Part 3

Stormwater Controls Emphasizing Infiltration, Evapotranspiration, and Beneficial Uses: green roofs, cisterns, biofiltration/bioretention, porous pavement, and swales

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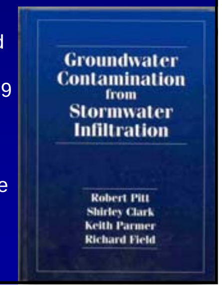
Groundwater Contamination Potential with Stormwater Infiltration

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

Karst formation at Barton Springs, San Antonio, Texas

Book published by Ann Arbor Press/CRC, 219 pages. 1996, based on EPA research and NRC committee work.



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 Increases Groundwater Contamination Potential

Older infiltration trench at parking lot

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

Perforated pipe for infiltrating stormwater

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.

Pitt, *et al*. (1994) EPA report available at: http://unix.eng.ua.edu/~rpitt/Publications/BooksandReports/Groundwater%20EPA%20report.pdf

Moderate to High Contamination Potential

Surface Infiltration after Sedimentation plus sorption/ion-exchange (MCTT and bioretention)	Surface Infiltration with minimal Pretreatment (biofiltration with marginal soils)	Injection after Minimal Pretreatment (dry wells, gravel trenches, and most porous pavements)
	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.
- 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), organic matter (OM) content, and sodium adsorption ratio (SAR) are soil factors that can be directly measured and water characteristics compared. These are not perfect measures, but can be used as indicators. Other soil processes (especially in complex mixtures) need to be evaluated using controlled experiments.

Effects of Compost-Amendments on Runoff Properties

A series of tests by Rob Harrison of the Univ. of Wash. and Bob Pitt examined soil modifications for rain gardens and other biofiltration areas. These were shown to significantly increase treatment and infiltration capacity compared to native soils.

Six to Eleven Times Increased Infiltration with Modified Soils	Average Infiltration Rate (in/h)
Test plot 1 Alderwood soil alone	**0.5**
Test plot 2 Alderwood soil with Ceder Grove compost (old site)	**3.0**
Test plot 5 Alderwood soil alone	**0.3**
Test plot 6 Alderwood soil with GroCo compost (old site)	**3.3**

Pitt, *et al*. 1999

King County, Washington, test plots of modified soils

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

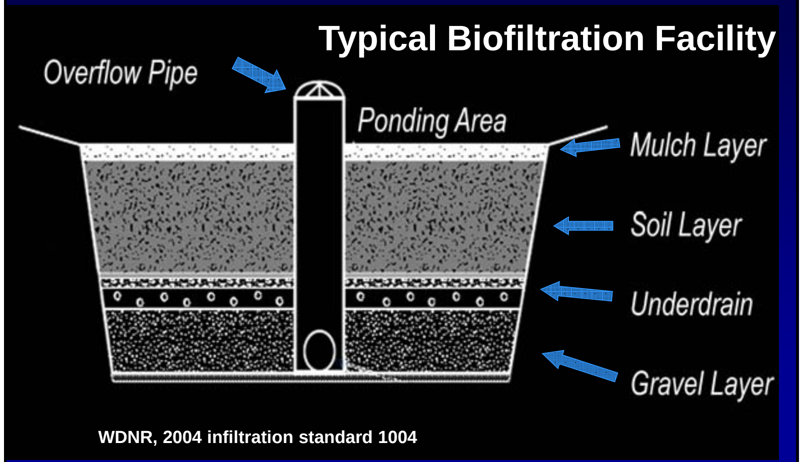
Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09 (test/control)	0.29 (due to ET)
Phosphate	0.62	3.0
Ammonia	0.56	4.4
Nitrate	0.28	1.5
Copper	0.33	1.2
Zinc	0.061	0.18

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.

Many states are publishing standards for biofiltration/bioretention facilities, including standards for engineered soils.



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 (CEC of 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, Irish peat harvesting is a surface mining operation of a non-renewable resource.

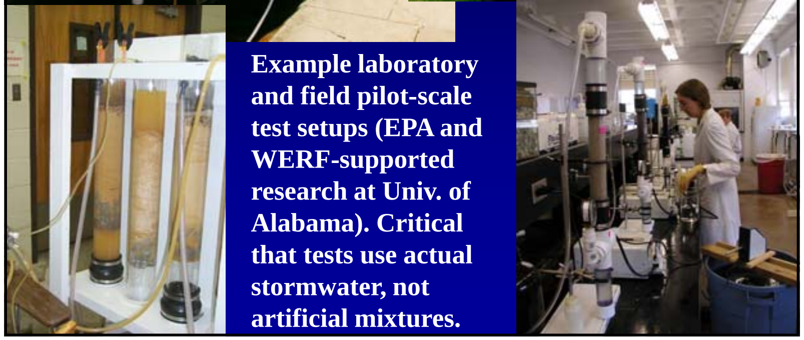
Locally available organic wastes (composts), appropriately processed, should be investigated as a preferable soil amendment.

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 and as a treatment media in stormwater controls.

Development and Testing of Treatment Methods

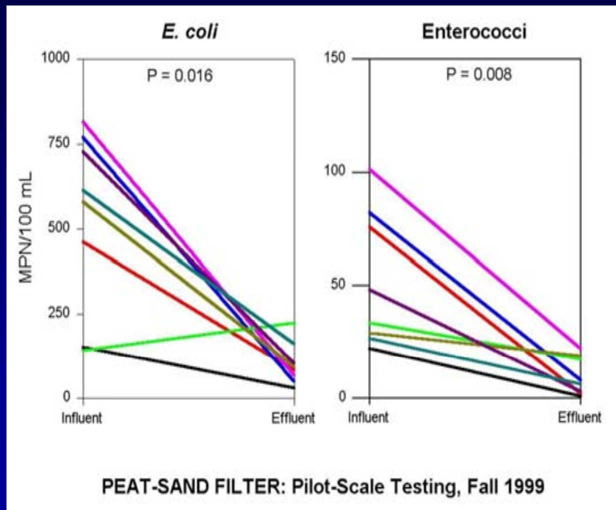
Example laboratory and field pilot-scale test setups (EPA and WERF-supported research at Univ. of Alabama). Critical that tests use actual stormwater, not artificial mixtures.



