

Technical Memorandum

MODELING ASSUMPTIONS AND RESULTS FOR THE WESTERN WASHINGTON RAIN GARDEN HANDBOOK

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Date: July 10, 2007

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MODELING ASSUMPTIONS AND RESULTS FOR THE WESTERN WASHINGTON RAIN GARDEN HANDBOOK

Background

The Rain Garden Handbook for Western Washington Homeowners provides guidelines for locating, designing and installing rain gardens on single family lots. This memo provides the assumptions and summary results of the modeling performed by Clear Creek Solutions for determining annual reduction of stormwater volume associated with various size rain gardens in the handbook.

The flow control modeling for the rain garden handbook was conducted for three primary reasons:

1. Determine the flow control benefits of rain gardens on single family lots using the latest modeling capabilities.
2. Provide designers and local jurisdictions with the necessary technical background to make informed decisions concerning the use of the handbook.
3. Provide homeowners with a simple and meaningful measurement of how well their rain garden is performing and hopefully encourage or challenge the homeowner to install as much capacity as possible to control as much annual volume as possible.

The handbook does not provide an equation or specific sizing guidelines. Instead, the handbook provides instructions to properly locate and design a rain garden considering what are likely the two most prevalent sizing constraints on a single family lot: 1) what drainage area does the homeowner want to manage; and 2) what area is available and what scale and aesthetic is appropriate within the lot.

Many rain garden handbooks for homeowners provide simple equations based on soil type, slope, location in the landscape, and single storm events for sizing the facility. However, Washington State Department of Ecology is encouraging the use of continuous simulation stormwater modeling to more accurately size flow and water quality treatment facilities. Accordingly, the flow control benefits stated in the handbook (page 11) are based on WWHM3 (Western Washington Hydrology Model version 3) PRO from Clear Creek Solutions. This latest version of WWHM includes enhanced capabilities for modeling rain gardens and is calibrated to three years of monitoring data collected at City of Seattle's SEA Street project by University of Washington.

An advisory committee was convened to consider content and structure of the handbook in late 2005. Since the handbook is targeted for homeowners, the modeling component of the handbook focused on the basic question: How much annual stormwater volume reduction can be expected for various size rain gardens in relation to impervious area contributing to the rain garden.

One of the initial issues was to determine the appropriate assumptions for developing flow control modeling scenarios specific to western Washington conditions. Initially, several geographic locations were selected to represent the range of rainfall patterns in the region (local NOAA hourly precipitation and the approximate precipitation multiplication factor provided in WWHM3). The locations include Seattle, Olympia, Bellingham, Port Angeles, and Vancouver. Typical small and large lot sizes were selected and impervious coverage for those lots were estimated by surveying managers in planning and engineering departments from local jurisdictions in the Puget Sound region. The initial modeling results provided information to guide more detailed analysis performed for Seattle and Olympia rainfall patterns.

The following assumptions were made for all the rain garden modeling scenarios:

- Two residential properties were modeled: 1) a small lot with a total area of 5000 sq. ft., of which 2500 sq. ft. is impervious and; 2) a large lot with a total of 10,000 sq. ft. with 3000 sq. ft. of impervious area; the remaining area on both lots is lawn.
- Two rain garden sizes were modeled (400 sq. ft. and 800 sq. ft.). The smaller rain garden was modeled with the small lot area and the larger rain garden with the larger lot.
- One vegetation type was modeled (shrub).
- Two rain garden soil mix depths were modeled (12 in. and 24 in.).
- The porosity of the rain garden soil mix is assumed to be 40%.
- Two rain garden soil mix infiltration rates were used (2 in./hr. and 0.5 in./hr.).
- Two native soils were modeled (till and outwash). The till native soil infiltration rate was set to 0.1 in./hr. The outwash native soil infiltration was set to 0.5 in/hr for the soil mix infiltration rate of 0.5 in./hr. and 1.0 in./hr. for the mix rate of 2.0 in./hr.
- The surface storage depth (before overflow) was set to 6 inches.
- The left and right side slopes are 1 ft./ft.
- The bottom slope of the rain garden was set to 0.01 ft./ft.
- The overflow weir is flat and 1 ft. wide.
- There is no underdrain.
- Stormwater consists of surface runoff and interflow (shallow subsurface flow). No groundwater goes to the rain gardens.
- Mean annual stormwater runoff for small residential lot forest vegetation on outwash soil is very small and was computed as zero by WWHM3.

For each scenario the model used 40-50 years of local NOAA hourly rainfall data to generate the same number of years of hourly stormwater runoff data.

Results

Annual volume reductions

The initial results from the five locations suggest that rain gardens can provide significant surface flow reduction on residential lots. In general, a 400 square foot rain garden that is approximately 15 percent of the impervious area (5,000 sq. ft. lot with 2,500 sq. ft. impervious area) and 12 inches deep will reduce mean annual stormwater volume by about 65 to 90 percent on till soil. On outwash, mean annual volume reduction is 99 to 100 percent (see Table 1).

As would be anticipated, rain gardens are more effective for reducing annual volume on outwash than till soils, and more effective in lower (Port Angeles) than higher (Olympia) rainfall locations. While rain gardens do not necessarily enhance the infiltration potential for outwash soil locations, the soil plant system can enhance pollutant removal capabilities for many pollutants and provide added protection in locations where rapid infiltration and ground water quality are a concern.

