Characteristics of Soils and Amendments to Enhance Stormwater Treatment, plus Case Studies of Large-Scale Infiltration Tests

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Introduction – Need for Infiltration

- Infiltration of stormwater has become an increasingly important stormwater management tool.
- Attempts are made to restore pre-development water balance, by increasing infiltration to balance increased paved surfaces.
- This has been a leading solution to protect the aquatic habitat in surface waters.
- Infiltration also important in areas having combined sewers to reduce frequency and magnitude of overflows (CSOs).

Stormwater Infiltration Controls in Urban Areas

- Roof drain disconnections
- Bioretention areas
- Rain gardens and amended soils
- Porous pavement and paver blocks
- Grass swales and infiltration trenches
- Percolation ponds
- Dry/injection wells

Disconnected roof drain

Directly connected roof drain

Rain Garden Designed for Complete Infiltration of Roof Runoff

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

Annual Birmingham, AL, rains (1.4 m) compared to Seattle, WA, rains (0.84 m), and Phoenix, AZ, rains (0.24 m)	Annual roof runoff volume reductions
Flat roofs instead of pitched roofs	13/21/25%
Cistern for reuse of runoff for toilet flushing and irrigation (3m D x 1.5 m H)	66/67/88%
Planted green roof	75/77/84%
Disconnect roof drains to loam soils	84/87/91%
Rain garden with amended soils (3m x 2m)	87/100/96%


Drainage swales with infiltration trenches


Temporary parking or access roads supported
by geogrids, turf meshes, or paver blocks


Wolfgang Geiger's Porous Paver Test Rig, Essen, Germany


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


Construction of Biofiltration Facility with
Amended Soils and Underdrain
Larry Coffman, Prince George's County


Portland, OR, biofiltration around parking areas

Retrofit biofiltration facility with overflow to drainage system, Portland, OR

Biofiltration (in use) at a heavily paved commercial site.

Larry Coffman, Prince George's County

Rain Garden in the inter-space of a high density town house project.

Depressed Curb Inlet.

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Longitudinal view of median strip biofilters with various plant layers.

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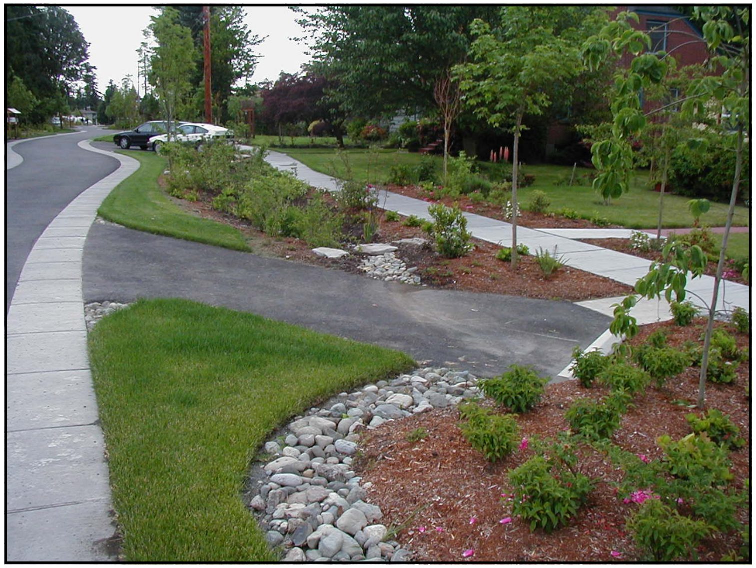
Retrofitted "SEA Street"
in Seattle, WA

SEA Streets - After Construction
2nd Ave NW - NW 117th St to NW 120th St



Potential Problems Associated Stormwater Infiltration

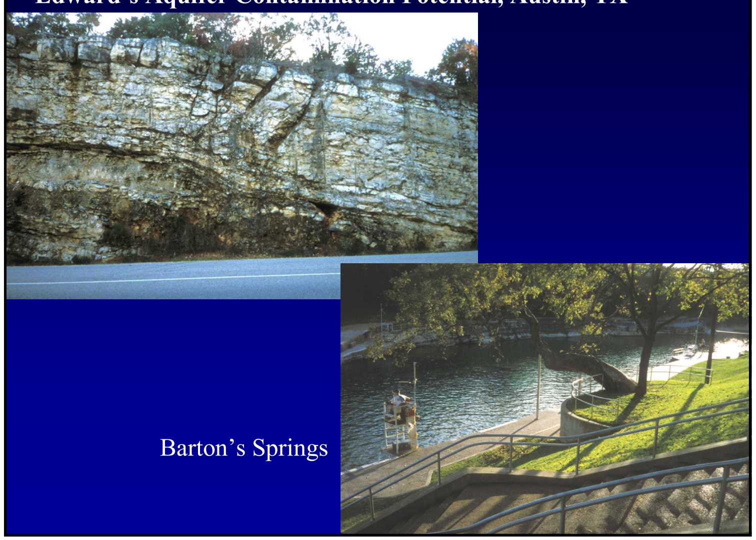
- Failure of infiltration device
- Groundwater contamination

Swale Problems

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.)

Edward's Aquifer Contamination Potential, Austin, TX



Minimal Pre-treatment before Infiltration Greater Groundwater Contamination Potential

Potential Problem Pollutants were Identified 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 restrictions before discharge.

Results

- Sources of pollutants were monitored
- Classes of stormwater constituents that may adversely affect groundwater quality:
  - Nutrients
  - Pesticides
  - Other organics
  - Microorganisms
  - Metals
  - Salts

Example Weak-Link Model Influencing Factors

Constituent	Abundance in Stormwater	Mobility (sandy/low organic soils)	Treatability Problems (filterable fraction)
Nitrates	low/moderate	mobile	high
Chlordane	moderate	intermediate	very low
Anthracene	low	intermediate	moderate
Pyrene	high	intermediate	high
Lead	moderate	very low	very low

Links Depend on Infiltration Method (contamination potential is the lowest rating of the influencing factors)

- Surface infiltration with no pretreatment (pavement or roof disconnections to pervious areas, use of porous pavement or rain gardens, etc.)
  - **Mobility and abundance** most critical
- Surface infiltration with sedimentation pretreatment (grass filters, treatment train such as percolation pond after wet detention pond or MCTT)
  - **Mobility, abundance, and treatability** all important
- Subsurface injection with minimal pretreatment (infiltration trench in parking lot or dry well)
  - **Abundance** most critical

Example Applications: Low Abundance

- Abundance is important for all cases, therefore if a constituent is in low abundance in stormwater, the groundwater contamination potential will "always" be low, irrespective of infiltration method.
- Examples for most areas include: 2-4-D, VOCs, anthracene, napthalene, and cadmium; some areas may have higher concentrations of problem constituents, with an increased contamination potential.

Example Applications: No Pretreatment Before Infiltration Through Surface Soils (pavement runoff to pervious area)

- Mobility also important
- If a compound is mobile, but in low abundance (such as for nitrates), the contamination potential is low.
- If compound is mobile and also in high abundance (such as chlorides in cold regions that use salt de-icers), the contamination potential would be high.

Example Applications: Sedimentation Pretreatment Before Infiltration (wet detention pond, treatment train)

- All three factors important
- Chlordane would have low contamination potential with sedimentation pretreatment (because much of the chlordane would be removed), even though it has moderate abundance and intermediate mobility.
- If no pretreatment, the chlordane contamination potential would be moderate.

Moderate to High Contamination Potential

Surface Infiltration with no Pretreatment	Surface Infiltration after Sedimentation	Injection after Minimal Pretreatment
Lindane, chlordane		Lindane, chlordane
Benzo (a) anthracene, bis (2-ethylhexl phthalate), fluoranthene, pentachlorophenol, phenanthrene, pyrene	Fluoranthene, 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. Low runoff pH values can decrease the available soil CEC.
- 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.

Recommendations to Reduce Groundwater Contamination Potential when using Infiltration in Urban Areas

- Combined sewer overflows should be diverted from infiltration devices because of poor water quality.
- Snowmelt runoff should be diverted from infiltration devices because of high concentrations of salts.
- Construction site runoff must be diverted from infiltration devices due to rapid clogging.

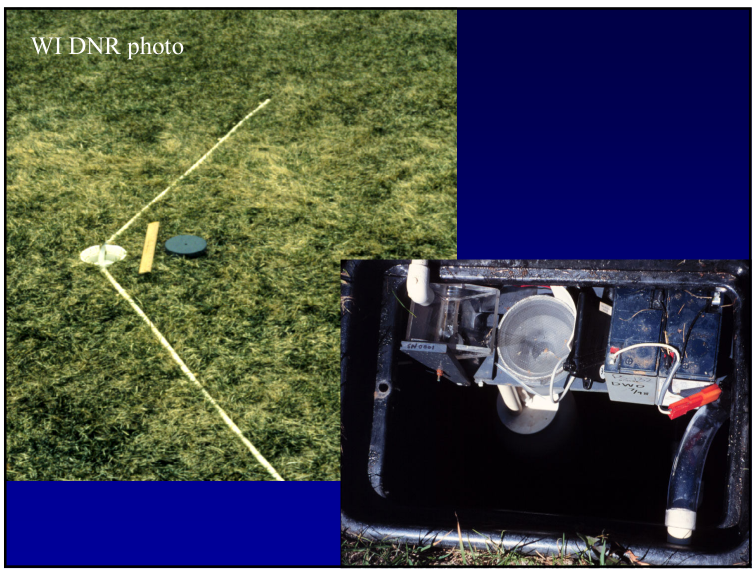
Recommendations to Reduce Groundwater Contamination Potential when using Infiltration in Urban Areas (cont.)

