

LID STORMWATER MODELING

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INTRODUCTION

LID (Low Impact Development) practices, such as green roofs, bioretention swales, rainwater cisterns, rain gardens, compost amended soil, and porous pavement can be used to reduce stormwater runoff and return urban creeks to more natural conditions.

Continuous simulation computer modeling of LIDs has been achieved by adding the ability to represent these practices in the Western Washington Hydrology Model version 3 (WWHM3), developed for the Washington State Department of Ecology (WSDOE) by Clear Creek Solutions, Inc.

WWHM3 was originally developed to size stormwater detention ponds throughout Western Washington to meet WSDOE requirements, using HSPF continuous simulation hydrology. New options and flexibility have been added to version 3 of the WWHM. This has made possible the ability to use HSPF continuous simulation to model complex LIDs for a range of purposes far beyond the initial intent of the Western Washington Hydrology Model.

This paper focuses on the modeling of LID porous pavement, impervious runoff dispersion, green roof, rain gardens, and bioretention swale practices in WWHM3. The LID modeling quantifies the reduction of stormwater runoff that can be expected for each LID practice.

Results from WWHM3 demonstrated the feasibility of modeling these small-scale LID practices in an urban environment and the potential effectiveness of implementing these practices to protect private property and public resources.

POROUS PAVEMENT MODELING

Porous pavement has been in use for the past 30 years, although applications have been limited due to concerns about the water infiltrating and weakening the soil under the pavement. Cost considerations also have been an issue.

WWHM3 represents porous pavement with multiple material layers underlain by native soil. Each material layer has a depth and porosity specified by the user. Typically porous pavement has two layers: the upper layer represents the pavement depth and the lower layer is the gravel underbed placed between the porous pavement and the native soil. If appropriate, the user can then infiltrate the water that travels through the porous pavement and the gravel layer into the native soil.

To evaluate the effectiveness of porous pavement a 1-acre impervious area (roadway) was modeled with a range of native soil infiltration rates (zero to 0.01 inches/hour). The pavement was assumed to be 4 inches (0.33 feet) thick with 1 foot of gravel in the underbed. The modeling was conducted using Seattle long-term (1948-1998) hourly precipitation. The results are shown in Table 1 and Figure 1 below.

Table 1. Porous Pavement Reduction of Total Runoff Volume

Site	Infiltration (in/hr)	Total Runoff (in/yr)	Reduction (in/yr)	Reduction (%)
Impervious	0	31.226	0.000	0.0%
Porous	0	15.887	15.339	49.1%
Porous	0.0010	11.749	19.478	62.4%
Porous	0.0020	8.183	23.043	73.8%
Porous	0.0030	5.270	25.956	83.1%
Porous	0.0040	3.109	28.117	90.0%
Porous	0.0050	1.596	29.631	94.9%
Porous	0.0060	0.779	30.447	97.5%
Porous	0.0070	0.339	30.888	98.9%
Porous	0.0080	0.119	31.107	99.6%
Porous	0.0085	0.057	31.170	99.8%
Porous	0.0090	0.009	31.217	99.97%
Porous	0.0100	0.000	31.226	100.0%

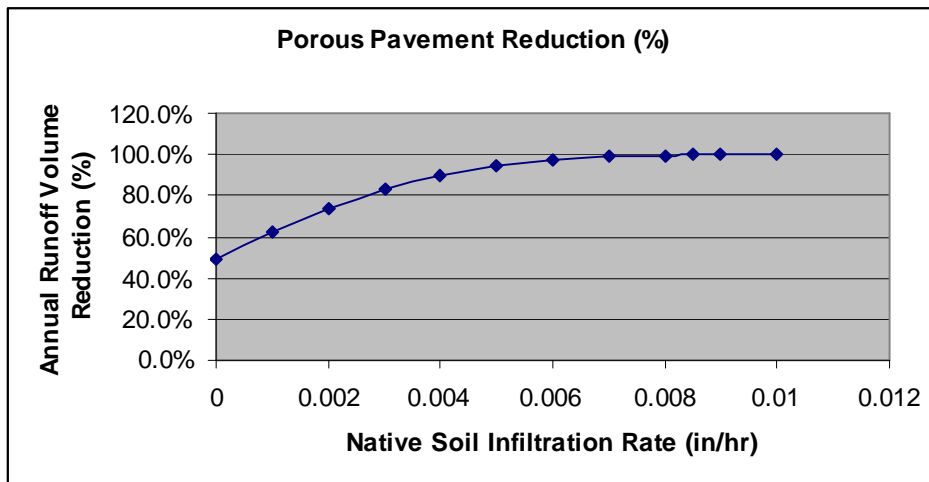


Figure 1. Porous Pavement Reduction of Total Runoff Volume

As shown in the table and figure, a native soil infiltration rate of zero still provides a reduction in annual runoff volume. This is because of the storage and then evaporation of water from the voids in the pavement and underbed gravel layers.