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 mixture	40%	45%	80%	100%	100%	100%	100%

Final underdrain quality is usually greater than 10 to 25 mg/L TSS

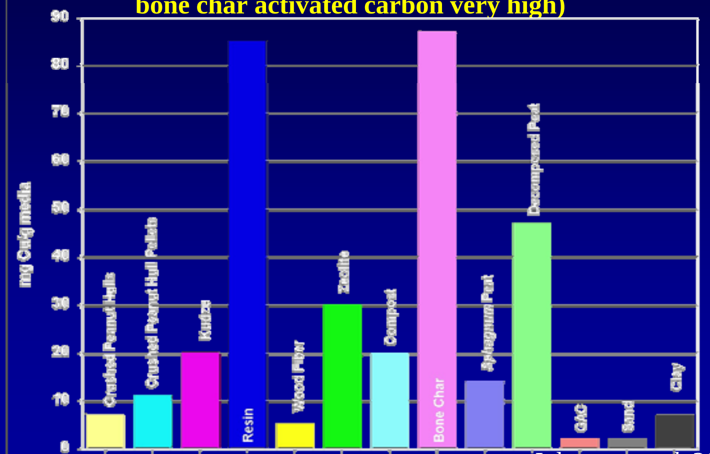


Laboratory Media Studies

- 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

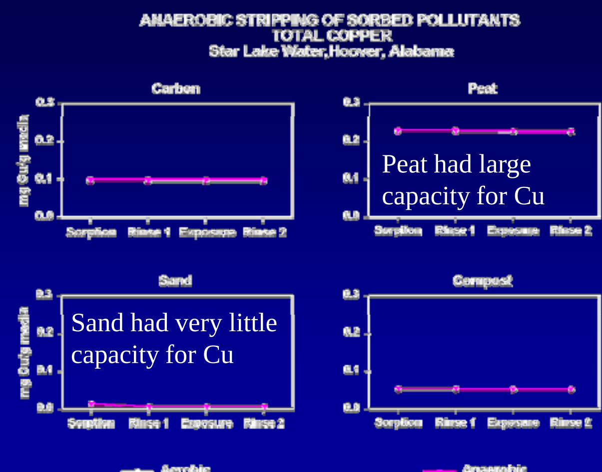
Example Media Capacities for Copper

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

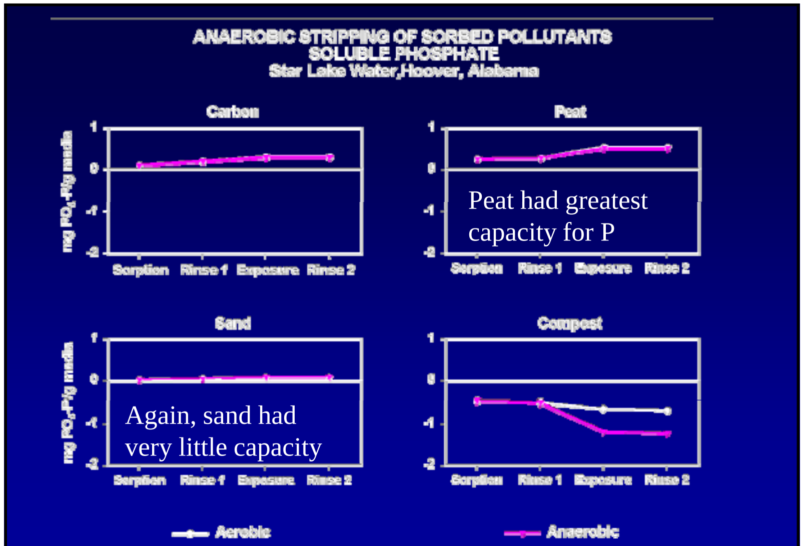


Johnson, *et al.* 2003

Contaminant Losses during Anaerobic vs. Aerobic Conditions between Events



No significant stripping of copper during aerobic and anaerobic conditions



Compost leached soluble P during all conditions, especially if anaerobic

Recent media tests for a broad range of metallic and organic toxicants

Media	Description
Granular Activated Carbon (GAC)	VCC 8X30 Virgin Coconut Shell Activated Carbon (Baker Corp.): 29 lbs/ft^3 (1.8 to 2.1 g/cm^3); $0.98/lb
Rhyolite Sand	D1 biofilter media sand (Rhyolite Topdressing Sand) from Golf Sand, Inc., North Las Vegas, NV;75 in/hr infiltration rate; particle density 2.38 g/cm^3; bulk density 1.28 g/cm^3; 98.6% sand, 1.1% silt, 0.3% clay; 45.4% greater than 0.25 mm; 44.6% between 0.18 and 0.25 mm.
Site Zeolite	Z-200 Modified Zeolite (Baker Corp.); $1.36/lb
Surface Modified Zeolite	14-40 Saint Cloud Zeolite with 325 µm Modified Zeolite at 3% Vol:Vol
Sphagnum Peat Moss	Purchased from nursery in Elizabethtown, PA
Site Sand	Fine textured silica sand

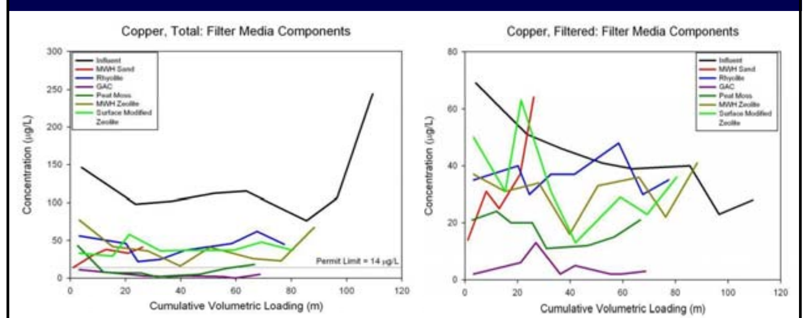
Long-Term Column Tests: Maintenance

- Infiltration rates typically decrease over a device's life due to solids capture on the surface of and in the media.
- Most media typically fail when the total solids loading is about 10 – 25 kg/m^2 of media surface (flow rate < 1 m/d, generally). Full-scale setups clog at about 5 times the capacity as the column tests.