- Infiltration devices should not be used in most industrial areas.
- Runoff from critical source areas (mostly in commercial areas) need to receive adequate pretreatment prior to infiltration.
- Runoff from residential areas (the largest component of urban runoff in most cities) is generally the least polluted and should be considered for infiltration.

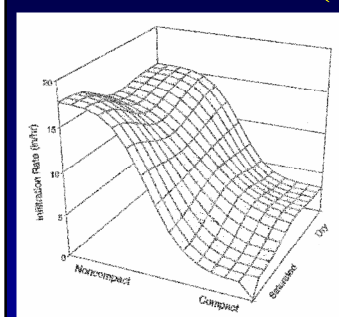
Measurement of Soil Infiltration Characteristics

Research Elements/Methodology

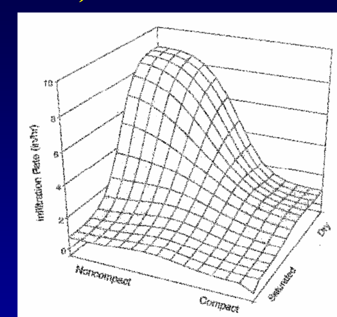
- Our research on stormwater and groundwater interactions began during an EPA cooperative agreement to identify and control stormwater toxicants.
- Our first efforts were based on extensive literature reviews for reported groundwater data beneath urban areas and management options.
- Initial stormwater - groundwater impact report published by EPA (1994) and Lewis Publishers, CRC Press (1996).
- Have since continued to investigate pollutant fates in amended and natural soils and filtration media.



Infiltration Rates in Disturbed Urban Soils (AL tests)



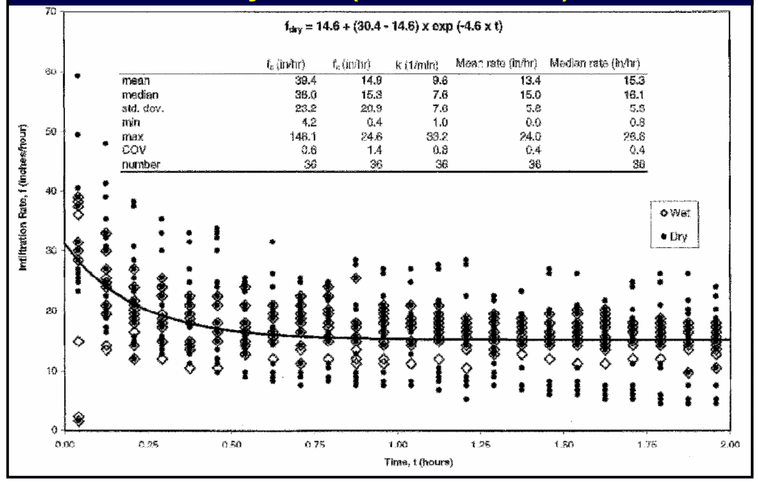
Sandy Soils



Clayey Soils

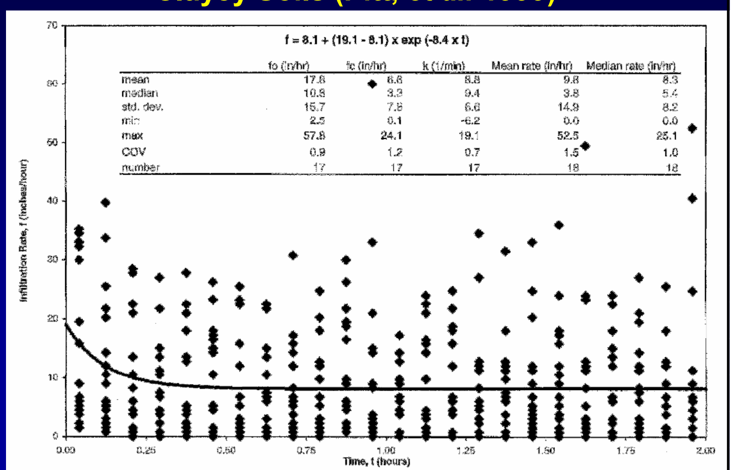
Recent research has shown that the infiltration rates of urban soils are strongly influenced by compaction, probably more than by moisture saturation.

Infiltration Measurements for Noncompacted, Sandy Soils (Pitt, *et al.* 1999)



	f_o (in/hr)	f_c (in/hr)	k (1/min)	Mean rate (in/hr)	Median rate (in/hr)
mean	39.4	14.9	9.6	13.4	15.3
median	38.0	15.3	7.6	15.0	16.1
std. dev.	23.2	20.9	7.6	5.8	5.5
min	4.2	0.4	1.0	0.0	0.8
max	146.1	24.6	33.2	24.0	26.6
COV	0.6	1.4	0.8	0.4	0.4
number	36	36	36	36	36

Infiltration Measurements for Dry-Noncompacted, Clayey Soils (Pitt, *et al.* 1999)



	fo (in/hr)	fc (in/hr)	k (1/min)	Mean rate (in/hr)	Median rate (in/hr)
mean	17.8	6.6	8.8	9.8	8.3
median	10.8	3.3	9.4	3.8	5.4
std. dev.	15.7	7.8	6.6	14.9	8.2
min	2.5	0.1	-6.2	0.0	0.0
max	57.8	24.1	19.1	52.5	25.1
COV	0.9	1.2	0.7	1.5	1.0
number	17	17	17	18	18

Results of Infiltration Tests in Disturbed Urban Soils

- Four general categories were found to be unique:
  - –Noncompacted sandy soils
  - –Compacted sandy soils
  - –Dry, noncompacted clayey soils
  - –All other clayey soils (compacted and dry, plus all saturated conditions)

Infiltration Rates during Tests of Disturbed Urban Soils

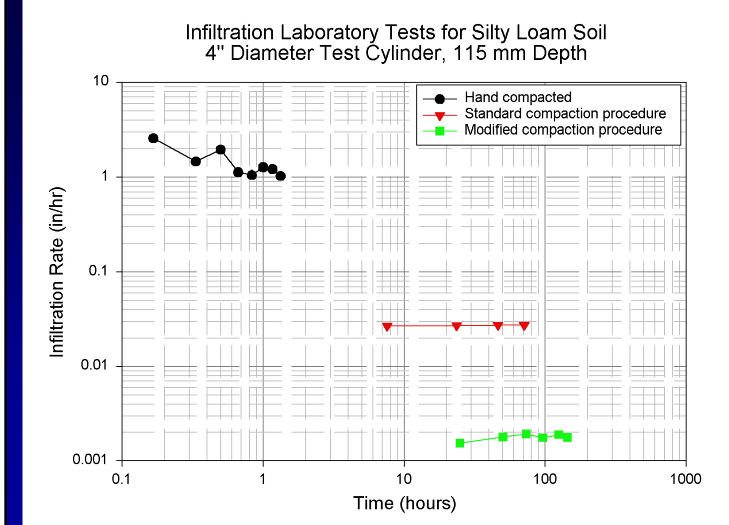
	Number of tests	Average infiltration rate (in/hr)	COV
Noncompacted sandy soils	36	13	0.4
Compacted sandy soils	39	1.4	1.3
Noncompacted and dry clayey soils	18	9.8	1.5
All other clayey soils (compacted and dry, plus all wetter conditions)	60	0.2	2.4

Method

- These newer tests were run for up to 20 days, although most were completed (when steady low rates were observed) within 3 or 4 days.
- Initial soil moisture levels were about 8% (sand was about 3%), while the moisture levels after the tests ranged from about 20 to 45%.
- Three methods were used to compact the test specimens: hand compaction, plus two Proctor test methods.
- Both Modified and Standard Proctor Compactions follow ASTM standard (D 1140-54).

Test Mixtures for Laboratory Tests

	Sand	Clay	Silt	Sandy loam	Clayey loam	Silty loam	Clay mix
% sand	**100**			**72.1**	**30.1**	**19.4**	**30**
% clay		**100**		**9.2**	**30.0**	**9.7**	**50**
% silt			**100**	**18.7**	**39.9**	**70.9**	**20**

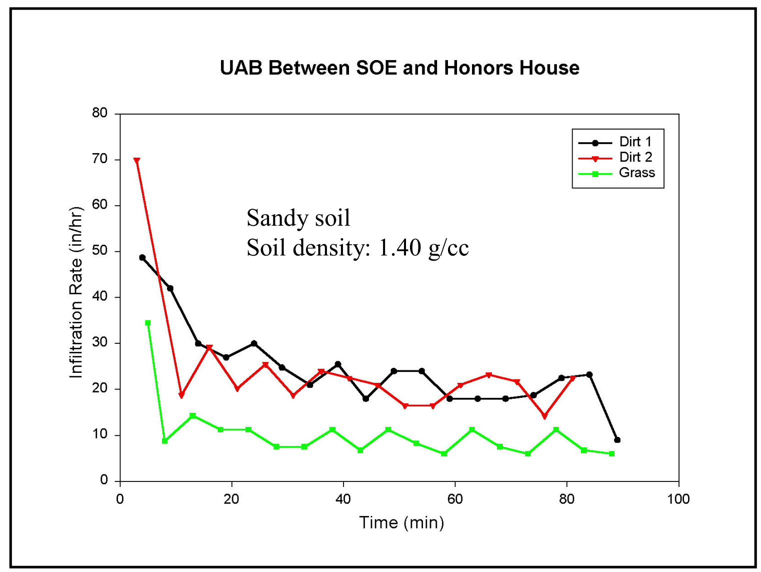


Long-Term Sustainable Average Infiltration Rates

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (in/hr)
Silt	Hand	1.508	May affect	0.7
	Standard	1.680	May affect +	0.034
	Modified	1.740	Restrict	0.0030
Sand	Hand	1.451	Ideal	Very high
	Standard	1.494	Ideal	0.5 ?
	Modified	1.620	May affect -	3.2
Clay	Hand	1.241	May affect	0.12
	Standard	n/a	n/a	0
	Modified	n/a	n/a	0

Long-Term Sustainable Average Infiltration Rates (cont.)