Infiltration of runoff into the native soil beneath the porous pavement further reduces annual runoff volume. With a native soil infiltration rate of 0.004 inches per hour, 90% of the annual runoff volume will infiltrate or evaporate. At 0.01 inches per hour there is 100% reduction.

IMPERVIOUS RUNOFF DISPERSION MODELING

Impervious surfaces produce surface runoff in response to rainfall. There is very little storage of runoff on the surface of an impervious area. Evaporation occurs, but is relatively small. In Western Washington where the average annual rainfall is approximately 40 inches per year, there is only about 8 inches of evaporation from impervious surfaces compared to 20 inches from pervious areas.

When impervious area surface runoff is dispersed on an adjacent pervious area the surface runoff has an opportunity to infiltrate into the soil. The rate of infiltration is a function of the soil's properties and antecedent soil moisture conditions.

WWM3 models impervious runoff dispersion on adjacent pervious areas with two lateral flow drainage basin elements. The impervious lateral flow basin produces surface runoff. This surface runoff is then applied onto the surface of the adjacent pervious lateral flow basin in proportion to the relative surface areas. For example, if the impervious area is half the size of the adjacent pervious area then an inch of surface runoff is dispersed at one-half inch depth over the pervious area. Think of a 1-acre parking lot which sheet flows onto an adjacent 2-acre lawn.

To evaluate the effectiveness of impervious runoff dispersion a 1-acre impervious area was modeled with a range of adjacent pervious areas. The size of the pervious areas ranged from 10% of the impervious area to 2000% (20 times the size of the impervious area). The modeling was conducted using Seattle long-term (1948-1998) hourly precipitation and till soils. The results are shown in Table 2 and Figure 2 below.

Table 2. Impervious Area Dispersion

Ratio Pervious/Impervious	Reduction %
0%	0.0%
10%	4.5%
20%	7.2%
30%	9.3%
40%	11.0%
50%	12.3%
75%	14.8%
100%	16.5%
150%	18.6%
200%	19.9%
400%	22.3%
600%	23.2%
800%	23.7%
1000%	24.0%
1500%	24.4%
2000%	24.6%

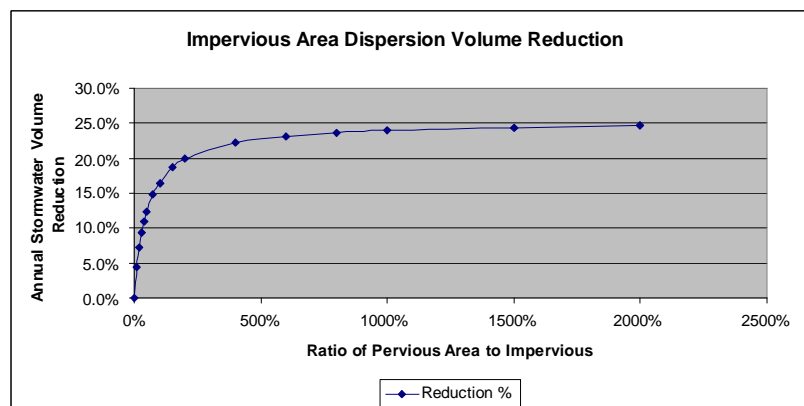


Figure 2. Impervious Area Dispersion Volume Reduction

As can be seen in Figure 2, the maximum surface runoff reduction approaches 25% of the total impervious surface runoff regardless of how the size of the adjacent pervious area. This is because the surface runoff from the impervious area has limited opportunity to infiltrate into the pervious area's soil before traveling across the pervious area to a stormwater collection system. During wet periods (especially common during the Seattle winters) the pervious soil is fully saturated and little or no infiltration of the surface runoff will occur.

GREEN ROOF MODELING

Green roofs (also known as eco-roofs and vegetated roofs) have the potential to reduce peak flows and total runoff volume from roofs that are otherwise impervious. Green roofs can be retrofitted on commercial buildings in the urban core where other stormwater mitigation measures are not feasible.

Green roof retrofitting can be used to reduce urban stormwater inflows to a city’s combined sewer system and eliminate CSOs to comply with state and federal regulations.