Examined potential maintenance options once flow rate < 5 m/d (effects of disturbing media vs. removing media from filter).

Media removal generally more effective, but must remove at least 4 – 6" because clogging solids are captured deep in the media (deeper than visible solids buildup).

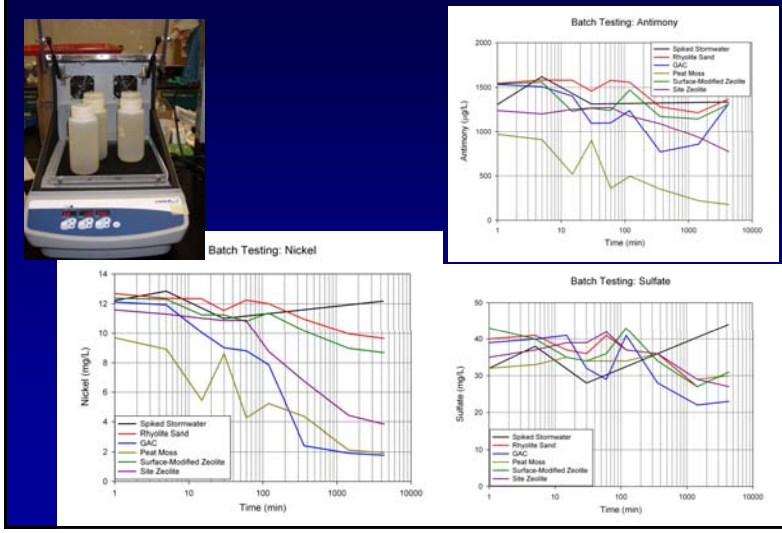
Long-Term Column Tests: Removal as a Function of Pollutant Form



Excellent removals of particulate associated pollutants, but removal of dissolved/colloidal components vary greatly by media.

- Primary removal mechanism is physical straining/removal of particulate-associated copper.
- Removal by GAC and then peat may be related to organic complexation of copper in influent water or complexation with the organic content of the media.
- Poorer removal by zeolites and sands (typically associated with CEC).

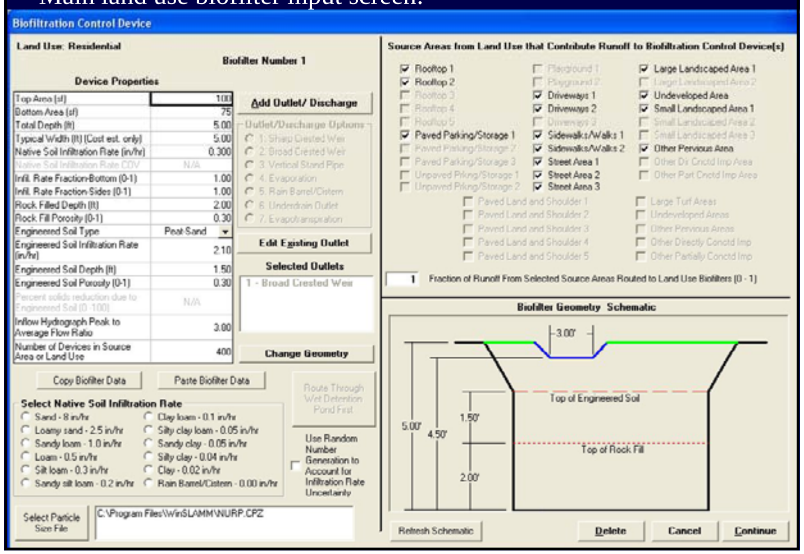
Batch Testing to Optimize Contact Time



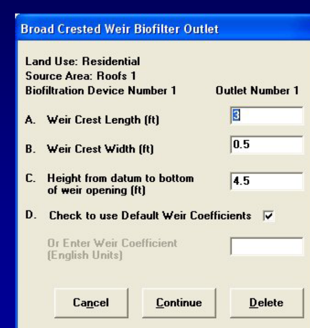
Modeling Bioretention Devices

- In this example, two curb-cut biofilters are located in front of each house. These are between the sidewalk and the street. The curb is cut to allow the gutter water to flow into the first unit, which overflows into the second unit. The second unit then overflows back into the gutter during large rains.
- Each biofilter is 20 feet long and 5 feet wide, with a total excavation depth of 5 feet.
- A 2 ft layer of rock fill is a storage layer on the bottom, with a 1-1/2 ft layer of a peat-sand mixture on top of the rock (no filter fabric is used, as they tend to clog with silts, rather a rock filter gradient layer is used instead). There is a one foot storage layer on top of the engineered soil before the overflow weir.
- The only outlets are the native soil and broad crested weir overflows and are therefore bioretention devices. A second example has an underdrain and are therefore biofilters.
- Since these are curb-cut biofilters, they are “land use” biofilters. The input form is located under the “land use” drop down menu then under “land use biofilter.” The contributing source areas that drain to the biofilters are selected. Since these are curb-cut biofilters, all of the source areas are selected.