Soil Texture	Compaction Method	Dry Bulk Density (g/cc)	Effects on Root Growth (per NRCS)	Long-term Average Infilt. Rate (in/hr)
Sandy Loam	Hand	1.595	May Affect	35
	Standard	1.653	May Affect	9
	Modified	1.992	Restrict	1.5
Silt Loam	Hand	1.504	May Affect	1.3
	Standard	1.593	May Affect	0.027
	Modified	1.690	May Affect +	0.0017
Clay Loam	Hand	1.502	May Affect	0.29
	Standard	1.703	Restrict	0.015
	Modified	1.911	Restrict	0



Subsurface Exploration Needed for Design of Large Infiltration Systems

- Backhoe Test Pits
- Test Borings
- Monitoring Wells

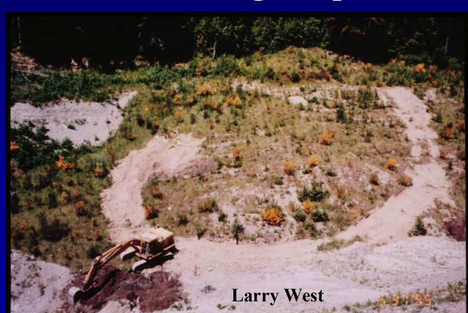
Site Characterization Costs

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



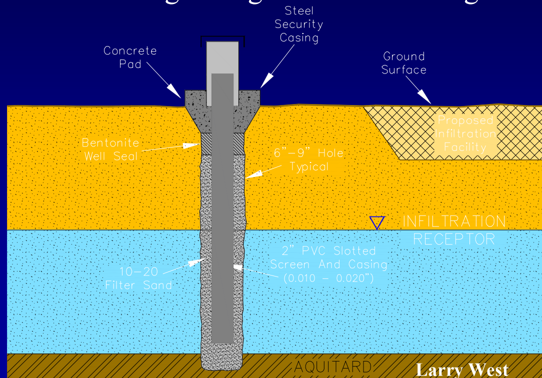
Test Borings

- Hollow Stem Auger
- Rotary Drill
- Cable Tool
- Bucket Rig
- Sampling Techniques

Hollow Stem Auger

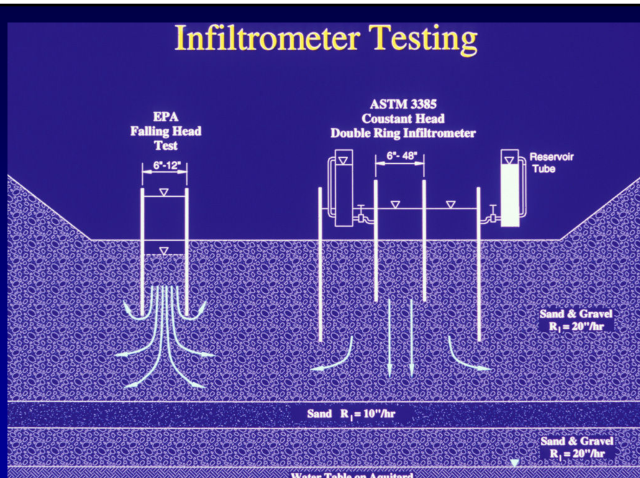
Monitoring Wells

- Measure water level changes over time
- Assist in determining seasonally high water levels
- Monitor mounding during infiltration testing



Correction Factors

- Correction factors are typically used to reduce the field measured infiltration values to values that should be considered for design.
- 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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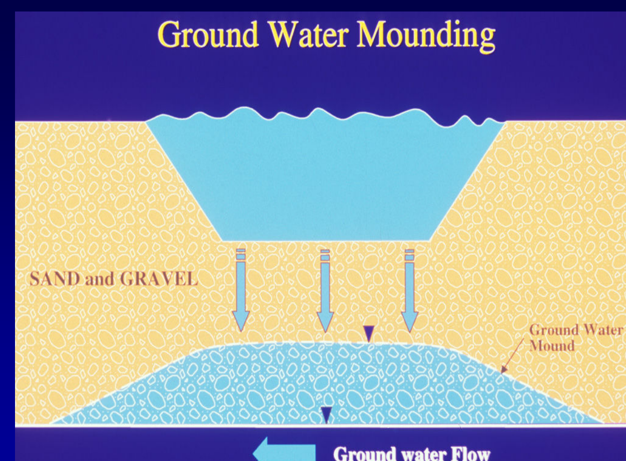

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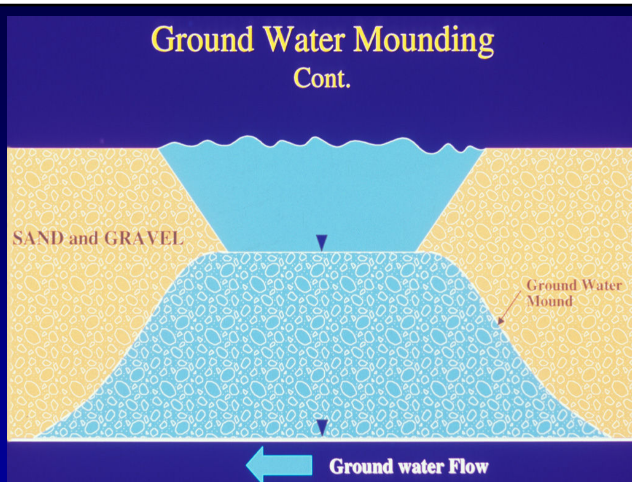

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Ground Water Mounding "Rules of Thumb"

- 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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Table 7.1 (Western Washington Stormwater Management Manual)

RECOMMENDED INFILTRATION RATES BASED ON USDA SOIL TEXTURAL CLASSIFICATION

USDA SCS 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

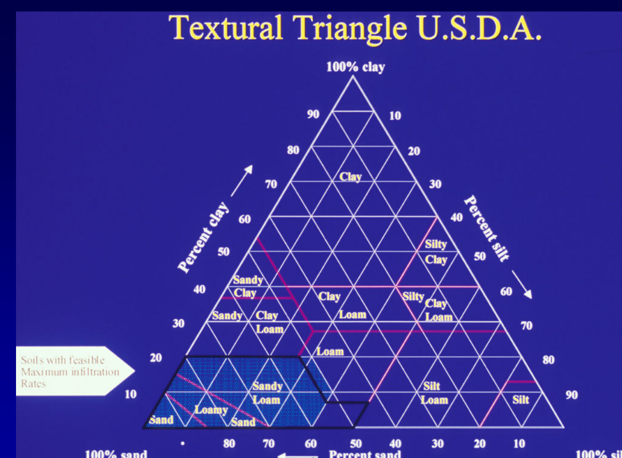


Table 7.2 (Western Washington Stormwater Management Manual)

ALTERNATIVE INFILTRATION RATES BASED ON ASTM GRADATION TESTING

D_{10} Size from ASTM D422 Soil Gradation Test (mm)	Estimated Long-Term (Design) Infiltration Rate (in./hr)
$\geq$ 0.4	9*
0.3	6.5*
0.2	3.5*
0.1	2.0**
0.05	0.8

* Not recommeded for treatment
** Refer to SSC-4 and SSC-6 for treatment acceptability criteria

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

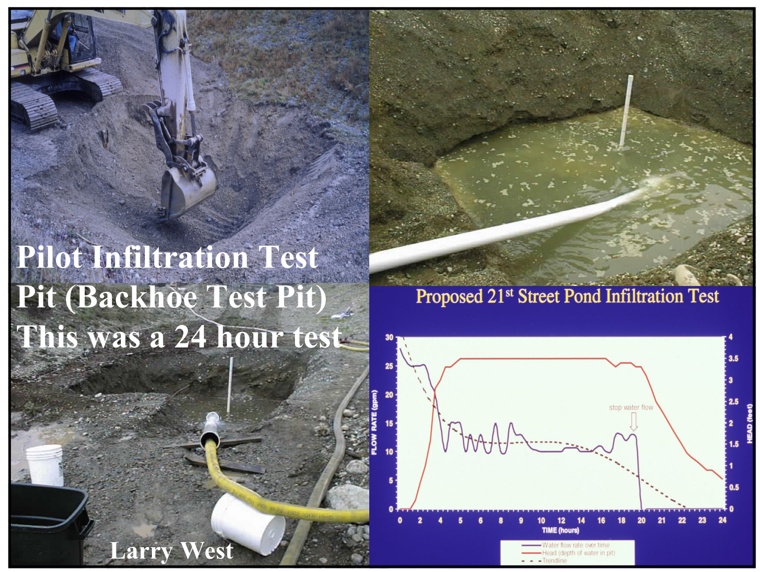
Issue	Partial Correction Factor
Site variability and number of locations tested	CF_v +1.5 to 6
Degree of long-term maintenance to prevent siltation and bio-buildup	CF_m+2 to 6
Degree of influent control to prevent siltation and bio-buildup	CF_i +2 to 6