On the till soils, increasing the rain garden soil mix depth improves annual volume reduction slightly and appears to be relatively more important than the rain garden soil mix infiltration rate. Volume reduction improves by 2 to 4 percent as depth increases from 12 to 24 inches. On till soils, the infiltration rate would be primarily controlled by the underlying native soil while increasing the depth from 12 to 24 inches provides approximately 4.8 inches added runoff storage (40 percent of 12 inches) within the rain garden soil mix.

Table 1: Rain garden mean annual stormwater reduction for five locations in western Washington

Scenario	Vegetation	Native Soil	Residential Site			Rain Garden			Stormwater Model Results: Mean Annual Volume Reduction (%)				
			Pervious Area (sq ft)	Impervious Area (sq ft)	Total Area (sq ft)	Surface Area (sq ft)	Soil Depth (in)	Infiltration (in/hr)	Seattle	Olympia	Bellingham	Port Angeles	Vancouver, WA
1	forest	till	5000	0	5000	0							
2	lawn	till	2500	2500	5000	0							
3	lawn	till	2500	2500	5000	400	12	2.0	81.0%	65.2%	82.3%	85.9%	83.4%
4	lawn	till	2500	2500	5000	400	12	0.5	81.0%	65.2%	82.2%	85.8%	83.4%
5	lawn	till	2500	2500	5000	400	24	2.0	84.5%	69.4%	85.4%	88.2%	86.8%
6	lawn	till	2500	2500	5000	400	24	0.5	84.5%	67.1%	84.3%	88.1%	85.5%
7	forest	till	10000	0	10000	0	0						
8	lawn	till	7000	3000	10000	0	0						
9	lawn	till	7000	3000	10000	800	12	2.0	84.4%	68.2%	85.2%	88.9%	86.5%
10	lawn	till	7000	3000	10000	800	12	0.5	84.3%	68.1%	85.2%	88.8%	86.5%
11	lawn	till	7000	3000	10000	800	24	2.0	86.2%	70.0%	87.0%	90.7%	88.2%
12	lawn	till	7000	3000	10000	800	24	0.5	86.1%	69.9%	86.9%	90.7%	88.1%
13	forest	outwash	5000	0	5000	0	0						
14	lawn	outwash	2500	2500	5000	0	0						
15	lawn	outwash	2500	2500	5000	400	12	2.0	100.0%	99.6%	99.9%	100.0%	100.0%
16	lawn	outwash	2500	2500	5000	400	12	0.5	99.1%	97.6%	99.4%	99.2%	99.7%
17	lawn	outwash	2500	2500	5000	400	24	2.0	100.0%	99.7%	100.0%	100.0%	100.0%
18	lawn	outwash	2500	2500	5000	400	24	0.5	99.3%	98.0%	99.5%	99.4%	99.7%
19	forest	outwash	10000	0	10000	0	0						
20	lawn	outwash	7000	3000	10000	0	0						
21	lawn	outwash	7000	3000	10000	800	12	2.0	100.0%	99.9%	100.0%	100.0%	100.0%
22	lawn	outwash	7000	3000	10000	800	12	0.5	100.0%	99.4%	99.9%	100.0%	100.0%
23	lawn	outwash	7000	3000	10000	800	24	2.0	100.0%	100.0%	100.0%	100.0%	100.0%
24	lawn	outwash	7000	3000	10000	800	24	0.5	100.0%	99.5%	99.9%	100.0%	100.0%

The basic assessment of various geographic locations and fixed rain garden sizes provided initial information for a more detailed evaluation of Seattle and Olympia rainfall patterns. Seattle was selected to represent an average rainfall and Olympia to represent higher rainfall amount in the region. Table 2 and figures 1 and 2 represent the typical small lot with 2,500 square feet of impervious area. The 2,500 square feet was routed to rain gardens ranging in size from 25 square feet (1%) to 2,500 square feet (100%). The rain garden soil mix depth is 12 inches.

Table 2: Rain garden mean annual stormwater reduction for Seattle and Olympia rainfall.

Ratio of Rain Garden Area to Impervious Area	Seattle Precipitation		Olympia Precipitation	
	Stormwater Reduction for Till Soil	Stormwater Reduction for Outwash Soil	Stormwater Reduction for Till Soil	Stormwater Reduction for Outwash Soil
0%	0%	0%	0%	0%
1%	15%	45%	11%	40%
2%	26%	68%	19%	62%
4%	44%	89%	34%	83%
6%	58%	96%	46%	92%
8%	69%	98.3%	55%	96.0%
10%	77%	99.2%	63%	98.0%
20%	94%	100%	85%	99.9%
40%	99.1%	100%	97.3%	100%
60%	99.9%	100%	99.4%	100%
80%	100%	100%	99.9%	100%
100%	100%	100%	100%	100%

Figure 1: Rain garden mean annual stormwater reduction for Seattle rainfall.