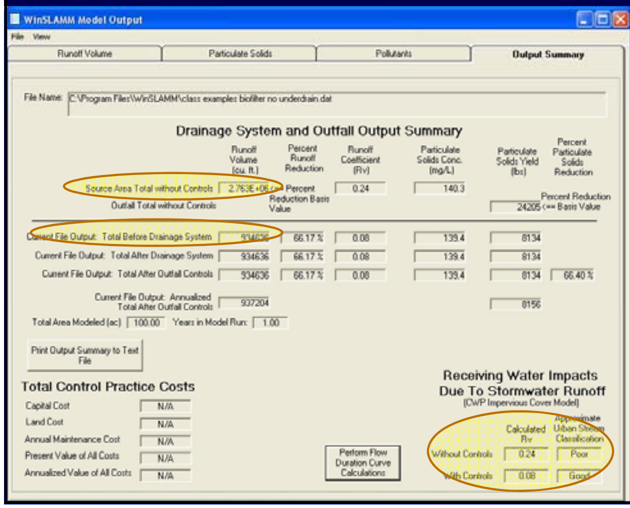
Main land use biofilter input screen:



The required broad-crested weir is the overflow for excessive stormwater that is not infiltrated:

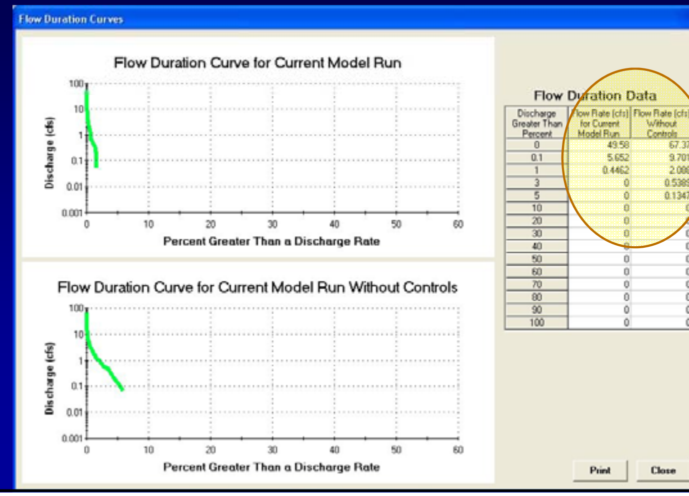


Summary output showing about 66% runoff and particulate solids reductions with the biofilters. Compare the “source area total without controls” with the “total before drainage system” for the performance of the biofilters:



The receiving water benefits show a calculated improvement from poor to good.

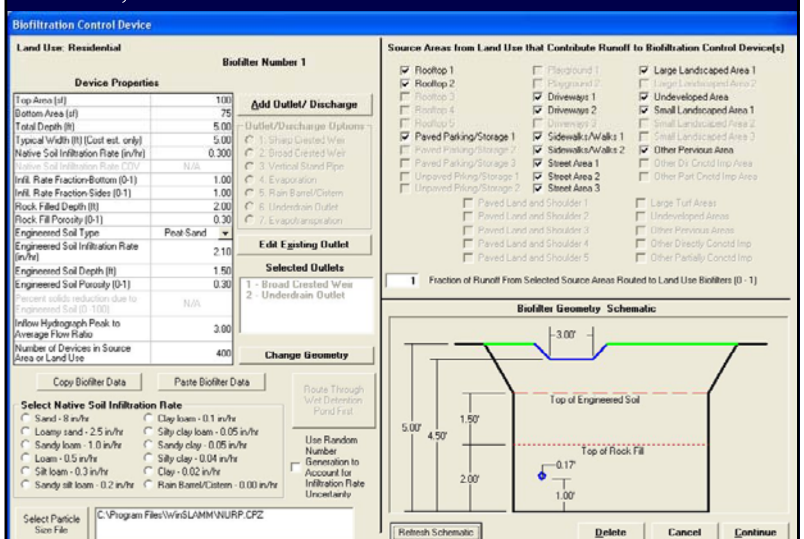
The program can also calculate the flow-duration curve for the study area, with and without the controls (select the “perform flow-duration curve calculations” on the output summary page). This shows that the peak flows are reduced by about 25% and the duration of large flows greater than 1 cfs are reduced from about 2% to less than 1% of the time.



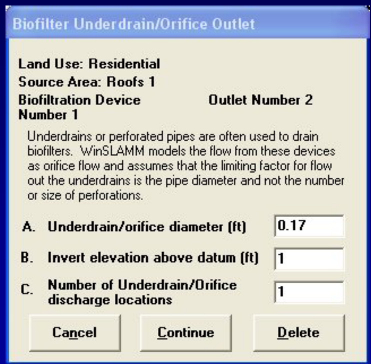
Biofilter (use of an underdrain)

- The following biofilter example is identical to the above example, except that each biofilter has a 2 inch underdrain that collects filtered water back to the drainage system.
- This is a common approach when the duration of standing water needs to be reduced in marginal soils, or if the filtered stormwater is needed to be discharged to the receiving waters as a water supply (such as may be desired in drought-prone areas), or if the biofilter is desired to be a retention device in a combined sewered area, and infiltration of the water is not desirable or needed.