Total Correction Factor $(CF)=CF_v+CF_m+CF_i$

Design Infiltration Rate

In-situ Field Testing

- Pilot Infiltration Test
- Correction Factors
  - Site variability
  - Long-term maintenance
  - Influent control
- Conservative correction factors
- Suggest comparing with texture/D_{10}



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

Thurston County (Olympia, WA) Table 3.9 Draft

Issue	Partial Correction Factor
Site Variability and number of PIT Test Locations	• Homogeneous soils, multiple PIT tests, CF = 1 • Homogeneous soils, one PIT test, CF = 1.5 • Non-homogeneous soils, multiple PIT tests, CF = 1.5 • Non-homogeneous soils, one PIT test, CF = 2
Maintenance effects on infiltration surface performance	• Al surface facilities, CF = 1.5 • All underground facilities, CF = 2
Watershed effects on infiltration surface performance	• Watershed with at least 65% impervious or with mainly Hydrologic Group A soils, CF = 1.25 • Watershed with less than 65% impervious and having mainly Hydrologic Group B soils, CF = 2; Hydrologic Group or D soils, CF = 3

Composite correction factor = Product of three partial correction factors. Product range = 1.88 minimum to 12 maximum. The design infiltration rate is equal to the average of all PIT tests divided by the composite correction factor. In no case shall the design infiltration rate exceed 20 inches per hour.

Long-Term Design Rates 21st Street Percolation Pond

Issue	Correction Factor	Example	Actual Correction Factor
Site Variability # of Tests	1.5 - 6	Recessional Outwash	1.5
Maintenance	2 - 6	Open Easy Access	2
Pre-Treatment	2 - 6	Good 1 Pond	4
Total Correction Factor	5.5 - 18		7.5

Therefore: Test Infiltration Rate = 12 inches/hour
Design Infiltration Rate = 12/7.5 = 1.6 inches/hour

Soil Restoration

- Mechanical aerators
- Natural soil processes
- Prevent compaction
- Amend soil

Recent Research Investigating Potential Groundwater and Stormwater Interactions

- Grass swales (different grasses and soils, and amended soils)
- Infiltration rates through disturbed urban soils (greatly affected by compaction)
- Soil amendments to improve infiltration in urban soils and to remove stormwater pollutants
- Column studies to test different material for amendments
- Large-scale and micro-scale water mass balances at locations using infiltration as a stormwater control

Amended Soil Compared to Unamended Soil

Constituent	Surface Runoff Mass Discharges	Subsurface Flow Mass Discharges
Runoff Volume	0.09	0.29
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

Significant removals (%) after 18 inch flow path

	Loam	Peat-Sand	Compost -Sand	Sand
Turbidity (unfiltered)		68 (0.04)	65 (0.01)	75 (0.01)
Total Solids		35 (0.05)		4 (0.01)
Dissolved Solids		40 (0.02)		
Hardness	13 (0.04)	68 (0.01)		
Calcium (total)	20 (0.01)	96 (0.02)		
Iron (total)		42 (0.05)	44 (0.05)	

	Soil-only plots		Percent reductions in average concentrations after infiltration
Constituent (mg/L)	Surface Runoff	Subsurface Flows	
PO_4-P	0.27 (1.4)	0.17 (2.0)	37%
TP	0.49 (1.0)	0.48 (2.2)	10
NH_4-N	0.65 (1.7)	0.23 (1.3)	65
NO_3-N	0.96 (1.4)	1.2 (2.5)	-125
TN	2.5 (0.9)	1.9 (0.7)	24
Cl	2.4 (1.0)	2.1 (0.9)	13
SO_4-S	0.68 (1.1)	0.95 (2.0)	-140

Constituent (mg/L)	Soil-only plots: Surface Runoff	Soil-only plots: Subsurface Flows	Percent reductions in average concentrations after infiltration
Al	11 (1.8)	1.7 (2.1)	85
Ca	12 (1.5)	17 (0.7)	-140
Cu	0.01 (0.8)	0.01 (1.6)	n/a
Fe	4.6 (1.4)	2.8 (1.6)	39
K	5.4 (1.0)	4.6 (0.8)	15
Mg	3.9 (0.8)	5.0 (0.6)	-128
Mn	0.75 (2.9)	0.41 (2.8)	45
Na	3.8 (0.9)	3.4 (0.5)	11
S	1.1 (0.8)	1.3 (1.5)	-120
Zn	0.2 (1.2)	0.05 (2.2)	75
Si	26 (1.7)	8.9 (0.5)	66

The following lists the categories of pollutants associated with each range of concentration reduction (12 inches of soil):

Large reductions (≥75%):
Al, Zn

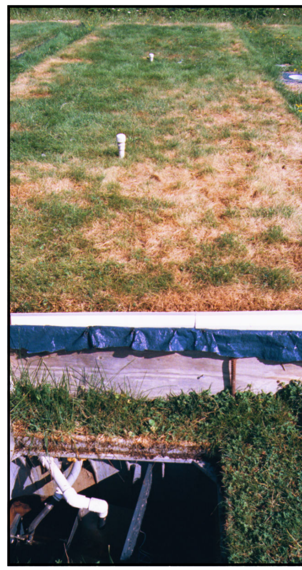
Moderate reductions (25 to 74%):
NH_4, Si, PO_4, Fe, Mn

Minimal reductions, or increases (<24%):
TP, TN, Cl, K, Na, NO_3, SO_4, Ca, Mg, S

Metals are removed much better than nutrients, and some major ions actually increase (due to ion exchange or leaching).

Effects of Compost-Amendments on Runoff Properties

- Another portion of the EPA-funded research was conducted by Dr. Rob Harrison, of the University of Washington
- They examined the benefits of adding large amounts of compost to glacial till soils at the time of land development



Water Quality and Quantity Effects of Amending Urban Soils with Compost

- Surface runoff rates and volumes decreased by five to ten times after amending the soils with compost, compared to unamended sites.
- Unfortunately, the concentrations of many pollutants increased in surface runoff from amended soils, 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.

Amended Soil Compared to Unamended Soil

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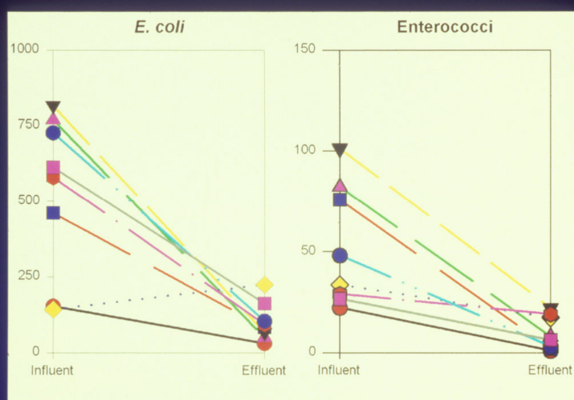
Zinc	0.061	0.18

E. coli AND *Enterococci* REMOVAL



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

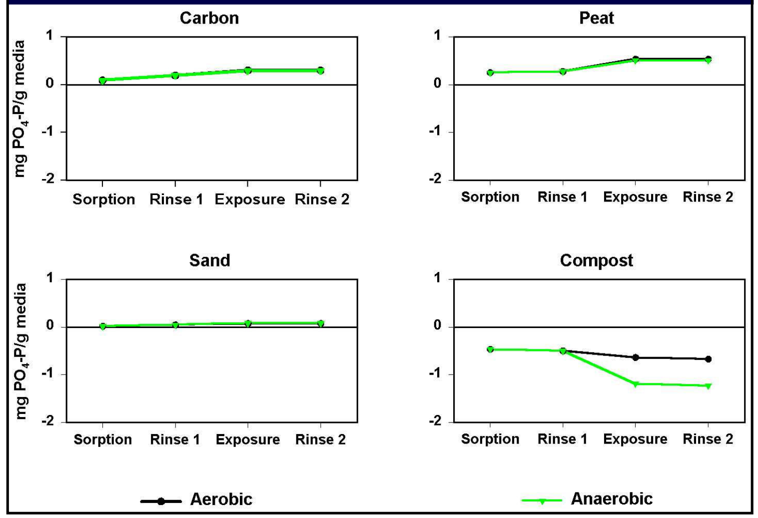
Enhanced Infiltration with Amendments

	Average Infiltration Rate (cm/h) (in/h)
UW test plot 1 Alderwood soil alone	1.2 (0.5)
UW test plot 2 Alderwood soil with Ceder Grove compost (old site)	7.5 (3.0)
UW test plot 5 Alderwood soil alone	0.8 (0.3)
UW test plot 6 Alderwood soil with GroCo compost (old site)	8.4 (3.3)
Timbercrest test plot Alderwood soil alone	0.7 (0.3)
Timbercrest test plot Alderwood soil with Cedar Grove compost (new site)	2.3 (0.9)
Woodmoor test plot Alderwood soil alone	2.1 (0.8)
Woodmoor test plot Alderwood soil with Cedar Grove compost (new site)	3.4 (1.3)

