STORMWATER BEST MANAGEMENT PRACTICE SIMPLIFIED SIZING TOOL

Kitsap County

Prepared for

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Note:
Some pages in this document have been purposefully skipped or blank pages inserted so that this document will copy correctly when duplexed.

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Introduction

Herrera Environmental Consultants was retained by the Kitsap County Public Works Department and the Kitsap Home Builders Foundation to develop a simplified sizing tool for low impact development (LID), infiltration, and detention best management practice (BMP) design in Kitsap County (County). Precipitation depths and rainfall patterns vary widely across the County with mean annual precipitation ranging from 26 inches in the north to 68 inches in the southwestern corner (Figure 1). The goal of this study was to develop simple mathematical relationships to allow sizing of pre-designed BMPs as a function of contributing impervious area, site infiltration rates, and mean annual precipitation. To develop the simplified sizing tool, benefits for selected BMPs were quantified either as flow control credits (runoff reduction credits) or sizing equations (relating the facility size to the impervious area mitigated). This tool allows the designer to size BMPs without extensive calculations or continuous modeling, and can streamline agency review of design submittals by providing “rule of thumb” sizing equations. By providing pre-designed and pre-sized LID BMPs, this tool helps reduce barriers to LID implementation across Kitsap County.

This report presents a description of the stormwater BMPs included, the infiltration rates evaluated, the stormwater management standards used, the modeling and regression analysis methods employed, and the resulting County-wide BMP sizing equations.

Pre-designed Stormwater BMPs

The sizing tool was developed for selected LID, infiltration, and detention BMPs (Table 1). To use the sizing tool, the BMPs must be designed per the design requirements listed in this section. Additional requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the Washington State Department of Ecology (Ecology) Stormwater Management Manual for Western Washington (Ecology 2005), the Kitsap County Stormwater Management Design Manual (Kitsap County 1997), and the Kitsap County Low Impact Development (LID) Guidance Manual (Kitsap Home Builders Foundation 2009). Supplemental design resources for LID BMPs (e.g., recommended construction specifications) are available in the City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual (Seattle 2009). Additional state-of-the-practice design guidance for LID BMPs will be forthcoming in 2011 in the updated LID design manual being prepared by Washington State University Cooperative Extension for the Puget Sound Partnership.

Low Impact Development BMPs

Sizing factors or flow control credits were developed for a suite of LID BMPs: bioretention, permeable pavement, trees, partial dispersion, and vegetated roofs. BMP descriptions and design requirements are presented below.

