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MSCE, San Jose State University, San Jose, CA 1971.
Ph.D., Environmental Engineering, University of Wisconsin, Madison, WI 1987.
35 years working in the area of wet weather flows; effects, sources, and control of stormwater. About 100 publications.

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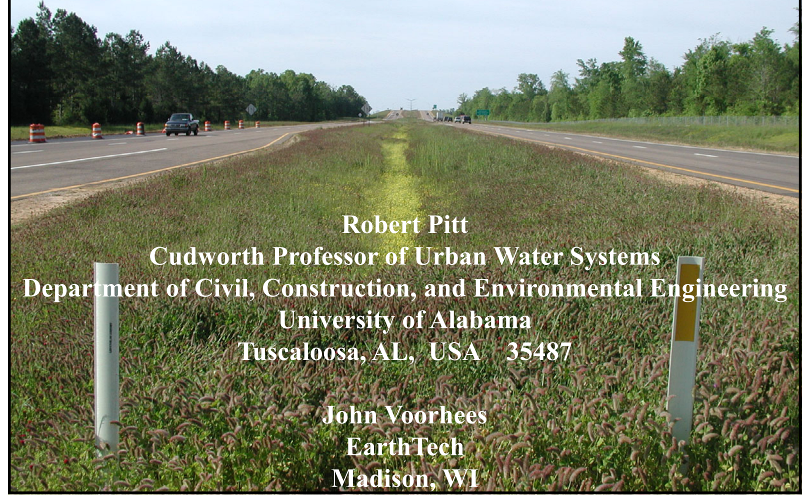
Evapotranspiration Calculations for Stormwater Quality Models



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Rain Garden Designed for Complete Infiltration of Roof Runoff

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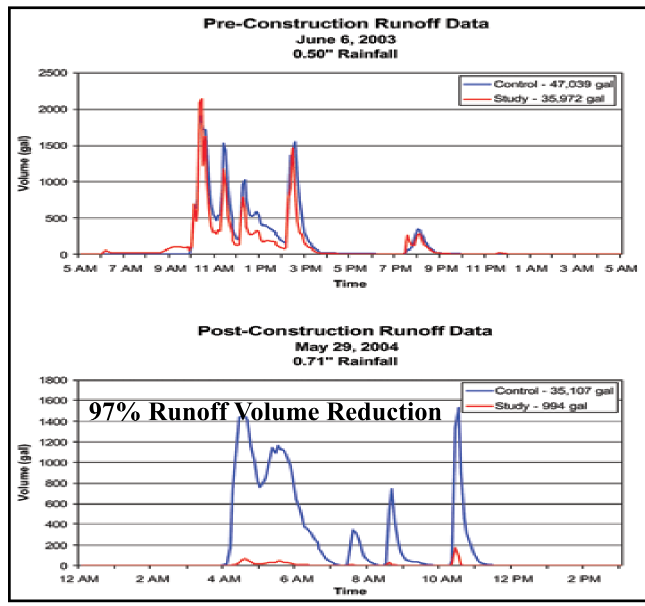

Land and Water, Sept/Oct. 2004

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

Annual roof runoff volume reductions	Birmingham, Alabama (55.5 in.)	Seattle, Wash. (33.4 in.)	Phoenix, Arizona (9.6 in.)
Flat roofs instead of pitched roofs	13	21	25%
Cistern for reuse of runoff for toilet flushing and irrigation (10 ft. diameter x 5 ft. high)	66	67	88%
Planted green roof (but will need to irrigate during dry periods)	75	77	84%
Disconnect roof drains to loam soils	84	87	91%
Rain garden with amended soils (10 ft. x 6.5 ft.)	87	100	96%

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The following is a brief listing of the major data needs for a biofiltration site:

a) pore volume of soil (porosity) (fraction of voids to total soil mass)
b) root depth (feet)
c) field moisture capacity for soil (% of dry weight of soil)
d) permanent wilting point (% of dry weight of soil; varies for different soil textures)
e) reference monthly ETo values (average inches per day for each month)
f) crop factor for actual crop compared to reference ET values
g) initial soil moisture conditions at beginning of study period
h) supplemental irrigation to be used?; common in the arid west, especially for green roofs
i) soil layer depths

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Soil Texture	Saturation Water Content (%) (Porosity)	Available Soil Moisture (Field Capacity to Permanent Wilting Point) inches water/inches soil	Infiltration Rate (in/hr) assumed to be slightly compacted	CEC (cmol/kg or meq/100 gms)	Dry density (grams/cm^3), assumed to be slightly compacted
Coarse Sand and Gravel	32	0.04	40	1	1.6
Sandy Loams	40	0.13	1	8	1.6
Fine Sandy Loams	42	0.16	0.5	10	1.6
Silty Clays and Clays	55	0.155	0.05	30	1.6
Peat as amendment	78	0.54	3	300	0.15
Compost as amendment	61	0.60	3	15	0.25

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

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Crop coefficient factors and root depths :

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

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

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Enhanced Infiltration and Groundwater Protection with Soil Amendments

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

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

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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).