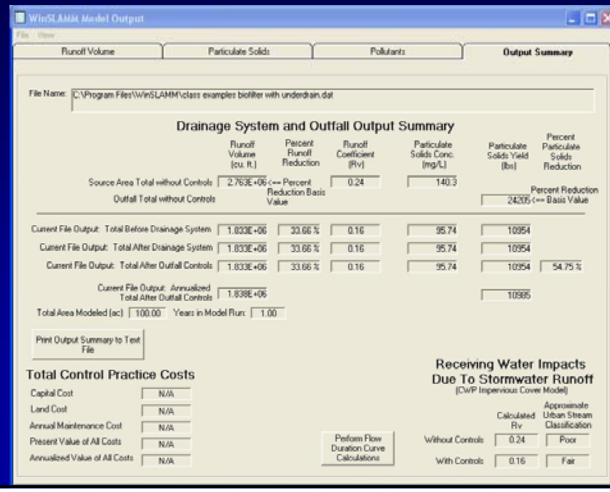
Biofilter, with a 2 inch underdrain:



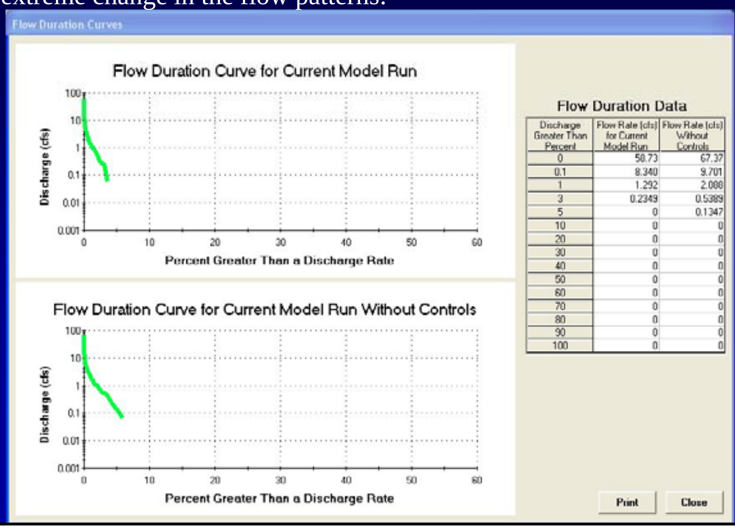
Input form for the underdrain:



Output summary for biofilter example, showing reduced infiltration of runoff, but similar particulate solids reductions:



Flow-duration curves for biofilter with underdrain showing a less extreme change in the flow patterns:



Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	58.73	67.37
0.1	8.340	9.701
1	1.292	2.088
3	0.2349	0.5389
5	0	0.1347
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

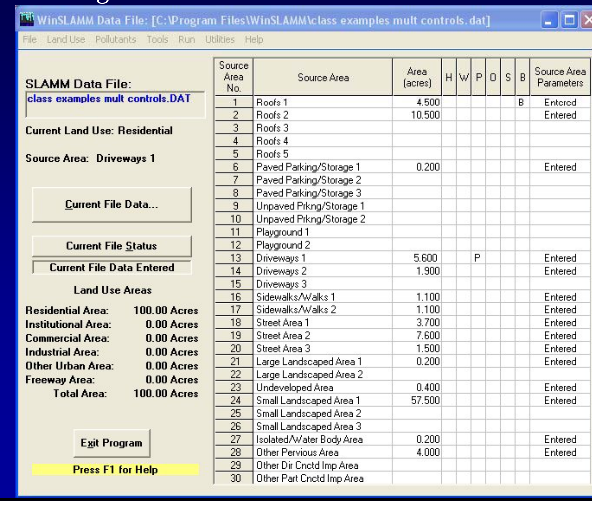
Example Site Designs and Evaluations Emphasizing Bioretention

- 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).

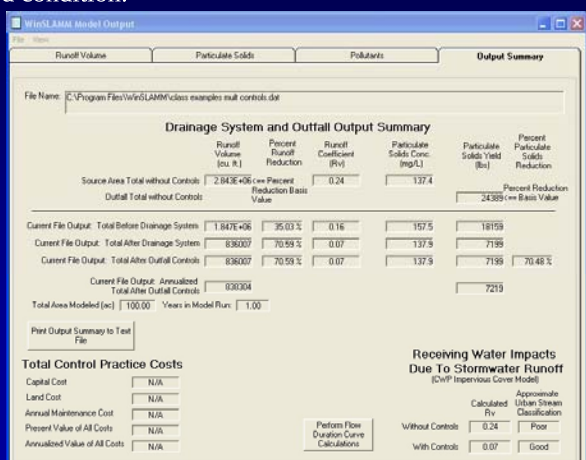
Modeling Combinations of Practices

- This example shows the effects of a combination of bioretention/biofiltration practices in the same area.
- Rain gardens for the homes with directly connected downspouts are combined with porous pavement driveways, and grass swales.
- These individual practices were copied from the prior examples using each practice's copy and paste function.

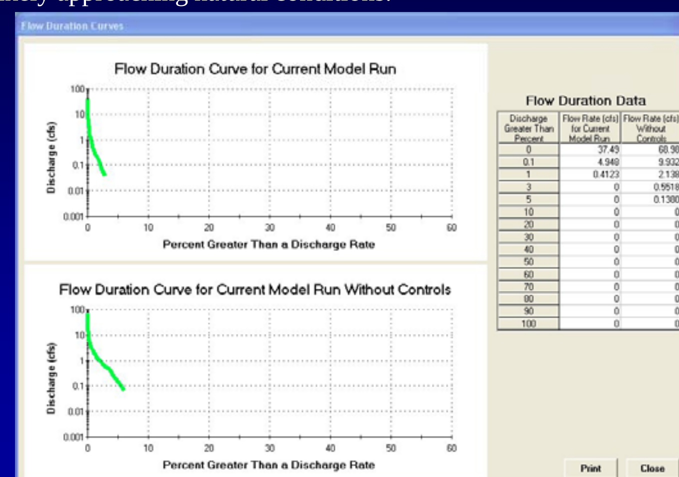
Land use screen showing the rain gardens and porous pavement controls. The swales are under the "land use" drop down menu under drainage controls.