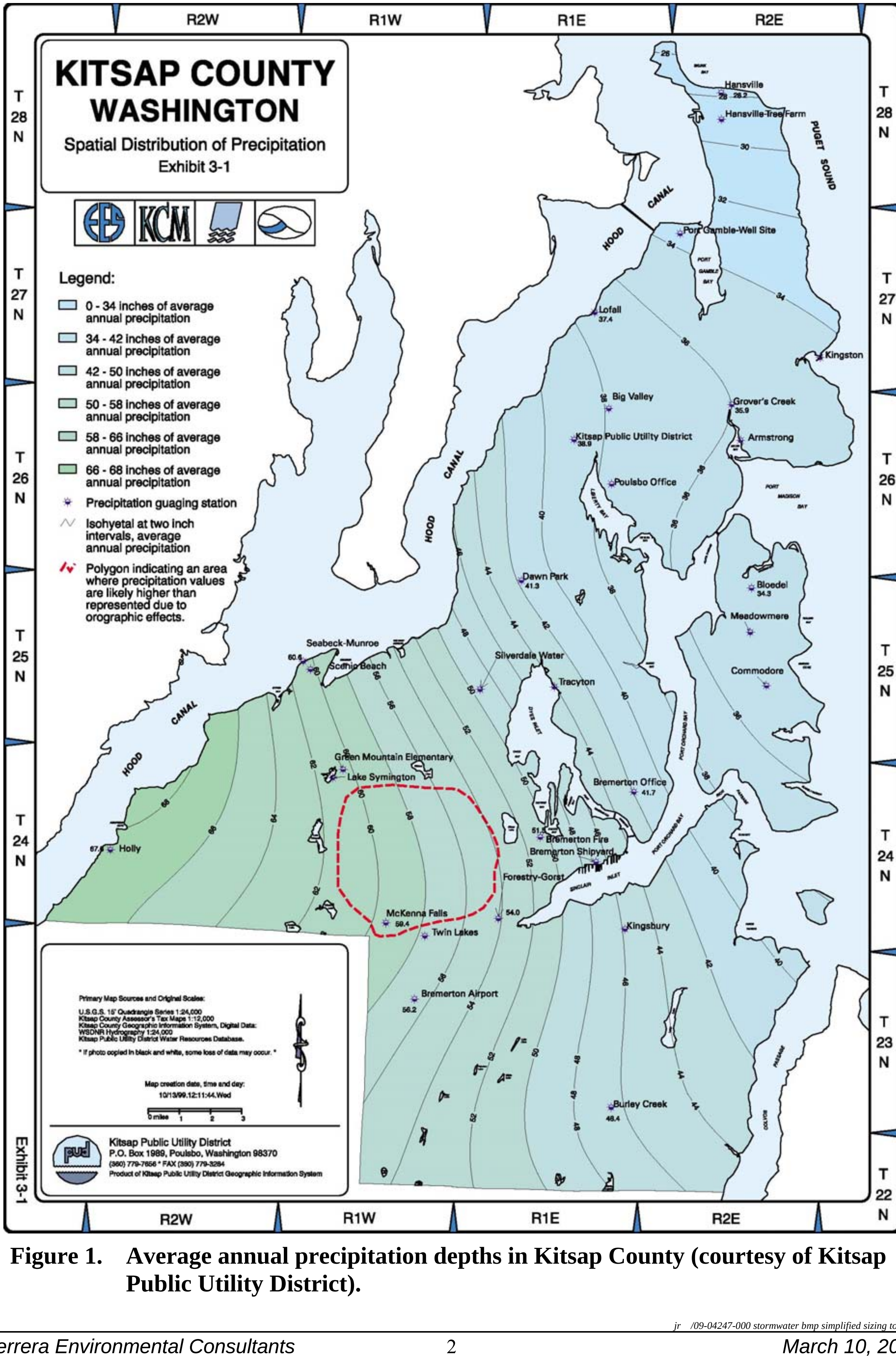


Figure 1. Average annual precipitation depths in Kitsap County (courtesy of Kitsap Public Utility District).

Table 1. BMPs included in the simplified sizing tool.

BMP	Design Configuration	BMP Sizing Tool		Design Infiltration Rate (inch per hour)				
		Flow Control	Treatment	0.13	0.25	0.5	1.0	2.0
LID Runoff Reduction Methods								
Retaining Tree	Evergreen & Deciduous	Flow Credit	NA					
Planting New Tree	Evergreen & Deciduous	Flow Credit	NA					
Partial Dispersion	Downspout & Sheet Flow	Flow Credit	NA					
Vegetated Roof	4- and 8-inch Growth Media Depth	Flow Credit	NA					
Permeable Pavement Surface	2-5% Slope	Credit & Factor	—	X	X			
Permeable Pavement Surface	<2% Slope	Credit & Factor	—	X	X			
LID Facilities								
Bioretention	2-, 6- & 10-inch Ponding Depth	Sizing Factor	Sizing Factor		X	X	X	X
Permeable Pavement Facility	6-inch Storage Reservoir Depth	Sizing Factor	—		X	X	X	
Traditional Infiltration Facilities								
Rock Trench		Sizing Factor	—	X	X	X		X
Gravelless Chamber		Sizing Factor	—	X	X	X		X
Detention Facilities								
Detention Pipe	42-inch Pipe, 0.5-inch Orifice	Sizing Equation	NA					

X evaluated as part of this study
— not evaluated as part of this study
NA not applicable
% percent

Bioretention

Bioretention facilities, also known as rain gardens, are shallow depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions. The healthy soil structure and vegetation promote infiltration, water storage, and slow release of stormwater flows to more closely mimic natural conditions. When used for flow control, bioretention facilities must not have an underdrain to intercept infiltrated runoff or an impermeable liner impeding infiltration to underlying soil. Three design variations were evaluated: a 2-inch, 6-inch, and 10-inch ponding depth.