The WWHM3 green roof element is a special lateral flow basin with unique characteristics. The element uses the HSPF hydrology algorithms to generate runoff, but the HSPF hydrology parameter values are modified to represent the green roof’s shallow soil depth and lack of a groundwater reservoir. All runoff becomes stormwater, unlike in a conventional pervious drainage basin where only the surface runoff and interflow contribute to stormwater and groundwater discharge (base flow) is not considered.

Our green roof modeling was based on Washington State Department of Ecology’s flow duration standard. Local long-term rainfall and pan evaporation data (35-50 years) were input for five different cities in Western Washington. For the purposes of the modeling we assumed a 10-acre commercial flat roof with 8 inches of soil on the roof. This allowed for about 4 inches of water storage in the soil column. Table 3 shows the results of our green roof modeling work.

Table 3. Green Roof Stormwater Storage Reduction

Location	Site	Precip (in)	Runoff (in)	Storage Needed (ac-ft)	Reduction (%)
Seattle	10 acres impervious roof	38.06	31.22	4.48	
	10 acres green roof	38.06	23.61	3.52	21%
Olympia	10 acres impervious roof	50.51	43.51	5.05	
	10 acres green roof	50.51	35.65	3.90	23%
Port Angeles	10 acres impervious roof	24.28	18.62	6.37	
	10 acres green roof	24.28	12.35	4.39	31%
Bellingham	10 acres impervious roof	38.87	32.00	3.34	
	10 acres green roof	38.87	23.41	2.76	17%
Vancouver, WA	10 acres impervious roof	37.33	30.53	5.05	
	10 acres green roof	37.33	22.92	4.05	20%

Of the five locations, Port Angeles showed the greatest percent reduction in stormwater storage: 31%. This is due to a lower annual rainfall (24 inches) than the other Western Washington locations. The other four cities (Seattle, Olympia, Bellingham, and Vancouver, WA) showed reductions in the range of 17-23%.

We also investigated the option of a blue roof. A blue roof is a green roof without the dirt and vegetation. All of the rainfall is stored on the rooftop. The advantage of a blue roof over the green roof is that the blue roof needs no additional stormwater detention storage (no stormwater vault is needed). An orifice on the roof controls the release of rooftop runoff to meet Ecology’s flow duration standard. Standing water on the rooftop evaporates at the potential rate.

For the five locations and using the same meteorological data and roof size as for the green roof analysis, blue roof rooftop storage varied from 0.35 feet (Bellingham) to 0.56 feet (Port Angeles). All of the blue roof runoff numbers are shown in Table 4.

Table 4. Blue Roof Roof-Top Storage

Location	Site	Precip (in)	Runoff (in)	Roof Top Storage (ft)
Seattle	10 acres impervious roof	38.06	31.22	
	10 acres green roof	38.06	23.61	

	10 acres blue roof	38.06	22.56	0.40
Olympia	10 acres impervious roof	50.51	43.51	
	10 acres green roof	50.51	35.65	
	10 acres blue roof	50.51	34.64	0.41
Port Angeles	10 acres impervious roof	24.28	18.62	
	10 acres green roof	24.28	12.35	
	10 acres blue roof	24.28	11.80	0.56
Bellingham	10 acres impervious roof	38.87	32.00	
	10 acres green roof	38.87	23.41	
	10 acres blue roof	38.87	22.86	0.35
Vancouver, WA	10 acres impervious roof	37.33	30.53	
	10 acres green roof	37.33	22.92	
	10 acres blue roof	37.33	22.45	0.48

Blue roofs out-perform green roofs in providing stormwater benefits, but other benefits (energy conservation, life cycle costs, etc.) favor green roofs.

RAIN GARDEN/BIORETENTION SWALE MODELING

Rain gardens (also known as bioretention swales or landscape swales) are increasing in popularity. In a rain garden the native soils have been excavated and replaced with amended soil. At the downstream end of the rain garden a berm or weir controls the surface discharge from the rain garden and detains runoff, encouraging it to infiltrate into the amended soil. Infiltration from the amended soil to the native soil is also possible, depending on the properties of the native soil. Rain gardens can include an underdrain pipe, but where infiltration to the native soil is feasible underdrains are not encouraged.

The WWHM3 rain garden/bioretention swale element is a special conveyance feature with unusual characteristics. The element uses the HSPF hydraulic routing and Special Action algorithms to route runoff first into the surface storage portion of the rain garden and then checks to determine the amount of runoff that can infiltrate into the subsurface amended soil. Water travels down through the amended soil based on its porosity and infiltration rate. Water is allowed to drain into the native soil based on a separate user-supplied infiltration rate for the native soil. If the inflow exceeds the amended soil infiltration rate or capacity then water ponds on the surface and is available for surface discharge to the next downstream conveyance feature.