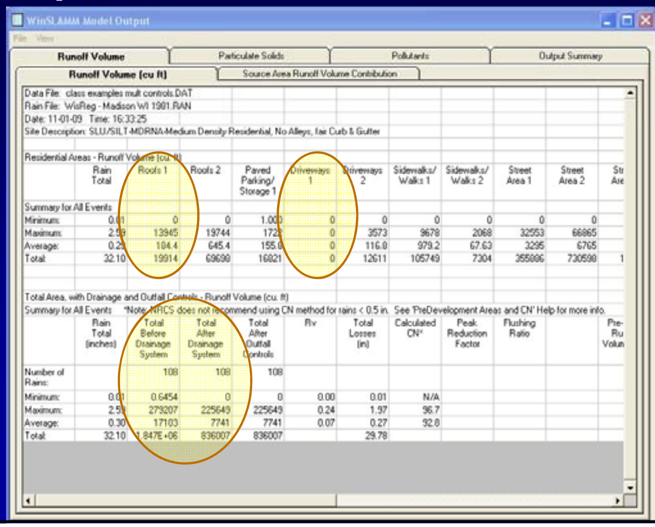
Overall benefits from these 3 sets of controls, showing about 70% reductions in runoff volume and particulate solids discharges. The receiving water conditions are also shown to improve from poor to good condition.



Flow-duration curves also show more than a 40% reduction in the peak flow expected and large changes in the runoff characteristics, likely approaching natural conditions.



The runoff volume summary also shows the effectiveness of each control practice:


WinSLAMM Model Output

Runoff Volume | Particulate Solids | Pollutants | Output Summary

Runoff Volume (cu ft) | Source Area Runoff Volume Contribution

Data File: class examples mult controls.DAT
Rain File: WisReg - Madison WI 1981.RAN
Date: 11-01-09 Time: 16:33:25
Site Description: SLU/SILT-MDRNA-Medium Density Residential, No Alleys, fair Curb & Gutter

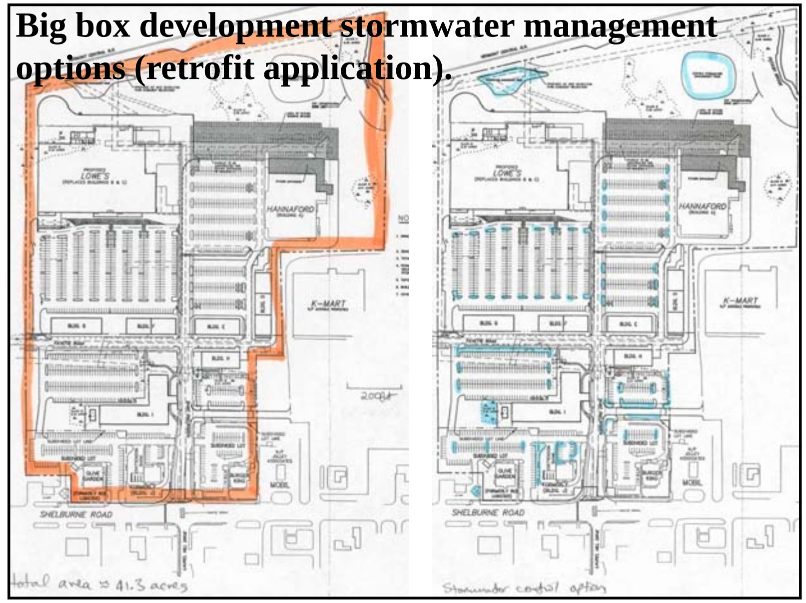
Residential Areas - Runoff Volume (cu. ft)

Summary for All Events	Rain Total	Roofs 1	Roofs 2	Paved Parking/ Storage 1	Driveways 1	Driveways 2	Sidewalks/ Walks 1	Sidewalks/ Walks 2	Street Area 1	Street Area 2	Str Are
Minimum:	0.01	0	0	1.000	0	0	0	0	0	0	
Maximum:	2.59	13945	19744	1722	0	3573	9678	2068	32553	66865	
Average:	0.29	184.4	645.4	155.0	0	116.8	979.2	67.63	3295	6765	
Total:	32.10	19914	69698	16821	0	12611	105749	7304	355806	730598	1

Total Area, with Drainage and Outfall Controls - Runoff Volume (cu. ft)
Summary for All Events *Note: NRCS does not recommend using CN method for rains < 0.5 in. See 'PreDevelopment Areas and CN' Help for more info.

	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio		Pre- Ru Volun
Number of Rains:		108	108	108							
Minimum:	0.01	0.6454	0	0	0.00	0.01	N/A				
Maximum:	2.59	273207	225649	225649	0.24	1.97	96.7				
Average:	0.30	17103	7741	7741	0.07	0.27	92.8				
Total:	32.10	1.847E+06	836007	836007		29.78					

Big box development stormwater management options (retrofit application).



Summary of Measured Areas

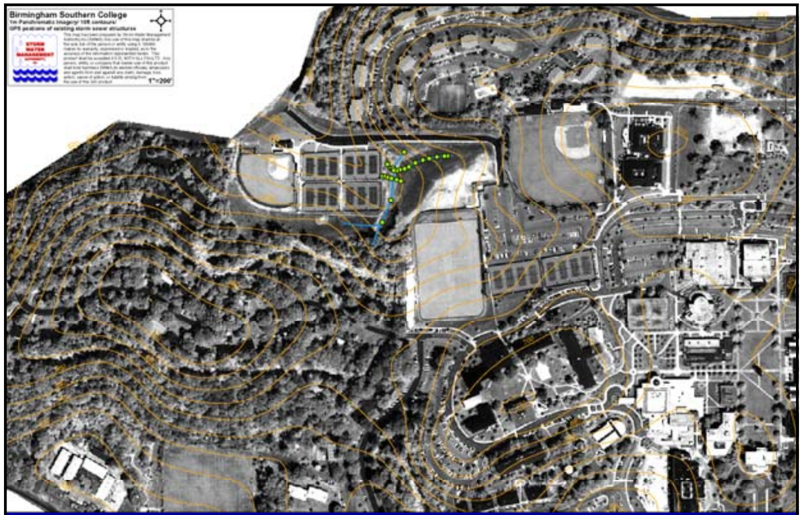
- Totally connected impervious areas: 25.9 acres
  - parking 15.3 acres
  - roofs (flat) 8.2 acres
  - streets (1.2 curb-miles and 33 ft wide) 2.4 acres
- Landscaped/open space 15.4 acres
- Total Area 41.3 acres