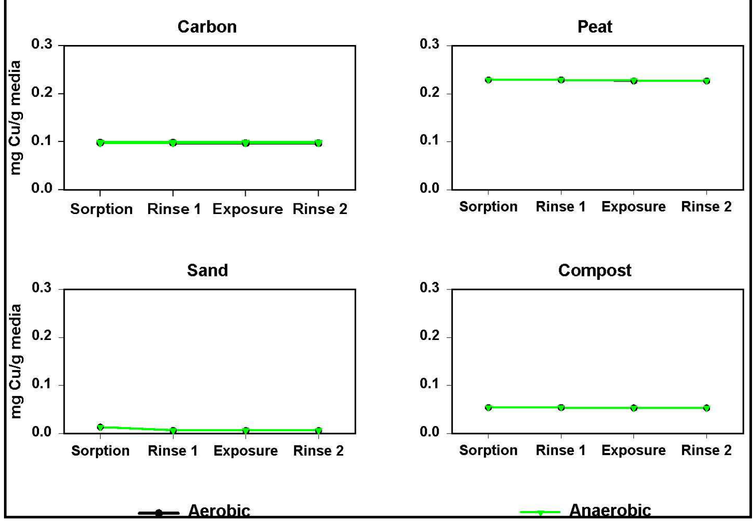
General rankings in pollutant removal capabilities of the different media tested with stormwater:

- Activated carbon-sand mixture (very good removals with minimal to no degradation of effluent)
- Peat-sand mixture (very good removals, but with some degradation of effluent with higher turbidity, color, and COD)
- Zeolite-sand mixture and sand alone (some removals with minimal degradation of effluent)
- Enretech (a cotton processing mill waste)-sand mixture (some removals with minimal degradation of effluent)
- Compost-sand mixture (some removals but with degradation of effluent with higher color, COD, and solids)

Behavior of phosphate under aerobic and anaerobic conditions



Behavior of copper under aerobic and anaerobic conditions



Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio can radically affect the performance of an infiltration device. Soils with an excess of sodium ions, compared to calcium and magnesium ions, remain in a dispersed condition, almost impermeable to rain or applied water.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+2} + Mg^{+2})}{2}}}$$

An SAR value of 15, or greater, indicates that an excess of sodium will be adsorbed by the soil clay particles. This can cause the soil to be hard and cloddy when dry, to crust badly, and to take water very slowly. SAR values near 5 can also cause problems, depending on the type of clay present.

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) can greatly increase the CEC of a soil that is naturally low in organic material, or clays.

- Problem: Determine the approximate "life" of the CEC of a soil in an infiltration device having the following characteristics:

- the soil in an urban infiltration device has a CEC of 200 meq/L (averaged for ½ m in depth and soil had a dry density of 1.6 g/cm3),
- receives the runoff from a paved area 30 times the area of the infiltration device,
- 1 m of rainfall a year, and paved area Rv is 0.85, and
- the total cation content of the runoff water is 1.0 meq/L

•**Solution**:

- total CEC content of soil (per m^2):

$$0.5\,m^3 \times \frac{1.6\,g}{cm^3} \times \frac{(100\,cm)^3}{m^3} \times \frac{200\,meq}{100\,g} = 1{,}600{,}000\,meq$$

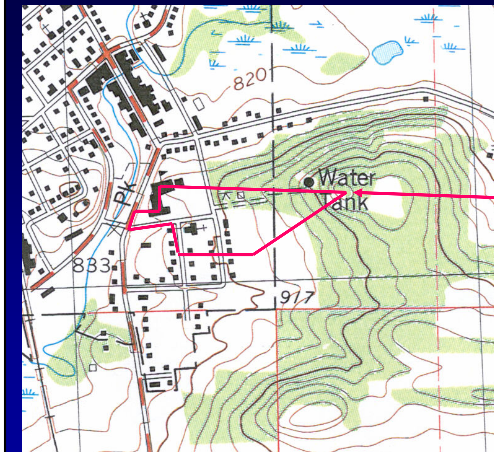
- total cation content of a years worth of runoff (per 30 m^2):

$$30\,m^2 \times \frac{0.85\,m}{year} \times \frac{(1000\,L)}{m^3} \times \frac{1\,meq}{L} = \frac{25{,}500\,meq}{year}$$

- therefore, the unit's CEC would be able to protect the groundwater for about 63 years, a suitable design period. However, if the soil CEC was only 5 meq/100 grams, then the facility would only protect the groundwater for about 3 years. In this case, either the infiltration device should be made larger, the contributing paved area made smaller, or the soil will have to be replaced every several years.

Case Studies of Enhanced Infiltration

Lodi, WI, Transportation Area Rain Garden



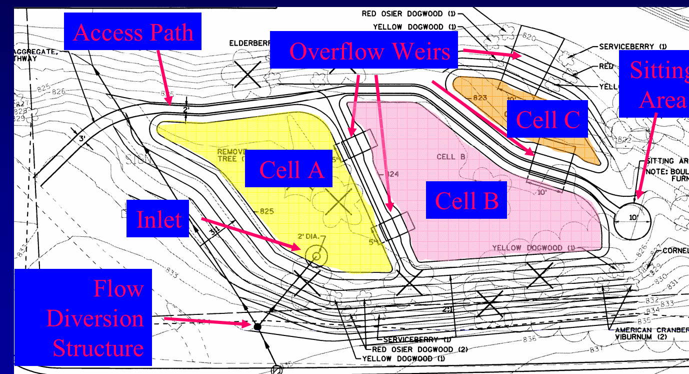
Drainage Basin Area = 16 acres

Paved Area – 20%

City of Lodi, Columbia County

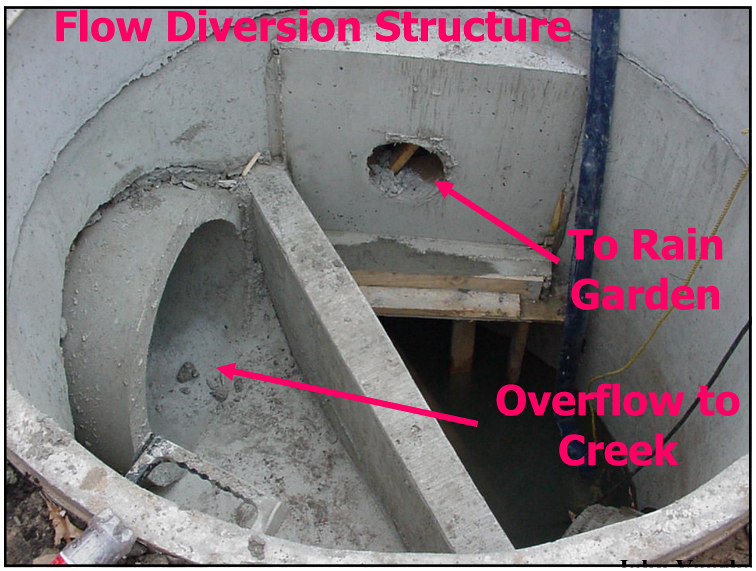
John Voorhees

Rain Garden Features

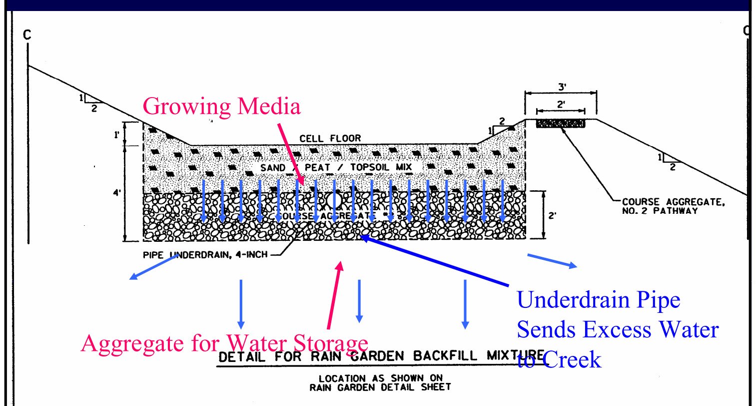


John Voorhees

Flow Diversion Structure



Rain Garden Backfill Material



John Voorhees

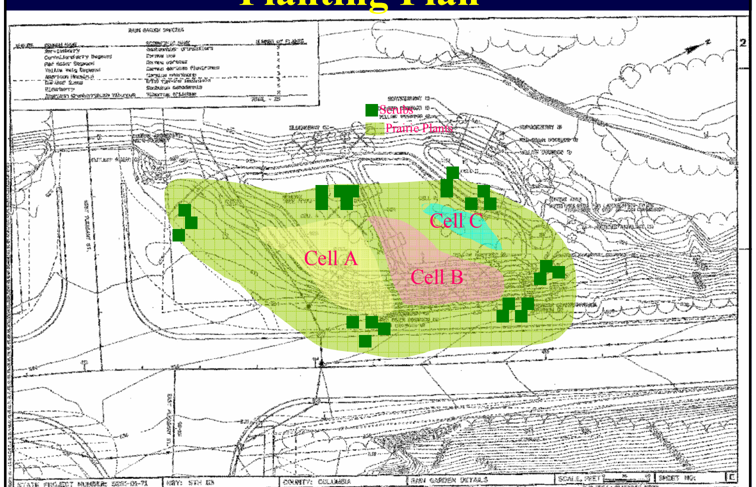

Soil Mixing
John Voorhees


Cell A
John Voorhees


Cell A
Cell B
John Voorhees


Cell C
John Voorhees

Planting Plan



John Voorhees

Lodi, WI, Rain Garden Costs

Pipe Underdrain and Endwalls	$700
Flow Regulation Structure	$3000
Plants	$2200
Shrubs	$450
Backfill	$11600
Excavation	$2200
Select Crushed Material/Riprap	$3850
Storm Sewer and Manholes	$3500
Total $4.70/sf	$27500

John Voorhees

Case Study

Issaquah Highlands Development

The right way to deal with a tough infiltration problem!