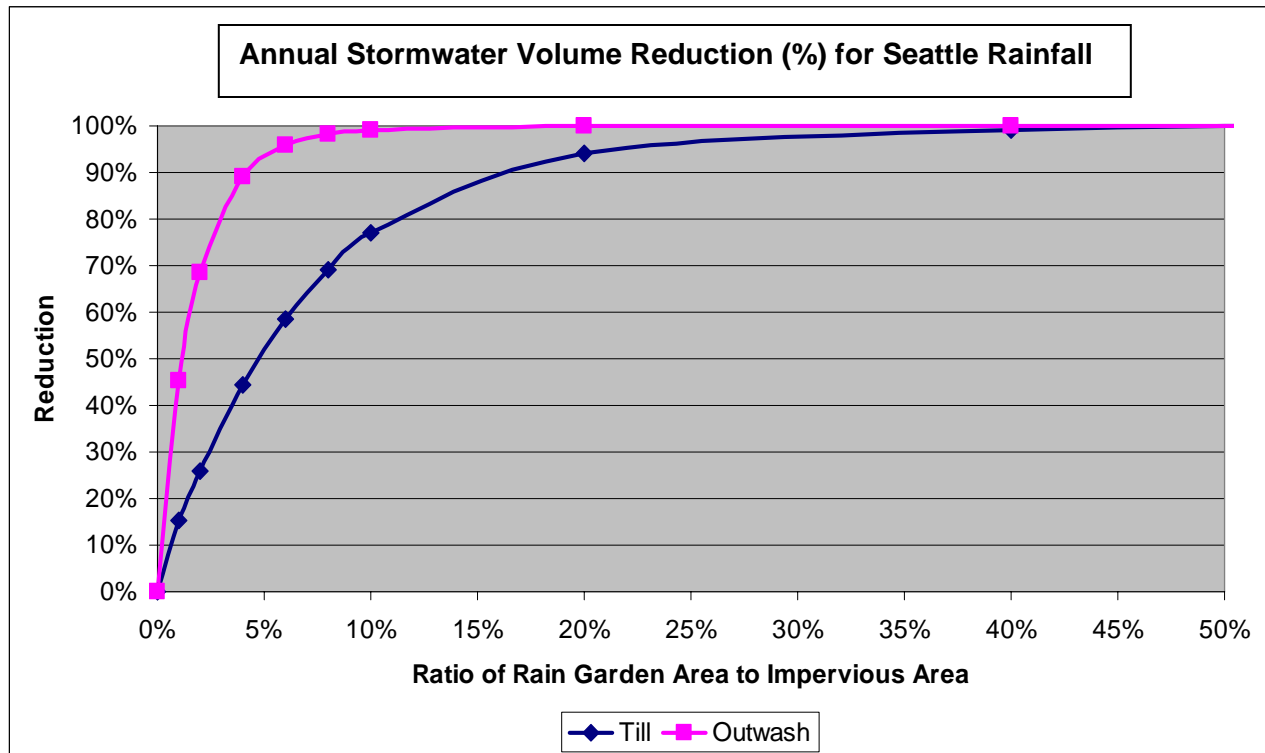
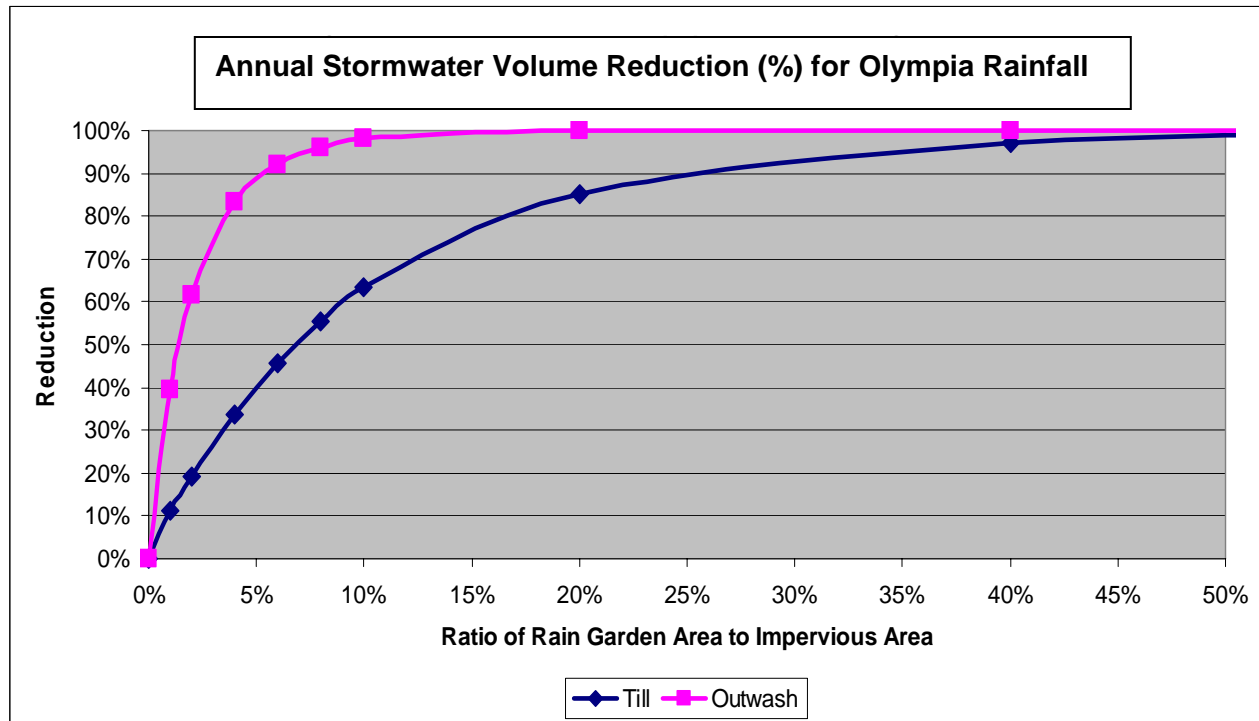


Figure 2: Rain garden mean annual stormwater reduction for Olympia rainfall.