In order for the pre-sizing results presented in this report to be applicable, the following bioretention facility design requirements must be met:

- The drainage area contributing runoff to an individual bioretention facility shall be no larger than 5,000 square feet of pollution generating impervious surface, 10,000 square feet of impervious surface, or 3/4 acre of lawn and landscape[1].
- Bioretention bottom area shall be sized using the sizing tool.
- Top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes, and the total facility depth (e.g., ponding and freeboard depth).
- Bottom area shall be flat (0 percent slope).
- Side slopes within the ponded area shall be no steeper than 3H (horizontal):1V (vertical).
- Imported bioretention soil per City of Seattle specifications shall be used. This draft specification is included as Attachment A. Future updates to this specification will be posted on the SPU green stormwater infrastructure website (http://www.seattle.gov/util/greeninfrastructure). This soil mix meets the Washington State Department of Ecology (Ecology) treatment soil requirements, has a design infiltration rate of 3.0 inches per hour[2], and has 40 percent porosity.
- Because imported bioretention soil is used, the design infiltration rate of the underlying native soil does not require a correction factor (i.e., the design, or "long-term" infiltration rate is the same as the "initial" infiltration rate).

[1] The area limitation is to ensure that bioretention facilities are small-scale and distributed. Also, the assumed infiltration rate correction factor applied to City of Seattle standard bioretention soil mixes is based on a contributing area that does not exceed 5,000 square feet of impervious surface.
[2] Modeling was performed using a 2.5 inch per hour design infiltration rate for the bioretention soil mix. Therefore, the sizing equations will result in conservative facility sizes.

- Bioretention soil depth shall be a minimum of 12 inches for flow control, and minimum of 18 inches for water quality treatment.
- No underdrain or impermeable layer shall be used if designed for flow control.
- Minimum ponding depth shall be as specified (2, 6, or 10 inches).

In addition to the requirements listed above, a maximum surface pool drawdown time of 24 hours is recommended, and often required. Allowing the soil to dry out periodically is necessary to restore hydraulic capacity of the system for subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and provide proper soil conditions for treatment. While bioretention facilities with 10 inches of ponding and an infiltration rate of 0.25 inch per hour were sized as part of this study, the surface pool drawdown time exceeds 24 hours, so this design configuration may not be permitted.

Permeable Pavement

Permeable pavement is a paving system that allows rainfall to percolate into an underlying aggregate storage reservoir, where stormwater is stored and infiltrated to underlying soil. A permeable pavement system consists of a pervious wearing course (e.g., porous asphalt concrete, porous cement concrete, paver blocks, or open-celled paving grids) and an aggregate subbase course installed over native soil. Two categories of permeable pavement systems were included in this study: permeable pavement *surfaces* and permeable pavement *facilities*.

A permeable pavement surface is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas.

A permeable pavement facility typically has a thicker aggregate storage reservoir than a surface and may be designed to receive stormwater run-on from other areas. For slopes greater than 2 percent, the subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration. Ponding may be accommodated using design features such as terracing berms (check dams) or intermittent infiltration trenches. When the subsurface soil slope is less than 2 percent, at least one low permeability check dam should be installed at the downslope end of the aggregate storage reservoir to contain water in the facility. Additional design features may be required, including an overflow to keep the top section of the pavement dewatered (to address freeze/thaw concerns).

In order for the pre-sizing results presented in this report to be applicable, the following permeable pavement *facility* design requirements must be met:

- Pervious pavement area shall be sized using the sizing tool.
- The infiltration rate used to determine the sizing equation shall be the design, or "long-term", rate and must be calculated using correction factors (safety factors) per the Ecology Stormwater Management Manual

for Western Washington (Ecology Manual). Based on conversations between Kitsap County and Ecology staff, the following minimum correction factors are recommended:

- ☐ Facility not receiving stormwater run-on: correction factor of 2
- ☐ Facility receiving stormwater run-on from an area less than twice that of the facility: correction factor of 2
- ☐ Facility receiving stormwater run-on from an area larger than twice that of the facility: correction factor of 4

- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches.
- For areas where the subgrade has a slope of 2 percent or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams).
- For areas where the subgrade has a slope of less than 2 percent, at least one low permeability check dam should be installed at the downslope end of the aggregate storage reservoir to contain water in the facility.
- Aggregate shall have a minimum void volume of 20 percent
- Slope of the subgrade underlying the pervious pavement shall be less than 5 percent.
- No underdrain or impermeable layer shall be used.
- The sizing relationship is not applicable for an infiltration rate of 0.25 inches per hour when the mean annual precipitation exceeds 37 inches.