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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).

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Example Calculation for Birmingham, AL Biofilter

Paved area draining to biofilter:

•1.0 acre paved parking lot

• 7.5 days until the start of the next rain (which is 0.47 inches in depth, lasting for 2.6 hours)

Total runoff quantity = 1,450 ft^3
Average runoff rate = 52 gal/min
Peak runoff rate = 198 gal/min

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Biofilter:
• 1,000 ft^2 in area, or 2.3% of the paved surface area contributing flow to the biofilter

• Current soil moisture level in biofilter engineered soil layer: 37%

• Engineered soil: 36 inches of sandy loam amended with 25% peat

• Biofilter plants: Half common shrubs (Kc crop coefficient factor of 0.50 and 2 ft root depth) and half annuals (Kc 0.64 and 1 ft root depth)

• Reference ETo: September in Birmingham, AL (0.141 inches per day ETo)

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Soil Texture	Saturation Water Content (%) (Porosity)	Available Soil Moisture (Field Capacity to Permanent Wilting Point) inches water/foot soil	Infiltration Rate (in/hr) assumed to be slightly compacted	CEC (cmol/kg or meq/100 gms)	Dry density (grams/cm³), assumed to be slightly compacted
Sandy Loams (75%)	40	1.56	1	8	1.6
Peat as amendment (25%)	78	6.48	3	300	0.15
Composite for soil and peat amendment	50	2.76	1.7	81	1.24

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Calculation Outline

1) How much water is in the engineered soil layer at the start of the analysis period?

2) How much water will drain by gravity before the next rain? If moisture level > field capacity, the soil will drain according to the saturated hydraulic conductivity rate (Ks) to the underlying storage layer.

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3) ET loss until start of next rain. ET only occurs in the root zones of the plants and only affects the soil water between the field capacity and permanent wilting point levels.

4) Determine moisture level at start of next rain, and the moisture deficit to saturated conditions.

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Engineered soil layer	Initial conditions (ft^3 of water) 37% moisture	Losses from gravity drainage (ft^3 of water)	Losses from shrubs and annuals ET (ft^3 of water)	Final conditions at start of next rain (ft^3 of water over 1,000 ft^2 biofilter area)	Deficit to saturated conditions (ft^3 of water)
Top foot	370	80	17	273 (27.3% moisture)	227
1 to 2 foot	370	80	7.3	282.7 (28.3% moisture)	217.3
2 to 3 foot	370	80	0	290 (29% moisture, the field capacity since there are no roots in this zone)	210
Total in 3 ft of engineered soil	1,100	240	24.3	845.7 (28.2% moisture) No irrigation needed, as still much greater than the wilting point of 6.1%.	654.3

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5) How much of the deficits will be satisfied by the rain event infiltrating water, and what will be the soil moisture level after the rain?

- The rain is expected to produce of 1,450 ft^3 of runoff.
- The actual deficit is 654.3 ft^3 to saturation conditions. The soil will therefore be saturated to 100% during the rain, leaving about 1,450 – 654.3 ft^3 = 795.7 ft^3 to potentially pond on the surface to be slowly infiltrated at the saturated hydraulic conductivity (Ks) rate.
- It would require about 10.1 hours to infiltrate into the biofilter and for the moisture levels to reach the field capacity moisture level in the engineered soil.

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6) Groundwater protection provided by this biofilter?

- With a 36 inch deep engineered soil, the contact time with the engineered soil is therefore 36 inches/3.4 in/hr = 10.6 hrs, sufficient time for ion exchange to occur.
- The engineered soil has an appreciable CEC level of 81 meq/100 grams of soil. The 3,000 ft^3 of engineered soil has a total CEC capacity of about 83,700,000 meq.
- With a total major cation content in the stormwater of about 1 meq/L, about 33 million gallons of stormwater can be treated by this biofilter before the CEC of the engineered soil is exhausted. This corresponds to about 1,000 inches of rainfall for this example site. With 52 inches of rain per year, the expected life of the CEC capacity would therefore be about 15 to 20 years. Without adding the peat amendment to the sandy loam soil, the CEC would only be about 0.1 of this amount, with a very short useful life of just a few years.

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7) Clogging of biofilter

Excessive loading of particulates on biofilters could have significant detrimental effects on their treatment rates. Media filtration tests indicate critical loadings of about 5 to 25 kg/m^2 of particulate solids before clogging.

