern College Fraternity Row (new construction at existing site)

	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

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)	

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

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

Elements of Conservation Design for Cedar Hills Development

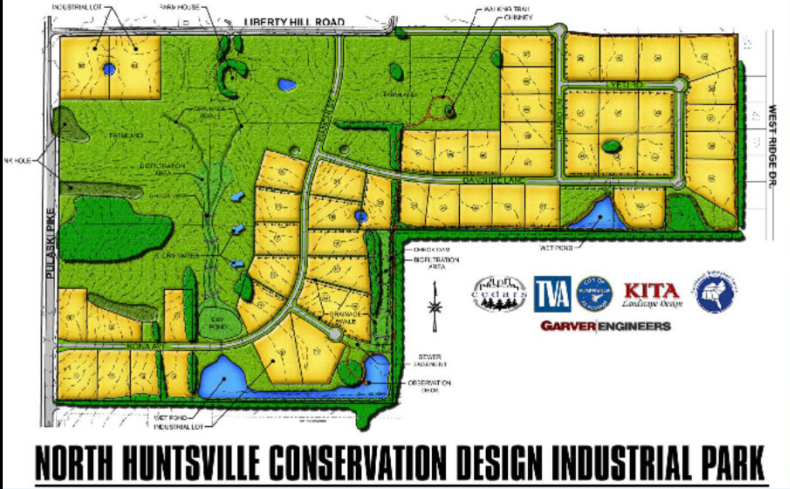
(near Madison, WI, project conducted by Roger Bannerman, WI DNR and USGS)

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


WI DNR photos

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

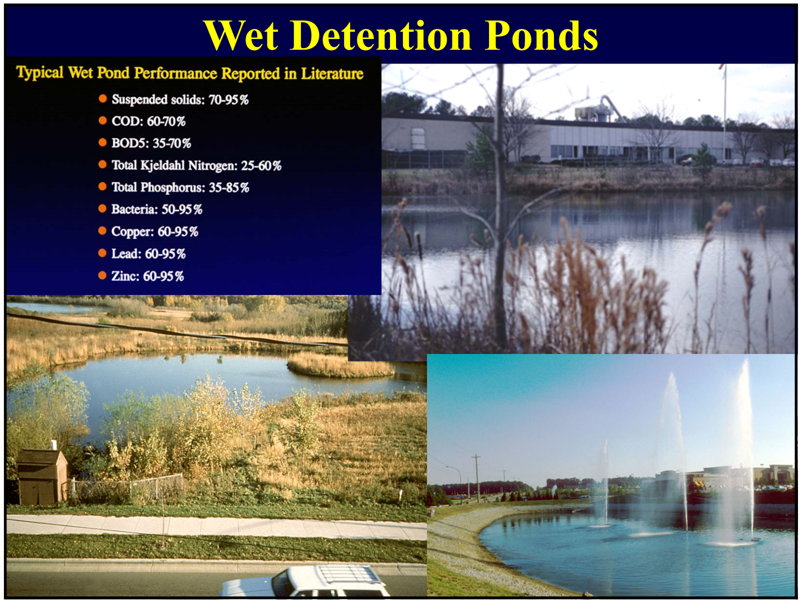


NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

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.

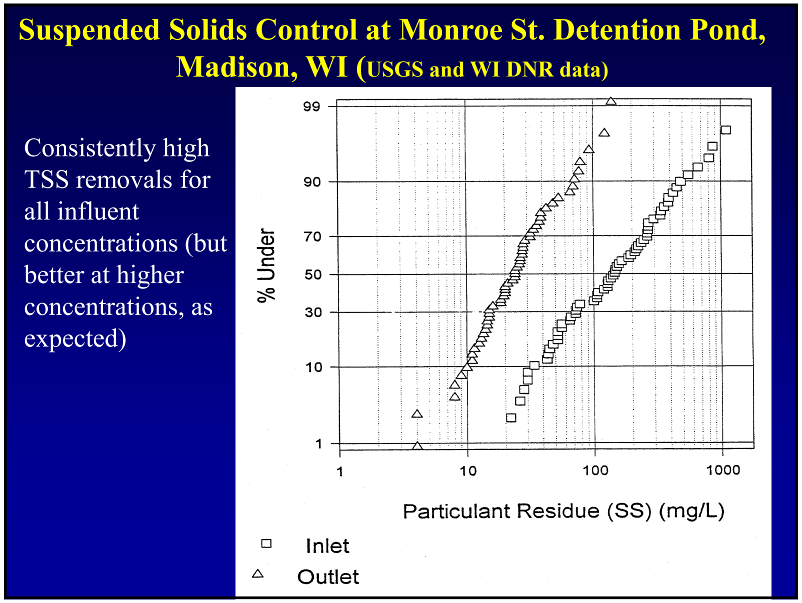
A new industrial site in Huntsville, AL, has 52 two acre individual building sites. Each site will be served with a grass-lined bioretention channel that will carry site water to a larger swale system. The on-site swales will also have modified soils to increase the CEC and organic matter content to protect groundwater resources.