In order for the pre-sizing results presented in this report to be applicable, the following permeable pavement *surface* design requirements must be met:

- Aggregate depth shall be sized using the sizing tool.
- For subgrade slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit.
- The pavement surface shall not receive stormwater run-on from other areas.
- Aggregate shall have a minimum void volume of 20 percent.

- Slope of the subgrade underlying the permeable pavement surface shall be less than 5 percent.
- No underdrain or impermeable layer shall be used.

Trees

Trees provide flow control via interception, transpiration, and increased infiltration. Additional environmental benefits include improved air quality, carbon sequestration, reduced heat island effect, pollutant removal, and habitat preservation or formation. When implemented in accordance with the criteria outlined below, retained and newly planted trees can viably be credited toward meeting flow control requirements. The degree of flow control provided by a tree depends on the tree type (i.e., evergreen or deciduous), canopy area, and whether or not the tree canopy overhangs impervious surfaces.

In order for the flow control credits presented in this report to be applicable, the following requirements must be met for both retained and newly planted trees:

- Trees shall be retained, maintained and protected on the site after construction and for the life of the development or until any approved redevelopment occurs in the future. Trees that are removed or die shall be replaced with like species during the next planting season (typically in fall). Trees shall be pruned according to industry standards.
- Tree credits are not applicable to trees in native vegetation areas used for flow dispersion or other flow control credit.
- Trees must be on the development site and within 20 feet of new and/or replaced ground level impervious surfaces (e.g., driveway, patio, or parking lot). Distance from impervious surfaces is measured from the edge of the surface to the center of the tree at ground level.
- Trees planted in planter boxes are not eligible for flow control credit.
- The total tree credit for retained and newly planted trees shall not exceed 25 percent of impervious surface area requiring mitigation.

Retained tree requirements include the following:

- Trees must be viable for long-term retention on the site (i.e., in good health and compatible with proposed construction).
- Retained trees shall have a minimum 6 inches diameter at breast height (DBH). DBH is defined as the outside bark diameter at 4.5 feet above the ground on the uphill side of a tree. For existing trees smaller than this, the newly planted tree credit may be applied.

- The retained tree canopy area shall be measured at the time of permit application as the area within the tree drip line. A drip line is the line encircling the base of a tree, which is delineated by a vertical line extending from the outer limit of a tree's branch tips down to the ground. If trees are clustered, overlapping canopies are not double counted.

- The existing tree roots, trunk, and canopy shall be fenced and protected during construction activities to avoid damage to the tree.

Newly planted tree requirements include the following:

- New deciduous trees shall be at least 1.5 inches in diameter measured 6 inches above the ground. New evergreen trees shall be at least 4 feet tall.

- Approved tree species are listed in the City of Seattle Tree List available via link from the SPU GSI web site (http://www.seattle.gov/util/greeninfrastructure).

- Mature tree height, size, and rooting depth must be considered to ensure that the tree location is appropriate given adjacent and above- and below-ground infrastructure.

- To help ensure tree survival and canopy coverage, the minimum tree spacing for newly planted trees shall accommodate mature tree spread (see City of Seattle Tree List). In no circumstance shall flow control credit be given for new tree density exceeding 10 feet on center spacing.

- Provisions shall be made for supplemental irrigation during the first three growing seasons after installation to help ensure tree survival.