Larry West

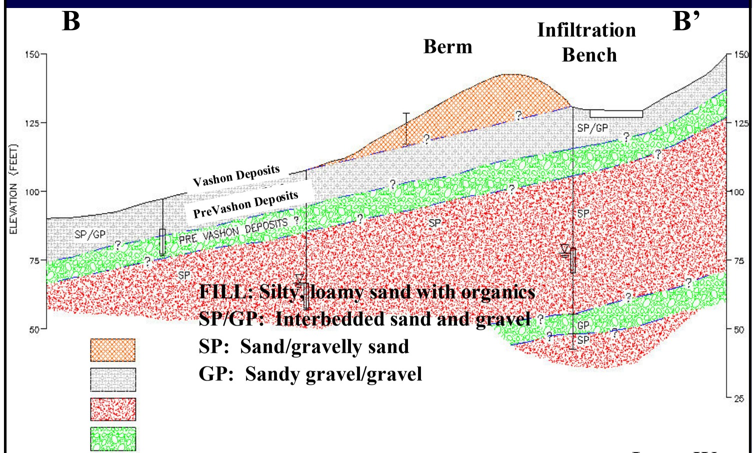
Issaquah Highlands Development

Issaquah Highlands Development

Larry West

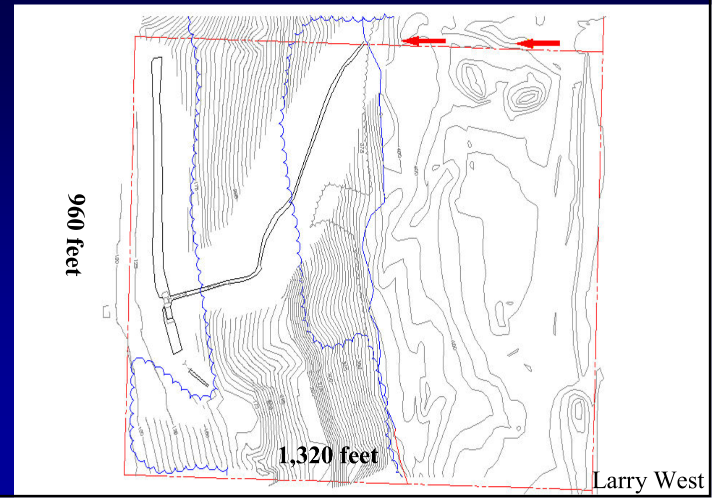
Infiltration Bench

Reid Bench Geology



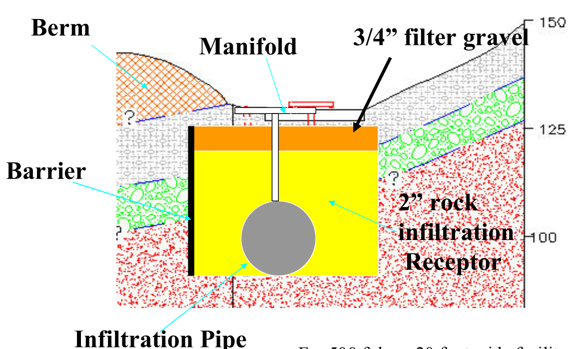
Larry West

Site Map



Larry West

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

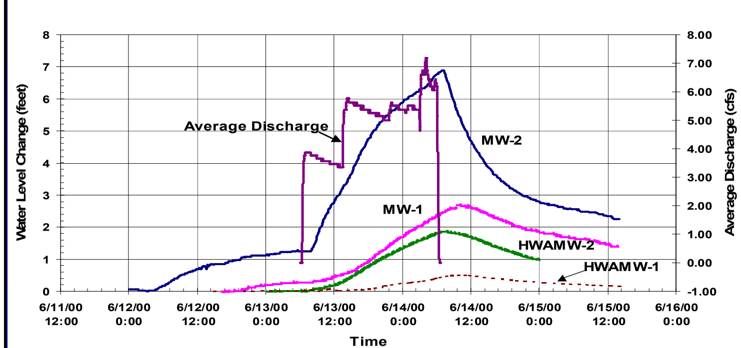
Larry West

Source Water Weir

Energy Block Dissipater

Discharge Flow Dissipater

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



Infiltration Rate Calculations

Summary of Flow Rates for 24-hour Infiltration Test

Time (hours)	Size of Infiltration Area (feet)	Water Depth (feet)	Average Flow Rate (CFS)	Cumulative Discharge (cubic feet)	Estimated Infiltration Rate (inches/hour)
5.5	205 X 15	0.3 to 0.7	3.7	91,000	52
13.5	152 X 15	0.4 to 0.7	5.4	261,000	62
3	255 X 15	0.4 to 0.7	6.6	74,000	75

Comparison of Infiltration Rates

Type of Test	Infiltration Rate (inches/hour)	Test Method
Grain Size	20	USDA Textural
2-hour Double Ring Infiltrometer	7 to 15	ASTM 3385
24-hour Pilot Infiltration Test	32 to 65	DOE 2001, App. V-b
Full-scale Test	52 to 75	

Larry West

Long-Term Design Rates
21st Street Percolation Pond

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		6.5

Therefore: Test Infiltration Rate = 52-75 inches/hour
Design Infiltration Rate = 52-75/6.5 = 8 to 12 inches/hour

Larry West

WinSLAMM v 9.1
Biofiltration

- Biofilter Model Algorithms
- Entering Biofilter Data into the Model
- Model Output

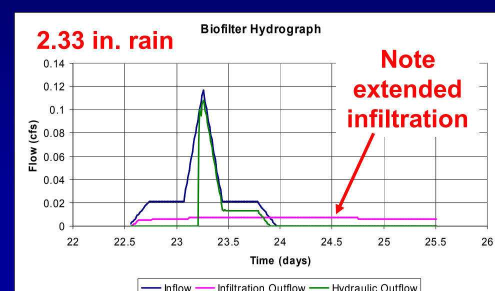
John Voorhees, PE, PH
Earth Tech, Inc.

Modeling Notes

- Biofilter routing is performed using the Modified Puls Storage – Indication Method.
- Time increments are established by the model and vary by event.
- Yield reductions due to runoff volume reduction through infiltration

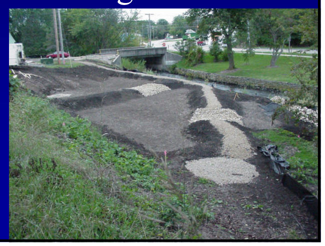
Biofilter Hydrograph Creation

- Flow rate calculated using Complex Triangular Hydrograph
  - Runoff Volume calculated from WinSLAMM
  - Runoff Duration = 1.2 times rainfall duration

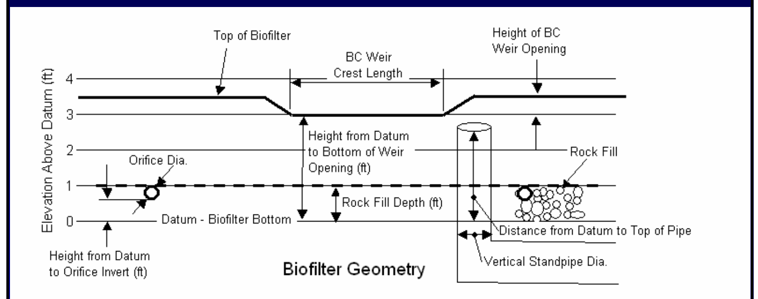


Four Components to Modeling Biofilters

1. Structure Geometry
2. Outlet Information
3. Infiltration Data
4. Hydrograph and Flow Routing Information

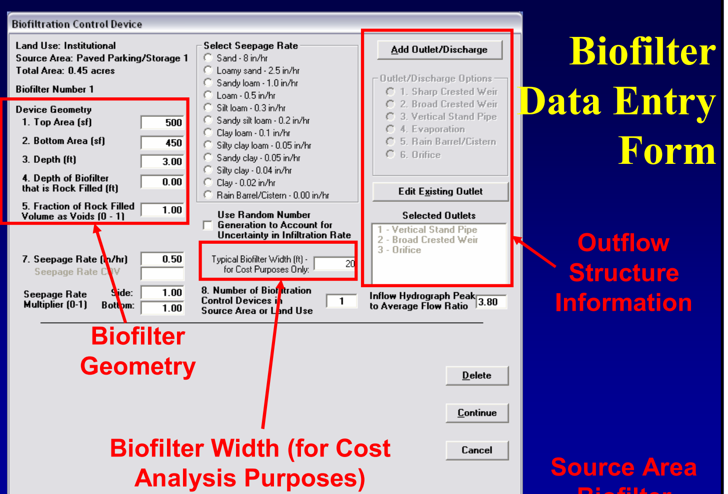


Biofilter Geometry



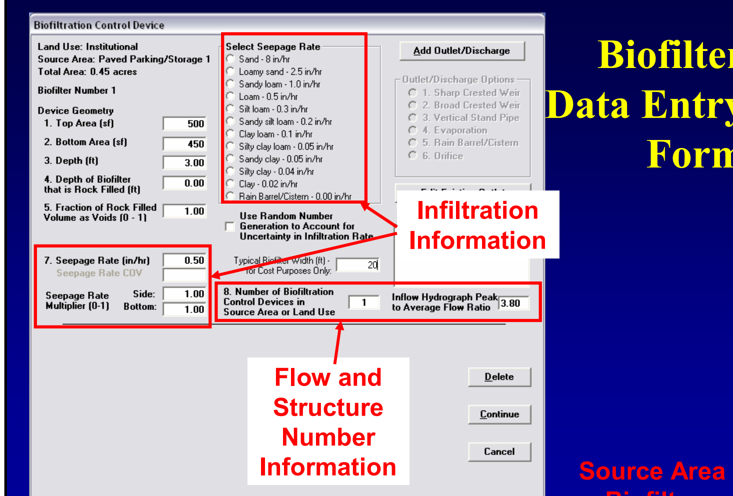
Biofilter Datum is always zero ft.