Flow control for 12 and 24 Inch deep rain gardens

Flow control for rain gardens on outwash soil is not significantly influenced by the soil mix depth. However, on lower infiltrating soils, depth does influence annual stormwater volume reduction to a small degree (see Table1). A basic sensitivity analysis was run to compare the square foot coverage required to achieve a specific annual volume reduction at 12 and 24 inch depths. This can be an important consideration to achieve the maximum performance of the rain garden for small lots on poor soils. Figure 3 compares the annual volume reduction for 12 and 24 inch rain garden soil mix depths for Seattle rainfall. Figures 4 and 5 present the same data; however, the axes are reversed and trend lines used to determine the difference in square foot coverage for specific annual volume reductions. Table 3 summarizes the percent difference in square foot

Table 3: Percent reduction in square foot coverage for 12- and 24-inch deep rain gardens

Percent annual Volume Reduction	Coverage 12" Depth (sq. ft.)	Coverage 24" Depth (sq. ft.)	Difference (sq. ft.)	Percent Reduction Increasing Soil Mix Depth from 12" to 24"
0.1	21.78	20.88	0.90	0.04
0.2	47.17	44.98	2.18	0.05
0.3	76.69	73.23	3.46	0.05
0.4	113.20	107.88	5.32	0.05
0.5	159.53	151.20	8.33	0.06
0.6	218.52	205.45	13.07	0.06
0.7	293.03	272.91	20.12	0.07
0.8	385.89	355.83	30.06	0.08
0.9	499.94	456.48	43.46	0.10

coverage. By increasing rain garden soil mix depth from 12 to 24 inches (with a 6-inch ponding depth, total depth is 18 and 30 inches respectively) the square foot coverage can be reduced by 5 to 10 percent depending on the ratio of rain garden to impervious area.

Figure 3: Comparing annual volume reduction for 12- and 24-inch rain garden soil mix depths

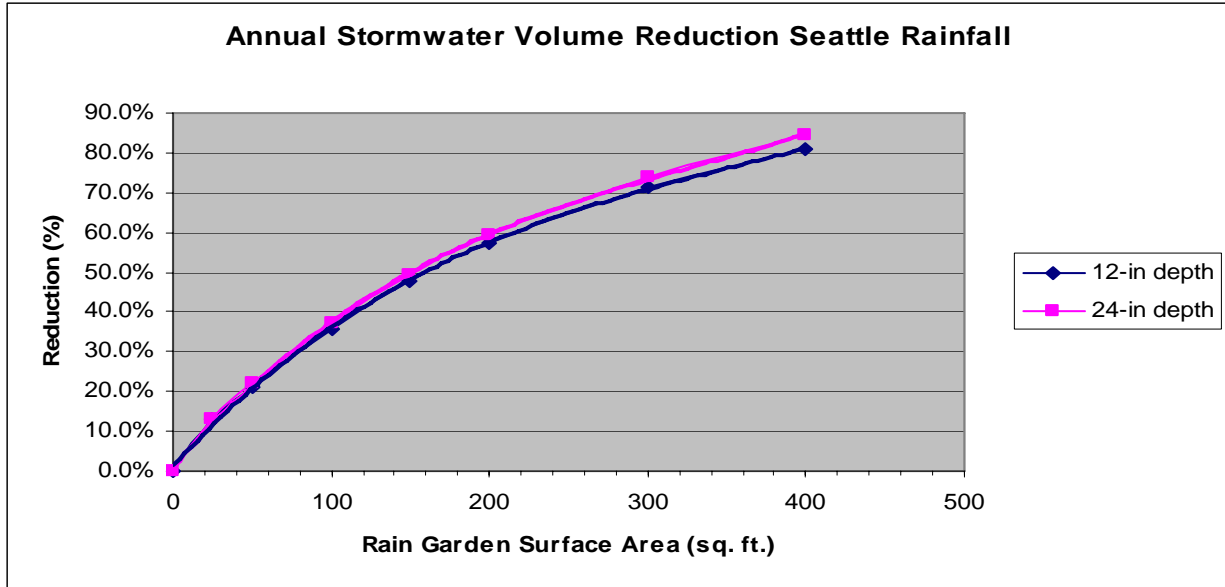


Figure 4: Rain garden square foot coverage and volume reduction for 12-inch soil mix depth