Wet Detention Ponds

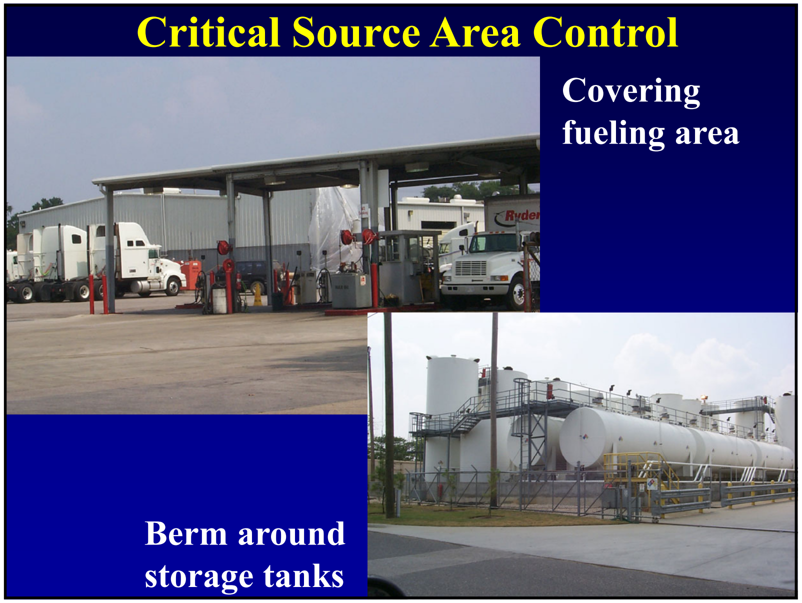
Typical Wet Pond Performance Reported in Literature

- 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%



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)



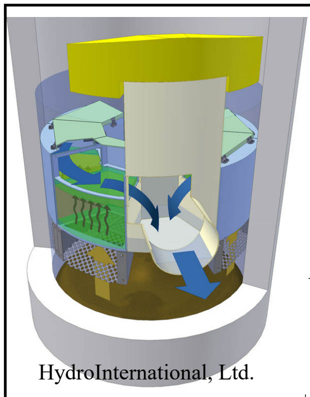
Critical Source Area Control

Covering fueling area

Berm around storage tanks

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

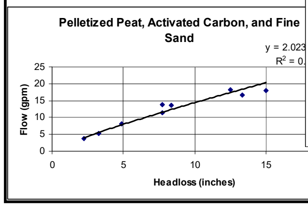
Milwaukee, WI, Ruby Garage Maintenance Yard MCTT

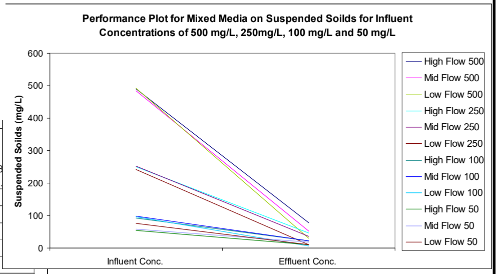


HydroInternational, Ltd.

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.