Partial Dispersion

Partial dispersion of stormwater runoff attenuates peak flows by slowing entry of the runoff into the conveyance system, allows for some infiltration, and provides some water quality benefits. Sheet flow dispersion is a simple BMP comprised of an impermeable surface that drains to a strip of vegetation in a non-concentrated form. Downspout dispersion BMPs are splashblocks or gravel-filled trenches that serve to spread concentrated flows over vegetated pervious areas. These partial dispersion techniques differ from Ecology’s full dispersion BMP which requires preservation of at least 65 percent of the site in a forest of native condition and achieves full flow control credit.

To use the flow control credits for sheet flow or downspout dispersion presented in this report, the BMPs must be designed per the requirements (e.g., minimum vegetated flow paths) presented in the Ecology Manual.

Vegetated Roofs

Vegetated roofs are areas of living vegetation installed on top of buildings to provide stormwater flow control via attenuation, soil storage, and losses to interception, evaporation, and transpiration. Vegetated roofs are also known as ecoroofs, green roofs, and roof gardens.

A vegetated roof consists of a system in which several materials are layered to achieve the desired vegetative cover and drainage characteristics. Design components vary depending on the vegetated roof type and site constraints, but typically include a waterproofing material, a root barrier, a drainage layer, a separation fabric, a growth medium (soil), and vegetation. Flow control credits were developed for 4- and 8-inches of growth media depth. Establishing detailed design requirements for vegetated roofs is outside of the scope of this report.

Traditional Infiltration BMPs

Sizing factors were developed for two traditional infiltration BMPs: rock trenches and gravelless chambers. BMP descriptions and design requirements are presented below.

Rock Trench

The rock trench BMP is based on guidance for downspout infiltration trench designs, presented in the Ecology Manual (Ecology 2005). A typical trench design is shown in Attachment B. This BMP consists of an aggregate-filled trench where collected stormwater is temporarily stored and then infiltrated into the underlying soil. The trench cross section is 24 inches wide and 18 inches high before overflow and the trench length was sized to meet Ecology's flow control requirements (outlined in detail below).

In order for the pre-sizing results presented in this report to be applicable, the following rock trench facility design requirements must be met:

- Rock trench length shall be determined using the sizing tool.
- The infiltration rate used to determine the sizing equation shall be the design, or "long-term," rate and must be calculated using correction factors per the Ecology Manual.
- Trench cross section shall be 24 inches wide by 18 inches high before overflow.
- Trench aggregate shall have a minimum void volume of 30 percent.

Gravelless Chamber

The gravelless chamber BMP is based on guidance presented in the Kitsap County Stormwater Management Design Manual (Kitsap County 1997). A typical chamber design is shown in

Attachment C. This BMP consists of a buried chamber where collected stormwater is temporarily stored and then infiltrated into underlying soil. Gravelless chambers create an underground cavity that can provide a greater void volume than rock trenches and often require a smaller footprint. Per County requirements, the chamber must have a minimum void volume of 2.6 cubic feet per linear foot and a minimum infiltrative surface of 2.8 square feet per linear foot.

In order for the pre-sizing results presented in this report to be applicable, the following gravelless chamber facility design requirements must be met:

- Chamber length shall be determined using the sizing tool.
- The infiltration rate used to determine the sizing equation shall be the design, or “long-term,” rate and must be calculated using correction factors per the Ecology Manual.
- Void (storage) volume provided by the chamber shall be at least 2.6 cubic feet per linear foot.
- Infiltrative surface under chamber footprint shall be at least 2.8 square feet per linear foot.

Detention BMPs

Sizing equations were developed for a 42-inch diameter detention pipe designed per Ecology requirements (Ecology 2005). In order for the pre-sizing results presented in this report to be applicable, the following additional detention pipe design requirements must be met:

- Pipe length shall be determined using the sizing tool.
- Detention pipe shall be a minimum of 42-inches in diameter.
- The low flow orifice diameter shall be 0.5 inches with its invert elevation set at 6 inches above the bottom of the pipe.
- The overflow invert elevation shall be set no lower than 3 feet above the invert of the low flow orifice (i.e., at the crown of the 42-inch diameter pipe).

Infiltration Rates

BMPs that infiltrate stormwater to underlying soil were sized for up to five design infiltration rates: 0.13, 0.25, 0.5, 1.0 and/or 2.0 inches per hour. The rates used vary by BMP and are presented in Table 1.