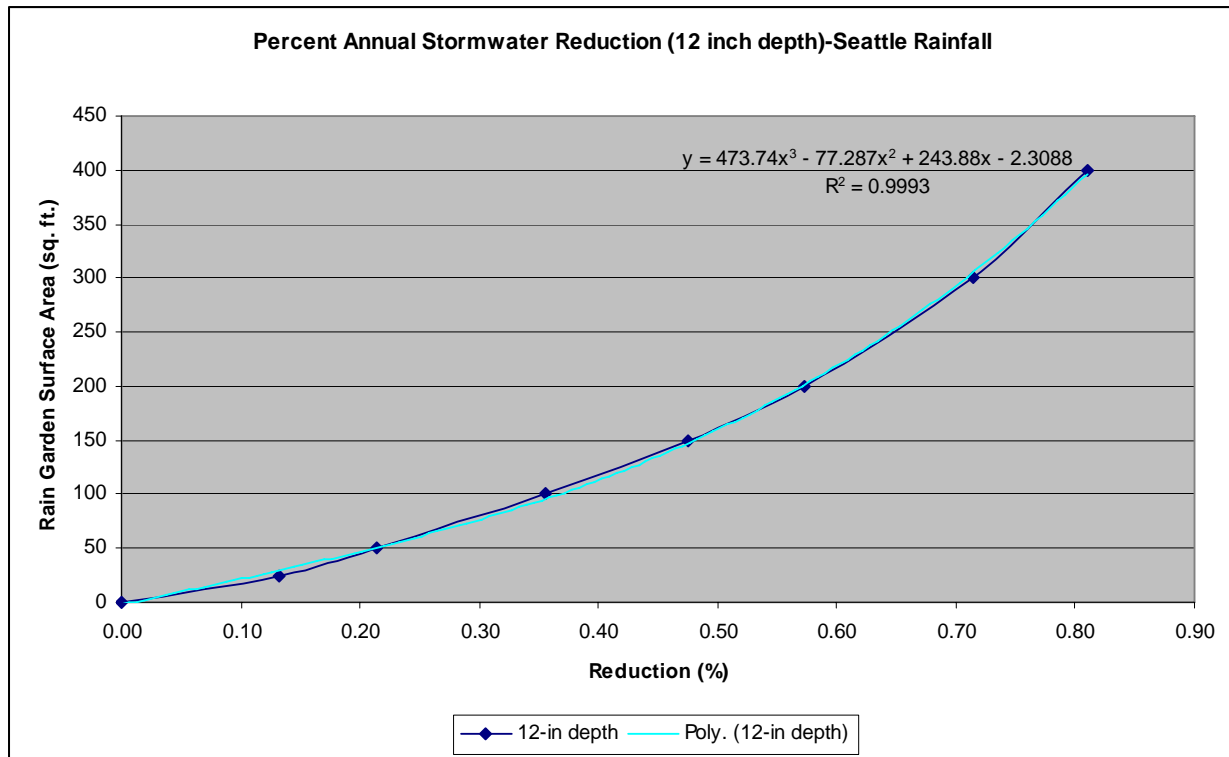
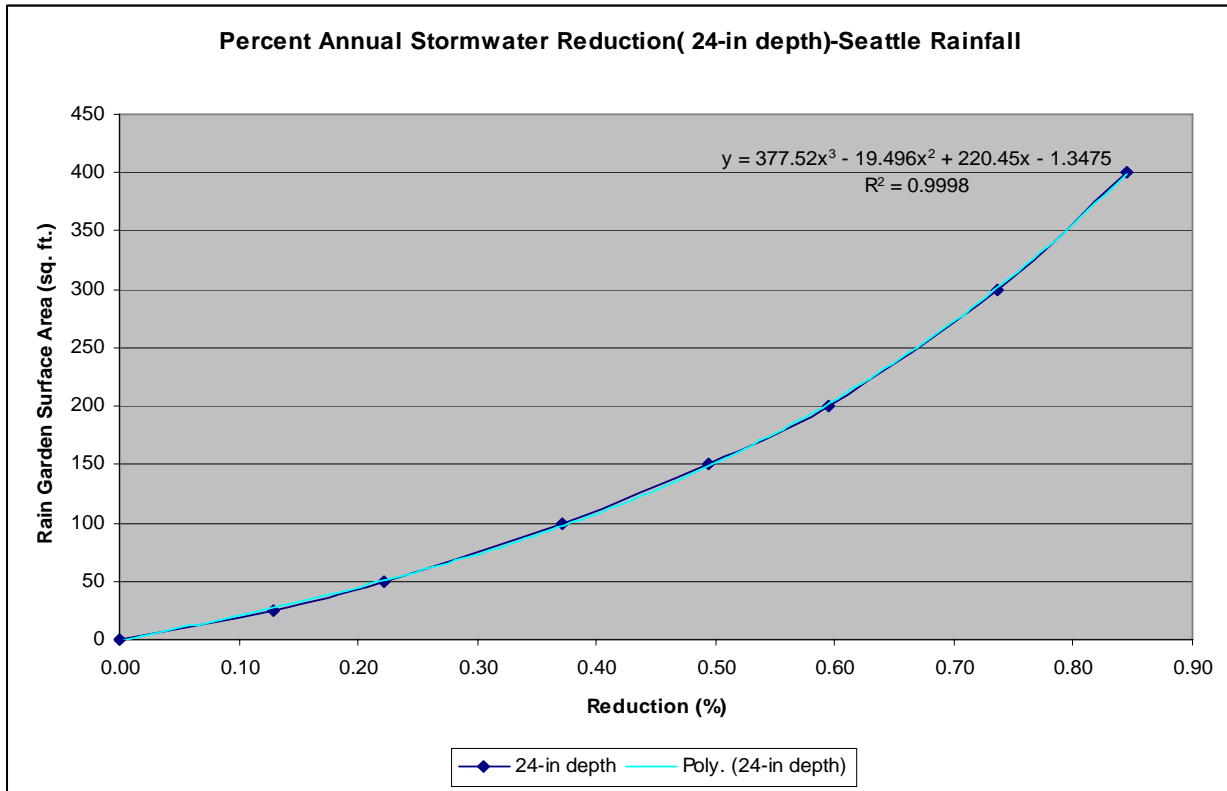