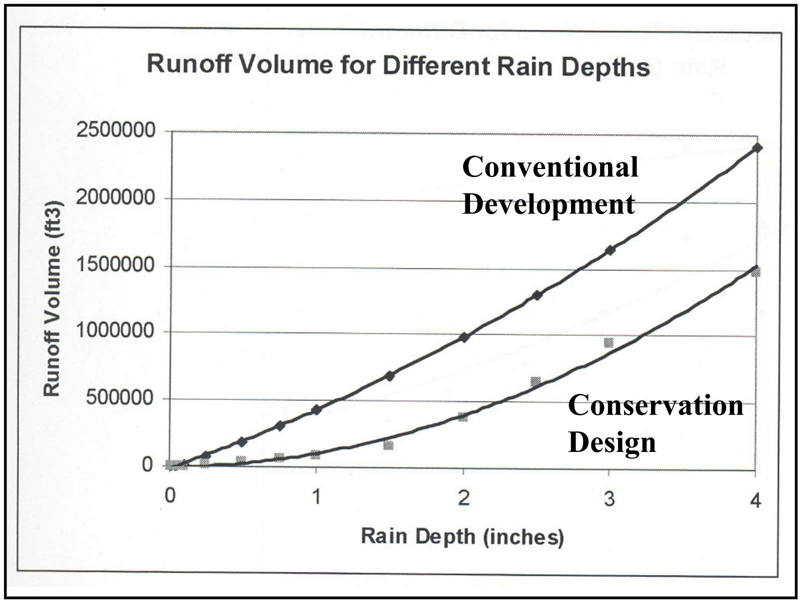


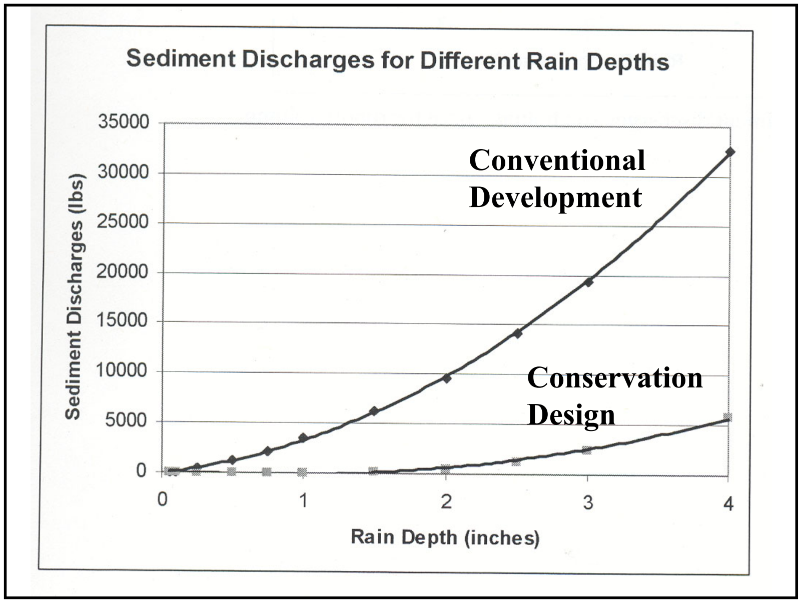
Different site subareas have different combinations of controls. Base conditions are for conventional development.

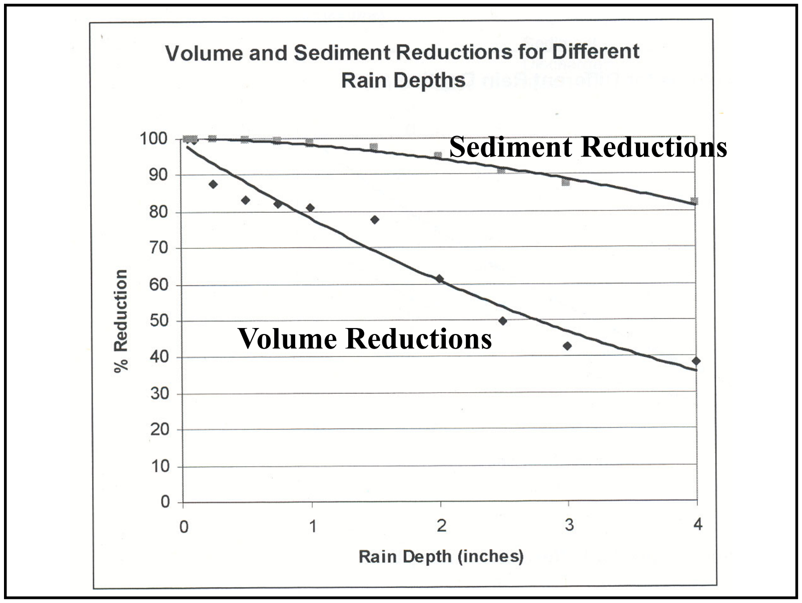
		Annual Runoff Volume (ft^3/year)	
Drainage Area	**Proposed Stormwater Components**	**Base Conditions**	**With Controls**
A	Pond, swale, and site bioretention	6.3 x 10^6	2.5 x 10^6 (61%)
B	Small pond and swale	5.4 x 10^6	1.7 x 10^6 (69%)
C	Pond and swale	2.5 x 10^6	0.83 x 10^6 (68%)
D (including off-site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

		Annual Particulate Solids Discharges (lb/year)	
Drainage Area	**Proposed Stormwater Components**	**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%)







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 bioretention and sedimentation practices is usually needed, at both critical source areas and at critical outfalls.

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