Assuming a particulate solids concentration of 50 mg/L for this site, the annual loading would be about 227 kg/year, or about 2.5 kg/m^2 per year. About 10 years would be needed to reach a critical loading of 25 kg/m^2.

Because of the relatively slow loading rate and the extensive use of plants, the site is likely to be useful for a much longer period. Additional protection can be provided by ensuring that pretreatment is used at the biofilter inlets.

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Another clogging issue is the soil and runoff SAR (sodium adsorption ratio) conditions. With elevated soil SAR values, clays can be become destabilized, leading to premature clogging. This is especially important in areas where salts are used for de-icing controls. The high sodium levels in the seasonal runoff can elevate the SAR to critical values, with additional time needed to leach the sodium from the soils. Of course, this may provide some advantages of reducing infiltration during snowmelt periods when groundwater contamination by chlorides is critical. Adding gypsum to the soil will reduce the SAR.

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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

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NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

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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.

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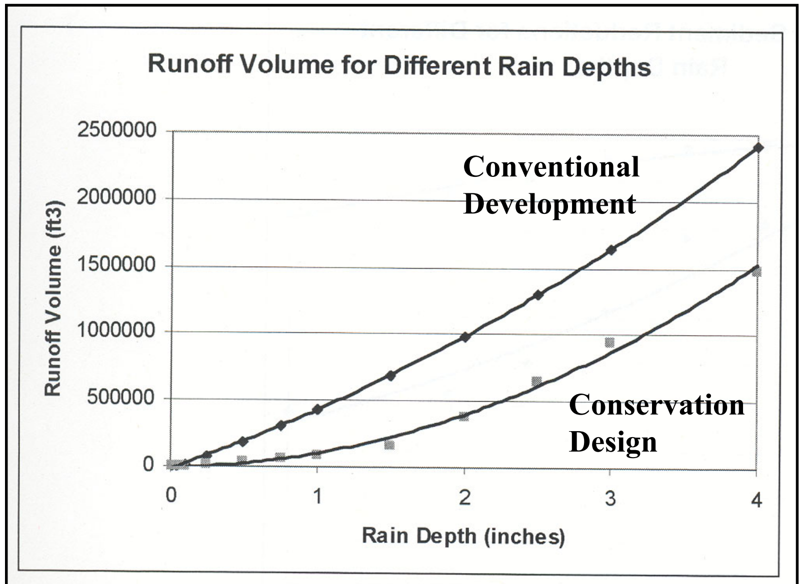

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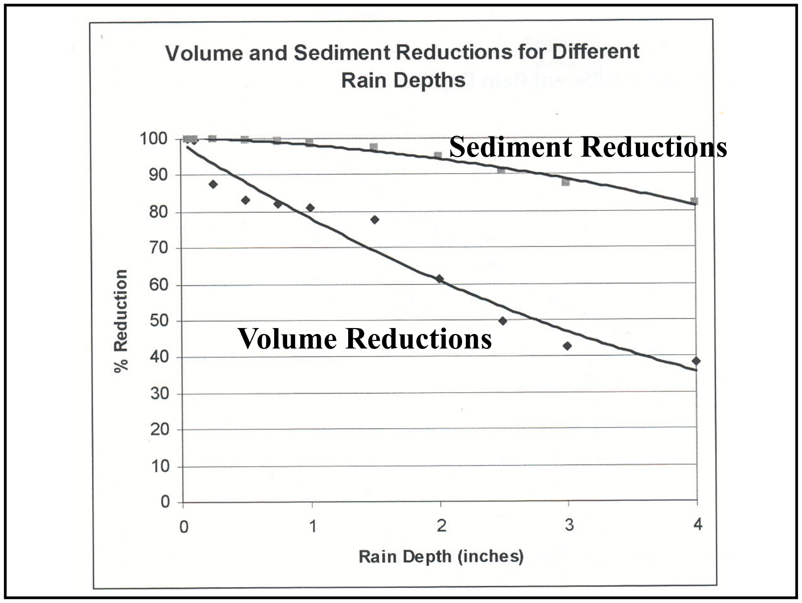

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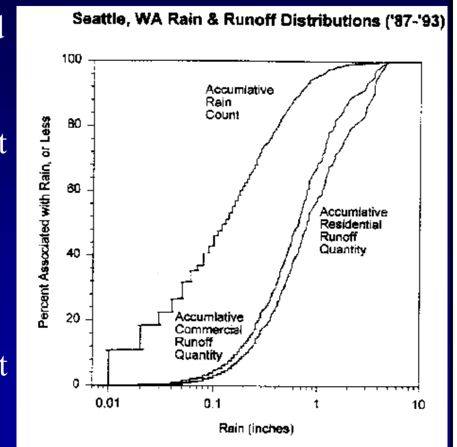
Combinations of Controls Needed to Meet Many Stormwater Management Objectives

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



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