Biofilter Data Entry Form

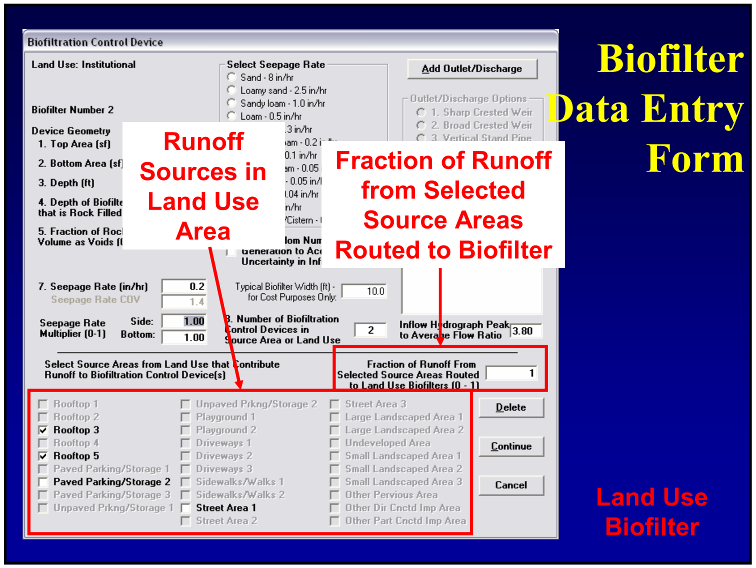


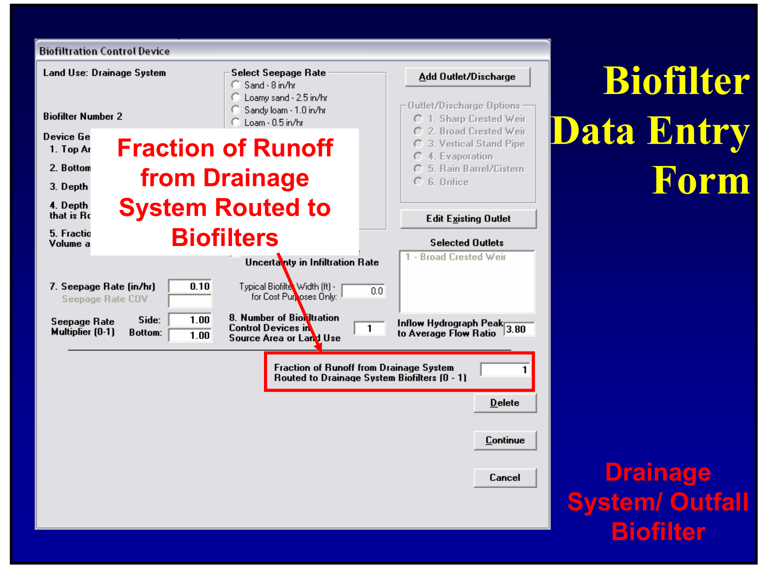
Source Area Biofilter

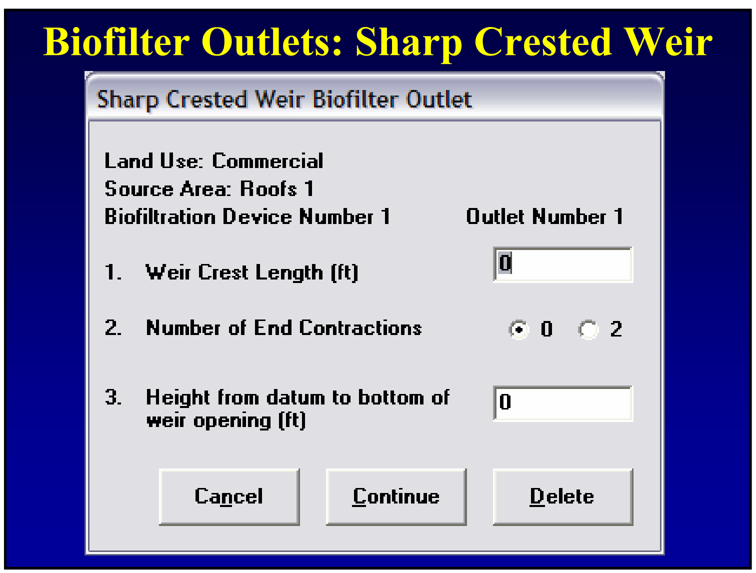
Biofilter Data Entry Form

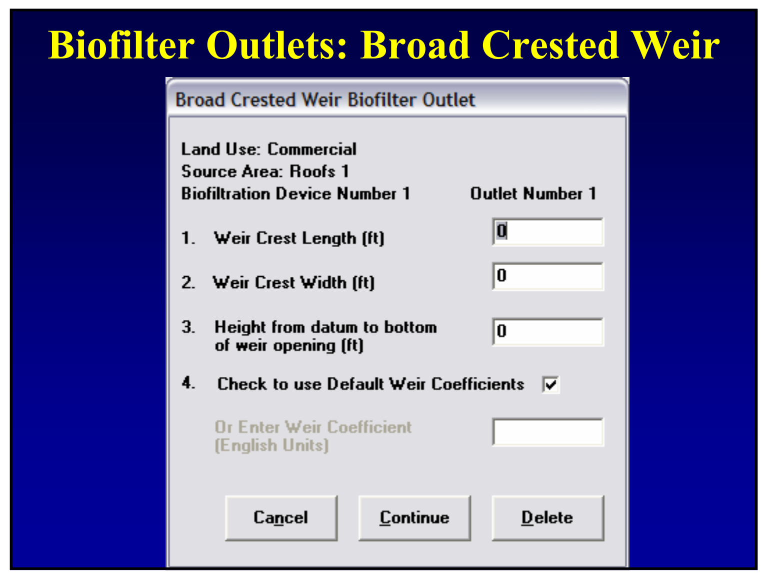


Source Area Biofilter


Biofilter Data Entry Form
Runoff Sources in Land Use Area
Fraction of Runoff from Selected Source Areas Routed to Biofilter
Land Use Biofilter
Biofiltration Control Device
Land Use: Institutional
Biofilter Number 2
Select Seepage Rate
Add Outlet/Discharge
Delete
Continue
Cancel


Biofilter Data Entry Form
Fraction of Runoff from Drainage System Routed to Biofilters
Drainage System/ Outfall Biofilter
Biofiltration Control Device
Land Use: Drainage System
Biofilter Number 2
Fraction of Runoff from Drainage System Routed to Drainage System Biofilters (0 - 1)
Delete
Continue
Cancel


Biofilter Outlets: Sharp Crested Weir
Sharp Crested Weir Biofilter Outlet
Land Use: Commercial
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 1
1. Weir Crest Length (ft)
2. Number of End Contractions
3. Height from datum to bottom of weir opening (ft)
Cancel
Continue
Delete


Biofilter Outlets: Broad Crested Weir
Broad Crested Weir Biofilter Outlet
Land Use: Commercial
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 1
1. Weir Crest Length (ft)
2. Weir Crest Width (ft)
3. Height from datum to bottom of weir opening (ft)
4. Check to use Default Weir Coefficients
Or Enter Weir Coefficient (English Units)
Cancel
Continue
Delete

Biofilter Outlets: Vertical Stand Pipe

Vertical Stand Pipe Biofilter Outlet

Land Use: Commercial
Source Area: Roofs 1
Biofiltration Device Number 1 Outlet Number 1

1. Pipe Diameter (ft) 0

2. Distance From Basin Bottom to Top of Pipe (ft) 0

Cancel Continue Delete

Biofilter Outlets: Evaporation

Biofilter Evaporation

Land Use: Commercial
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 1

Month	Evaporation Rate (in/day)
January	0.00
February	0.00
March	0.00
April	0.00
May	0.00
June	0.00
July	0.00
August	0.00
September	0.00
October	0.00
November	0.00
December	0.00

Cancel Continue Delete

Biofilter Outlets: Rain Barrel / Cistern

Biofilter Cistern

Land Use: Commercial
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 1

Month	Water Use Rate (gal/day)
January	0.00
February	0.00
March	0.00
April	0.00
May	0.00
June	0.00
July	0.00
August	0.00
September	0.00
October	0.00
November	0.00
December	0.00