Figure 5: Rain garden square foot coverage and volume reduction for 24-inch soil mix depth



Flow durations

The final modeling exercise examined the flow durations associated with various ratios of rain garden area to impervious area, and the size of rain garden necessary to reduce durations to or below native forest levels. Flow durations reduced to or below forest levels do not require the use of additional stormwater control facilities, as mandated by Ecology’s 2005 *Stormwater Management Manual for Western Washington*.

While rain gardens alone can provide significant volume reduction, an LID approach encourages the use of multiple practices dispersed across the developed site for improved flow control. This exercise does not suggest that rain gardens are necessarily a stand alone practice, but rather was conducted to provide designers with a sense of the contribution that rain gardens can make to an integrated LID design.

The flow duration modeling routed surface flow from 2500 square feet of impervious area into rain gardens ranging in size from 500 square feet (20% of impervious area) to 5,000 square feet (200%) on till soil (see Table 4). The modeling results (Seattle rainfall) show that the ratio of rain garden area to impervious surface area needs to be about 80% to reduce flow durations to or below forest levels for flows between half the 2-year and the 50-year flood frequency (Ecology’s flow control standard). However, rain gardens that are 30 and 40 percent of the impervious area can make a significant contribution for meeting flow duration goals.

All results are compared with a baseline of 2,500 square feet of forest without a rain garden. The results of the modeling represent the duration (percent of time) that flows exceed specified values ranging from zero to 0.004 cfs (approximately the 100-year forest flood frequency value).

Table 4: Rain garden stormwater flow durations for Seattle rainfall.

Flow(CFS)	Forest	RG 2%	RG 4%	RG 8%	RG 20%	RG 40%	RG 80%	Frequency
0.00000	100.00000%	100.00000%	100.00000%	100.00000%	100.00000%	100.00000%	100.00000%	
0.00025	5.18997%	6.62304%	4.37292%	1.93389%	0.22405%	0.02761%	0.00000%	
0.00050	1.82893%	5.51008%	3.78404%	1.75706%	0.21333%	0.02601%	0.00000%	
0.00075	0.80609%	4.72703%	3.33297%	1.60306%	0.20215%	0.02533%	0.00000%	half 2-yr
0.00100	0.42917%	4.13495%	2.95399%	1.45589%	0.19348%	0.02510%	0.00000%	
0.00125	0.25075%	3.63300%	2.63594%	1.32698%	0.18093%	0.02373%	0.00000%	
0.00150	0.15812%	3.21090%	2.36694%	1.21701%	0.17066%	0.02213%	0.00000%	2-yr
0.00175	0.10085%	2.85999%	2.13193%	1.11502%	0.16040%	0.02099%	0.00000%	
0.00200	0.06297%	2.53190%	1.91198%	1.02011%	0.14876%	0.02031%	0.00000%	
0.00225	0.04198%	2.26198%	1.72900%	0.92975%	0.14169%	0.01825%	0.00000%	5-yr
0.00250	0.02898%	2.01192%	1.54396%	0.84784%	0.13233%	0.01734%	0.00000%	
0.00275	0.01643%	1.78695%	1.38904%	0.78008%	0.12435%	0.01711%	0.00000%	10-yr
0.00300	0.00776%	1.58092%	1.24804%	0.70707%	0.11682%	0.01688%	0.00000%	
0.00325	0.00411%	1.40889%	1.12597%	0.65026%	0.10883%	0.01620%	0.00000%	25-yr
0.00350	0.00091%	1.26104%	1.01303%	0.59322%	0.10267%	0.01574%	0.00000%	50-yr
0.00375	0.00023%	1.12803%	0.90968%	0.54690%	0.09697%	0.01460%	0.00000%	100-yr
0.00400	0.00000%	1.00801%	0.82115%	0.49967%	0.09240%	0.01437%	0.00000%	

Table 5 shows another way to look at this information. The number of hours that the flows exceed a specific value are divided by the number of corresponding forest hours for the same flow value. All of the percentages between half the 2-year and the 50-year should be less than or equal to 100 percent. Only rain garden values of 80 percent or more are in this required range.

Table 5: Ratio of rain garden flow duration hours exceeding to forest flow duration hours exceeding specific forest flood frequency values for Seattle rainfall.