Stormwater Controls

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

Modeled Runoff Volume Changes

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



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 Infiltration Controls to Reduce Runoff Volume at Birmingham Southern College Site

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

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

USGS

science for a changing world

In cooperation with the Wisconsin Department of Natural Resources

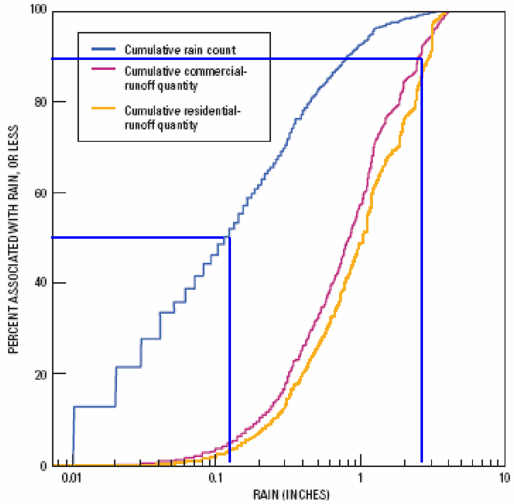
A Comparison of Runoff Quantity and Quality from Two Small Basins Undergoing Implementation of Conventional- and Low-Impact-Development (LID) Strategies: Cross Plains, Wisconsin, Water Years 1999–2005

Scientific Investigations Report 2008–5008

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

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

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



About 90% of the site runoff is associated with rains less than about 2.5 inches in depth. These are the events that need attention when trying to reduce runoff at this site. 50% of the rains, by count, are less than about 0.12 inches in depth.

Figure 9. Relation of cumulative-discharge volume to precipitation depth for residential land use in Madison, Wis., based on model predictions (modified from Pitt, 1999).

Parallel study areas, comparing test with control site

Figure 2. Land use in the low-impact-development (left) and conventional-development (right) basins and location of water-quality monitoring stations, Cross Plains, Wis.

Some of the stormwater management features at Cedar Hills site.

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

Monitored Performance of Controls at Cross Plains Conservation Design Development

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

WI DNR and USGS data

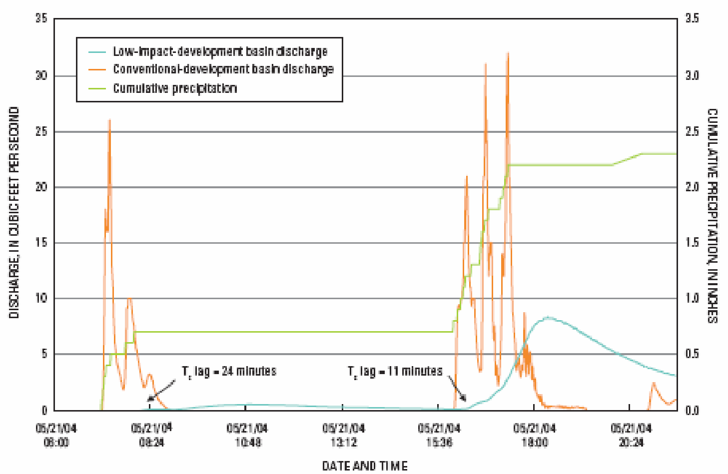
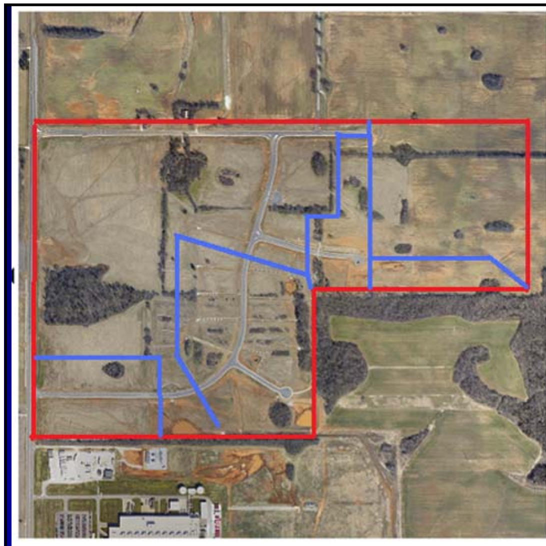


Figure 10. Hydrologic response of low-impact-development (LID) and conventional-development basins to two consecutive precipitation events, Cross Plains, Wis. [T_c, time of concentration]

NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

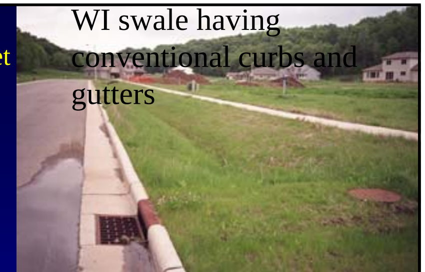
Aerial Photo of Site under Construction (2006 Google Earth image)



- On-site bioretention swales
- Level spreaders
- Large regional swales
- Wet detention ponds
- Critical source area controls
- Pollution prevention (no Zn!)
- Buffers around sinkholes

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

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



WI swale having conventional curbs and gutters

Large swale at MS industrial site

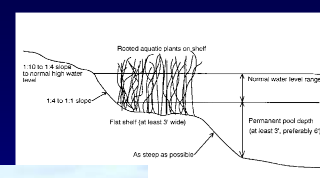
Biofilters to drain site runoff (paved parking and roofs) to regional swales:

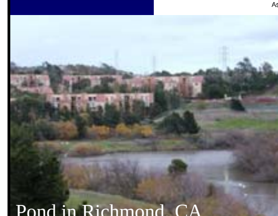
- Top area: 4400 ft^2
- Bottom area: 2000 ft^2
- Depth: 2 ft
- Seepage rate: 2 in/hr
- Peak to average flow ratio: 3.8
- Typical width: 10 ft
- Number of biofilters: 13 (one per site)

Parking lot biofilter example, Portland, OR

Wet Detention Ponds

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

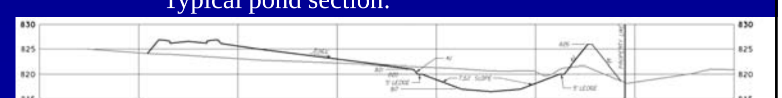


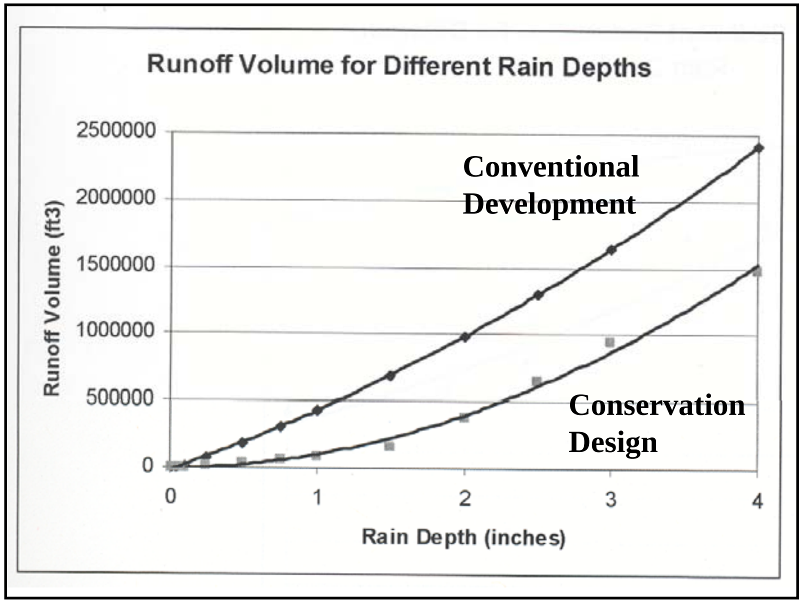


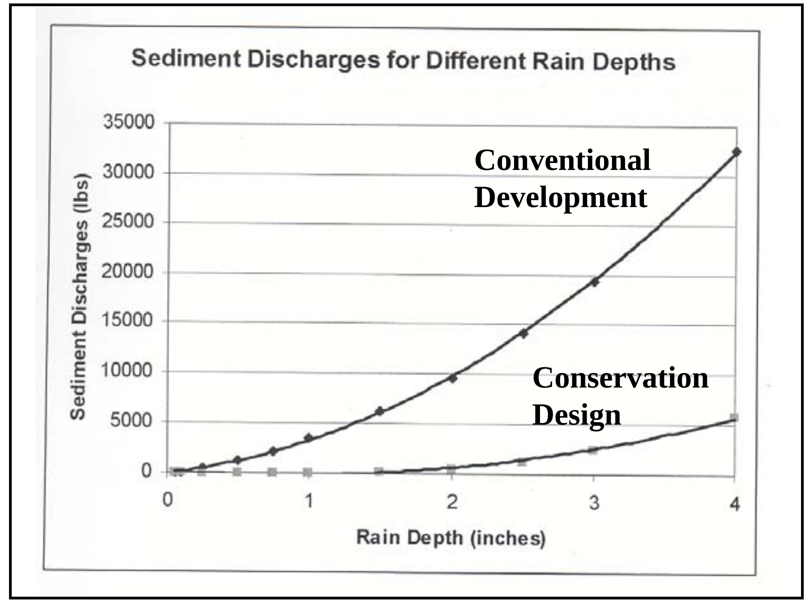
Pond in Richmond, CA

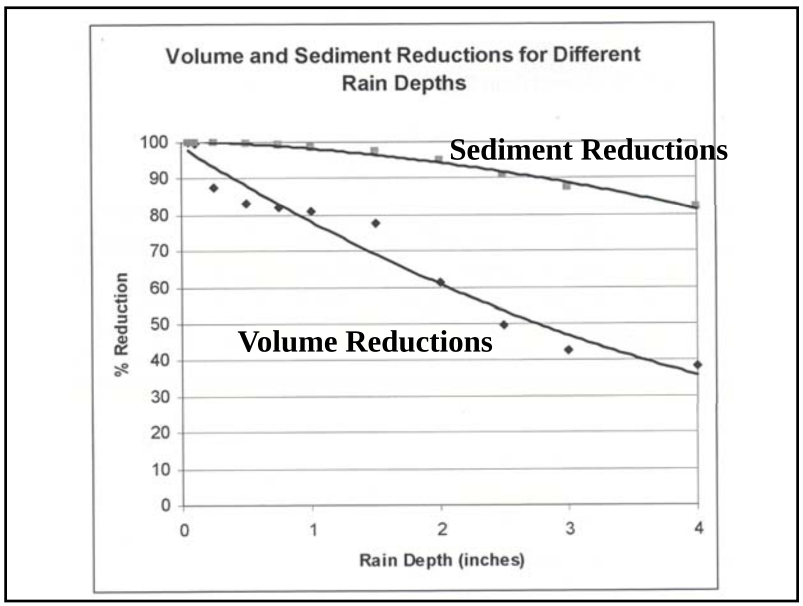
The pond surface areas vary from 0.5 to 1% of the drainage areas, depending on the amount of upland infiltration. The ponds have 3 ft. of standing water above 2 ft. of sacrificial storage. Additional storage volume provides necessary peak flow control.

Typical pond section:









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