Rain gardens are used to reduce the stormwater volume. The effectiveness of a rain garden to decrease the average annual runoff volume is proportional to the size of the rain garden relative to the size of the contributing drainage area.

The WWHM3 rain garden sizing table has been computed for Seattle site with a native soil infiltration rate of 0.25 inches per hour. The size of the rain gardens was determined based on the goal of reducing the average annual runoff volume from impervious areas to be equal to or less than the corresponding average annual pasture runoff volume. This analysis was done for impervious areas ranging from 750 square feet to 10,000 square feet for two live pond depths (5 inches and 10 inches) before overflow. The bioretention swales were assumed to have 12 inches of amended soil with an infiltration rate of 1 inch per hour. The results are shown in Figures 3 and 4.

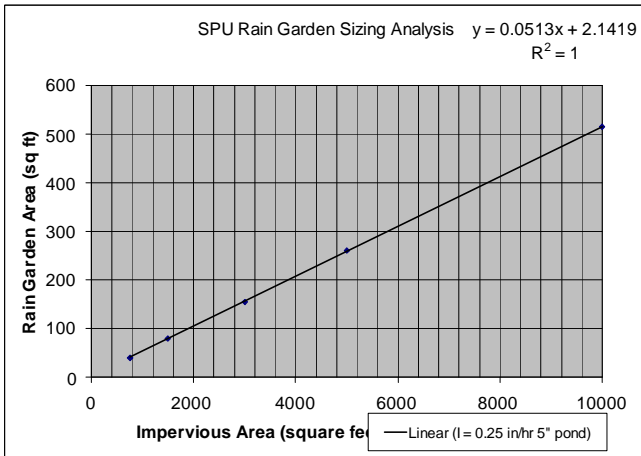


Figure 3. Seattle Rain Garden with Live Storage Depth of 5 Inches

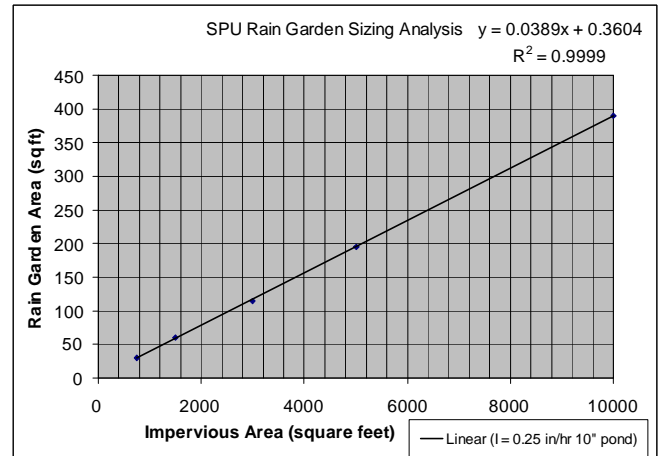


Figure 4. Seattle Rain Garden with Live Storage Depth of 10 Inches

Rain garden sizes can be determined from the linear equations shown in Figures 1 and 2. The equations are summarized below in Table 5.

Table 5. Linear Equations for Sizing Rain Garden Facilities

Infiltration Rate (in/hr)	Ponding Depth (in)	Rain Garden Size (sq ft)
0.25	5	$Y = 0.0513X + 2.14$
0.25	10	$Y = 0.0389X + 0.36$

Y = bioretention bottom area (square feet); X = impervious area (square feet).

SUMMARY

LIDs (porous pavement, impervious runoff dispersion, green roofs, and rain gardens) show great promise in reducing stormwater runoff and its associated problems. WWHM3 is a powerful stormwater modeling tool to help inform and persuade the public and city policy makers of the value of using low impact development (LID) practices that can solve many urban stormwater problems.

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BIO

Doug Beyerlein is co-founder of Clear Creek Solutions and specializes in continuous simulation hydrologic modeling. He has led the engineering community in the development of new, more accurate tools to analyze the hydrologic impacts of human activities on rivers, streams, and fish habitat.

He is licensed as a Registered Professional Engineer in Washington and California and is certified as a Professional Hydrologist by the American Institute of Hydrology. He is also a member of the American Water Resources Association and the American Geophysical Union. Doug currently lives in Mill Creek, Washington, with his wife Joan and malamute Nisqually.