Flow(CFS)	Forest	RG 2%	RG 4%	RG 8%	RG 20%	RG 40%	RG 80%	Frequency
0.00000	438288	100%	100%	100%	100%	100%	100%	
0.00025	22747	128%	84%	37%	4%	1%	0%	
0.00050	8016	301%	207%	96%	12%	1%	0%	
0.00075	3533	586%	413%	199%	25%	3%	0%	half 2-yr
0.00100	1881	963%	688%	339%	45%	6%	0%	
0.00125	1099	1449%	1051%	529%	72%	9%	0%	
0.00150	693	2031%	1497%	770%	108%	14%	0%	2-yr
0.00175	442	2836%	2114%	1106%	159%	21%	0%	
0.00200	276	4021%	3036%	1620%	236%	32%	0%	
0.00225	184	5388%	4118%	2215%	338%	43%	0%	5-yr
0.00250	127	6943%	5328%	2926%	457%	60%	0%	
0.00275	72	10878%	8456%	4749%	757%	104%	0%	10-yr
0.00300	34	20379%	16088%	9115%	1506%	218%	0%	
0.00325	18	34306%	27417%	15833%	2650%	394%	0%	25-yr
0.00350	4	138175%	111000%	65000%	11250%	1725%	0%	50-yr
0.00375	1	494400%	398700%	239700%	42500%	6400%	0%	100-yr
0.00400	0							

Rain Garden Modeling Process in WWHM3

Rain gardens are represented in the Western Washington Hydrology Model version 3 (WWHM3) by the bioretention swale element. The WWHM3 bioretention swale element is a special conveyance feature with unique characteristics. The element uses the HSPF (Hydrologic Simulation Program Fortran) hydraulic algorithms to route runoff, but the HSPF routing is modified to represent the two different flow paths that runoff can take. The routing is dependent on the inflow to the swale and the swale soil capacity to absorb additional runoff. HSPF Special Actions is used to check the swale soil capacity to determine the appropriate routing option.

A bioretention swale is a swale in which the native soils have been excavated and replaced with amended soil. At the downstream end of the swale a weir controls the surface discharge from the swale 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. Swales can include an under-drain pipe.

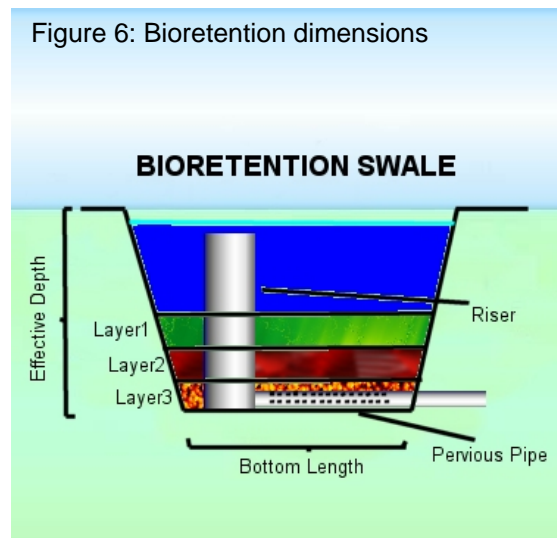
The amended soil placed in the swale is assumed to have storage capacity equal to its porosity and volume. Runoff infiltrates from the surface of the swale to the amended soil at an infiltration rate set by the user. The infiltration rate cannot exceed the available storage capacity of the amended soil. The available storage capacity is determined each time step by HSPF Special Actions. Once the amended soil is saturated then water has the opportunity to infiltrate into the underlying native soil at the native soil's infiltration rate. The native soil infiltration is input by the user and is assumed to be constant throughout the year.

Inflow to the swale can exceed the amended soil infiltration rate. When this occurs the extra water ponds on the surface of the swale. The extra water can then infiltrate into the soil during the next time step or can flow out of the swale through its surface outlet if the ponding exceeds the surface outlet's storage.

Runoff in both the surface storage and amended soil storage is available for evapotranspiration. Surface storage evapotranspiration is set to the potential evapotranspiration (pan evaporation factor equals 0.76) and the amended soil evapotranspiration pan evaporation factor is set to 0.50 to reflect reduced evapotranspiration from the amended soil.

The bioretention swale dimensions are specified in terms of swale length, bottom width, freeboard, over-road flooding, effective total depth, bottom slope, and left and right side slopes (see figures 6 and 7). The user is required to enter the following information about the bioretention swale:

- Swale Length (ft): length dimension of swale surface bottom.
- Swale Bottom Width (ft): width dimension of swale surface bottom.
- Freeboard (ft): depth of surface ponding before weir/street overflow occurs.
- Over-road Flooding (ft): maximum depth of flow over weir/street.



- Effective Total Depth (ft): the total depth of the amended soil layer(s) plus freeboard plus over-road flooding plus vertical orifice elevation plus vertical orifice diameter; effective total depth is computed by WWHM3.
- Bottom Slope of Swale (ft/ft): the slope of the swale length (must be greater than zero).
- Left Side Slope (ft/ft): H/V ratio of horizontal distance to vertical (zero for vertical swale sides).
- Right Side Slope (ft/ft): H/V ratio of horizontal distance to vertical (zero for vertical swale sides).

The amended soil is represented in the bioretention swale input by an infiltration rate and up to three soil layers of different depth and porosity. Input for amended soil infiltration include:

- Infiltration Rate (inches per hour): infiltration rate of the amended soil for all layers.
- Layer Thickness (feet): depth of amended soil.
- Layer Porosity (fraction): fraction of amended soil volume that is empty pore space available for water storage.

Infiltration to the native soil can be turned on by setting Native Infiltration to YES. The parameters for native soil infiltration are:

- Measured Infiltration Rate (inches per hour): infiltration rate of the native soil.
- Infiltration Reduction Factor: between 0 and 1 (1/safety factor).
- Use Wetted Surface Area (sidewalls): YES or NO; YES allows infiltration to the native soil through the sidewalls of the swale; otherwise all infiltration is through the bottom only.