Cancel Continue Delete

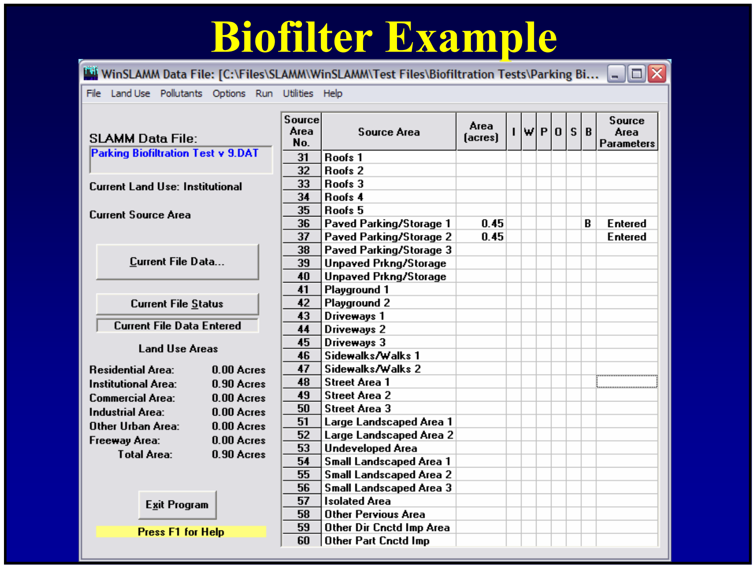
Biofilter Outlets: Orifice Outlet

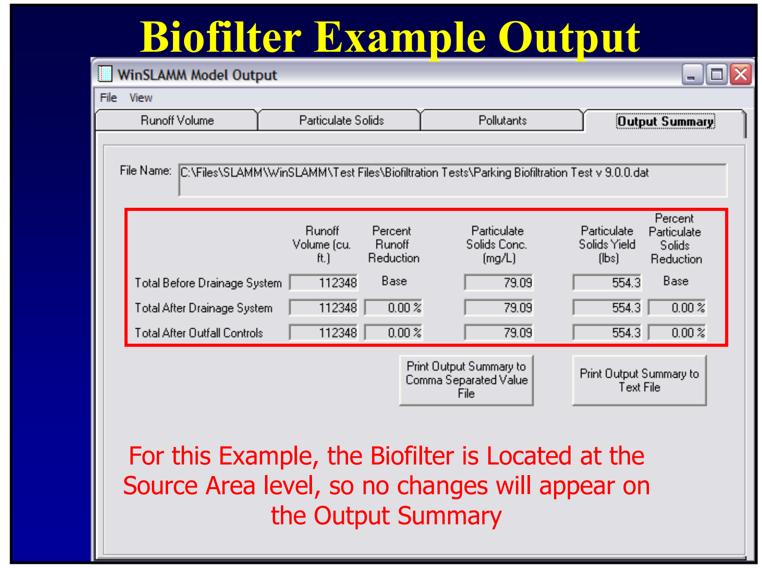
Biofilter Orifice Outlet

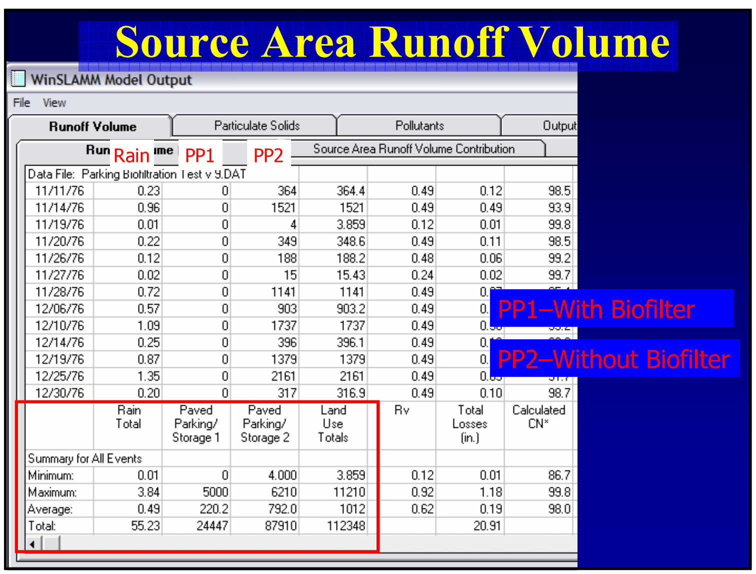
Land Use: Drainage System
Source Area: Drainage System
Biofiltration Device Number 1 Outlet Number 2

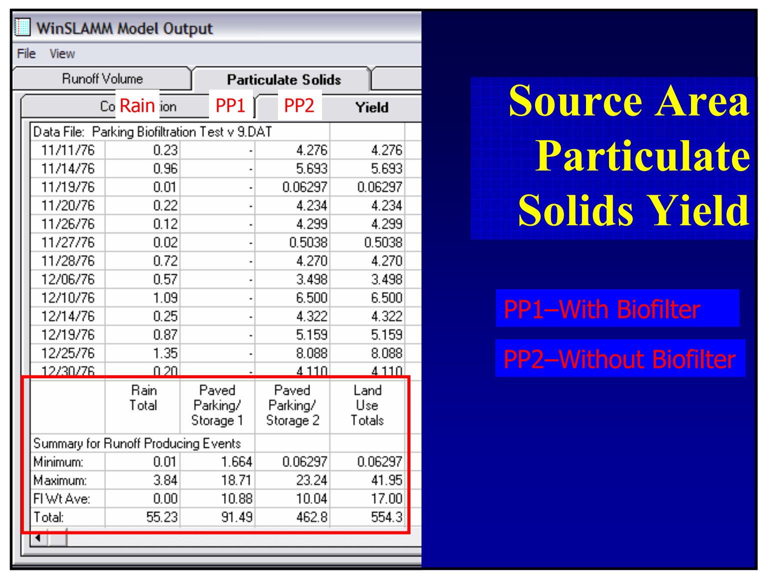
1. Orifice diameter (ft) .25
2. Invert elevation above datum (ft) 1.5
3. Number of Orifices 3

Cancel Continue Delete


Biofilter Example
WinSLAMM Data File: [C:\Files\SLAMM\WinSLAMM\Test Files\Biofiltration Tests\Parking Bi...
SLAMM Data File:
Parking Biofiltration Test v 9.DAT
Current Land Use: Institutional
Paved Parking/Storage 1 0.45
Paved Parking/Storage 2 0.45
Institutional Area: 0.90 Acres
Total Area: 0.90 Acres
Press F1 for Help


Biofilter Example Output
WinSLAMM Model Output
File Name: C:\Files\SLAMM\WinSLAMM\Test Files\Biofiltration Tests\Parking Biofiltration Test v 9.0.0.dat
Total Before Drainage System 112348 Base 79.09 554.3 Base
Total After Drainage System 112348 0.00 % 79.09 554.3 0.00 %
Total After Outfall Controls 112348 0.00 % 79.09 554.3 0.00 %
For this Example, the Biofilter is Located at the Source Area level, so no changes will appear on the Output Summary


Source Area Runoff Volume
WinSLAMM Model Output
Rain
PP1
PP2
Total: 55.23 24447 87910 112348
PP1–With Biofilter
PP2–Without Biofilter


Source Area Particulate Solids Yield
WinSLAMM Model Output
Rain
PP1
PP2
Yield
Total: 55.23 91.49 462.8 554.3
PP1–With Biofilter
PP2–Without Biofilter

Additional Output

- StageOutflowBF.csv
- <filename>.SEP
- <filename>. BFO
- <filename>BWB & <SANum>.csv

Biofilter Water Balance Performance Summary, by Event

BioF Source Area Number	Rain Number	Rain Depth (in)	Time (Julian Date)	Maximum BioF Stage (ft)	Minimum BioF Stage (ft)	Event Inflow Volume (ac-ft)	Event Hydr Outflow (ac-ft)	Event Infil Outflow (ac-ft)	Event Evap Outflow (ac-ft)	Event Cistern Outflow (ac-ft)	Event Orifice Outflow (ac-ft)	Event Total Outflow (ac-ft)	Event Flow Balance (ac-ft)	Volume Reduction Fraction	Solids Reduction Fraction
7	1	0.01	0	0.12	0	0	0	0	0	0	0	0	0	1	0
7	2	0.05	31	0.57	0	0.007	0	0.001	0	0	0.006	0.007	0	0.183	0
7	3	0.1	59	0.71	0	0.015	0	0.002	0	0	0.013	0.015	0	0.095	0
7	4	0.25	90	1.2	0	0.042	0	0.002	0	0	0.041	0.042	0	0.043	0
7	5	0.5	120	2.03	0	0.084	0	0.002	0	0	0.082	0.084	0	0.024	0
7	6	0.75	151	2.46	0	0.125	0	0.002	0	0	0.122	0.125	0	0.018	0
7	7	1	181	2.5	0	0.165	0.007	0.002	0	0	0.156	0.165	0	0.014	0
7	8	1.5	212	2.52	0	0.249	0.034	0.003	0	0	0.213	0.249	0	0.01	0
7	9	2	243	2.52	0	0.335	0.066	0.003	0	0	0.266	0.335	0	0.008	0
7	10	2.5	273	2.53	0	0.416	0.087	0.003	0	0	0.326	0.416	0	0.008	0
7	11	3	304	2.52	0	0.497	0.097	0.004	0	0	0.396	0.497	0	0.008	0
7	12	4	334	2.53	0	0.661	0.149	0.004	0	0	0.507	0.661	0	0.007	0