The user has two swale surface outlet configuration choices: 1) vertical orifice + overflow (see Figure 7); or 2) riser outlet structure (see Figure 6). The input information required for the vertical orifice plus overflow is:

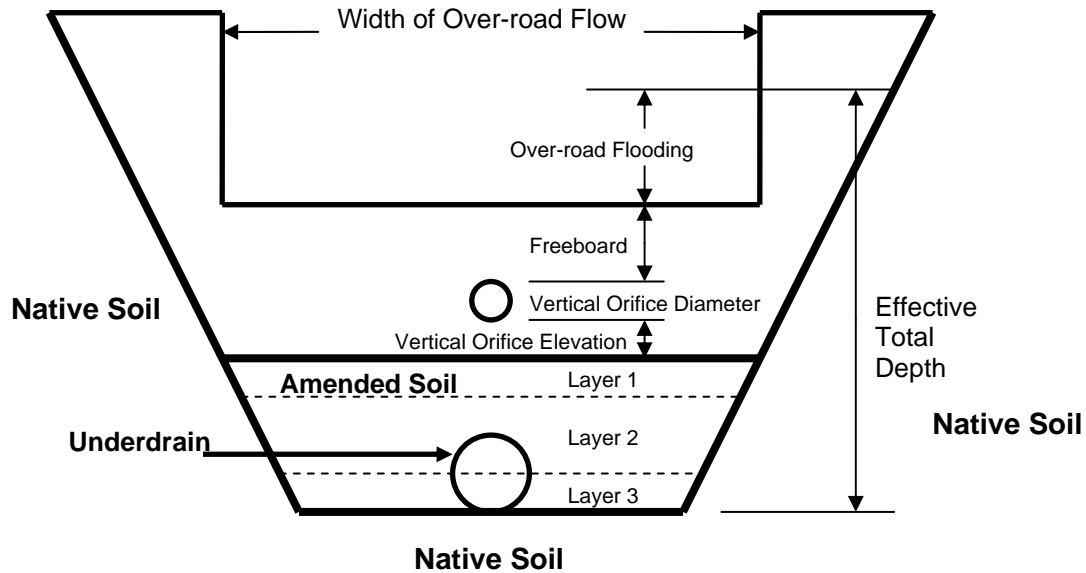
- Vertical Orifice Diameter (inches): diameter of vertical opening below the weir.
- Vertical Orifice Elevation (inches): vertical distance from the top of the amended soil surface to the bottom of the vertical orifice.
- Width of Over-road Flow (feet): weir/street length.

The input information required for the riser outlet structure is:

- Riser Height above Swale Surface (feet): same as the freeboard (depth of surface ponding before the riser is overtopped).
- Riser Diameter (inches): diameter of the stand pipe.
- Riser Type: Flat or Notched.
- Notch Type: Rectangular, V-Notch, or Sutro.
- For a rectangular notch:
 - Notch Height (feet): distance from the top of the weir to the bottom of the notch.
 - Notch Width (feet): width of notch; cannot be larger than the riser circumference.

Note: the typical residential rain garden will use a surface outlet configuration similar to that shown in Figure 7 with a vertical orifice diameter of zero and without an under-drain.

Figure 7: Diagram of bioretention swale with vertical orifice plus overflow:



The amended soil layer fills with stormwater from the top on down to where it can drain to the native soil (if Native Infiltration is set to YES) and/or the underdrain pipe (if Underdrain Used box is checked).

Water enters the underdrain when the amended soil becomes saturated down to the top of the underdrain. The underdrain pipe fills and conveys water proportionally to the depth of amended soil saturation. When the amended soil is fully saturated the underdrain pipe is at full capacity.

To use the underdrain, click the Underdrain Used box and input an underdrain diameter (feet). The bottom of the underdrain pipe is assumed to be at the bottom of the amended soil layer.

If native infiltration is turned on then native infiltration will start when/if:

1. Water starts to fill the underdrain (if an underdrain is used).
2. Water enters the amended soil (if Use Wetted Surface Area (sidewalls) is set to YES).
3. Water saturates the amended soil layer(s) to 2/3rds of the total amended soil depth (if there is no underdrain and Wetted Surface Area is set to NO).

There is a simple swale option. It is computationally much faster than the standard bioretention swale. Before using the simple swale option read the note below to understand the limitations of the simple swale.

The standard bioretention swale routine uses HSPF Special Actions to check the available amended soil storage and compares it with the inflow rate. Using the bioretention swale routine takes much longer than simulations not using bioretention swales because of the soil storage check done by HSPF Special Actions simulations. Simulations that normally take only seconds may take multiple minutes when one or more bioretention swales are added, depending on the computational speed of the computer used.

One solution to this problem is to use the simple swale option (check the Use Simple Swale box). The simple swale does not include HSPF Special Actions. It is less accurate than the standard swale. Tests have shown that the simple swale option should only be used when the swale area (and volume) is relatively small compared to the contributing basin area. If in doubt, model the bioretention swale both ways and see how close the simple swale answer is to the standard swale method. The standard swale method will always be more accurate than the simple swale.