The Department of Ecology offers the USDA Soil Textural Classification approach as one method to determine long-term infiltration rates for a given project. Table 2 is excerpted from the Ecology Manual (Ecology 2005), and provides infiltration rates for four soil classifications. The short-term infiltration rates presented in Table 2 do not consider the effects of site variability and long-term clogging due to siltation and biomass buildup in the infiltration facility. To develop long-term infiltration rates, Ecology recommends dividing the short-term rates by a correction factor of 4 to account for the reduction in infiltration rate over time.

Table 2. Infiltration rates recommended by the Department of Ecology.

USDA Soil Textural Classification	Short-Term Infiltration Rate (inch/hour)	Correction Factor, CF	Estimated Long-Term (Design) Infiltration Rate (inch/hour)
Sand	8	4	2
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

Source: Table 3.7 in Volume III of the Stormwater Management Manual for Western Washington (Ecology 2005)

Four of the five infiltration rates used in this study correspond to the long-term, or "design," infiltration rates corresponding to sand, loamy sand, sandy loam and loam. This enables easy use of the sizing tool for sites where the USDA Soil Textural Classification approach is used to determine site infiltration rates.

Stormwater Management Standards

BMPs were sized to meet Ecology's minimum requirements for flow control assuming a pre-developed forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a pre-developed forest condition[3].

Bioretention facilities were also sized to achieve the Ecology water quality treatment requirement (i.e., facilities were sized to infiltrate 91 percent of all runoff volume for the period modeled). Bioretention facilities meet Ecology's basic, phosphorus and enhanced water quality treatment requirements when at least 91 percent of the total runoff volume is infiltrated through soil meeting Ecology's treatment soil requirements (such as 18 inches of the City of Seattle bioretention soil mix).

[3] The Ecology standard states that "stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow." Matching discharge durations does not always result in matching peak flow rates. For this study, both peak flow and flow durations were matched to the pre-developed condition. This resulted in relationships with higher linear correlation and somewhat conservative facility sizes.

Modeling Methods

The Western Washington Hydrology Model, Professional Version 3 (WWHM3 Pro) was used for this study. WWHM3 Pro is a continuous simulation hydrologic model that simulates rainfall runoff based on topography, soils, and vegetation. The model was run at a one-hour time step. Till (hydrologic group C) soil and moderate slope conditions were assumed.

The range of rainfall depths and patterns in Kitsap County were represented by an extended precipitation and evaporation timeseries developed by MGS Engineering Consultants, Inc. (MGS 2002). The "Puget West" timeseries covers most of the County and is applicable to sites with mean annual precipitation depth ranging from 32 to 60 inches. The extended timeseries has a length of 158 years at an hourly time step. BMPs were evaluated for mean annual precipitation depths of 32, 36, 44, and 52 inches per year. These precipitation depths were selected to provide the best coverage of the Urban Growth Areas of Kitsap County, including Port Orchard/South Kitsap Industrial, Bremerton/Silverdale, Poulsbo, and Kingston.

Detailed modeling methods, assumptions and inputs for each BMP are presented in Attachment D.

Sizing Factors for Infiltration Facilities

Sizing factors were developed for LID and traditional infiltration BMPs including bioretention, permeable pavement, rock trench and gravelless chamber facilities. BMPs were sized to meet flow control or water quality treatment standards for the following scenarios:

- Contributing impervious area: 2,000, 5,000, and 10,000 square feet
- Native soil design infiltration rate: 0.13, 0.25, 0.5, 1.0, and/or 2.0 inches per hour (see Table 1)
- Mean annual precipitation depth: 32, 36, 44, and 52 inches per year

The BMP facility size (area or length) under each scenario was plotted against contributing impervious area. Example plots for bioretention and permeable pavement, for a site with mean annual precipitation depth of 52 inches are shown in Figures 2 and 3, respectively. Results for all scenarios are included in Attachment E.

It is important to note that the bioretention area reported by the sizing tool is the bottom area. The top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes and the total facility depth (e.g., ponding and freeboard depth).

The relationships between the size of the BMP and the area of contributing impervious surface were evaluated using regression analysis. Microsoft Excel software was used to apply the

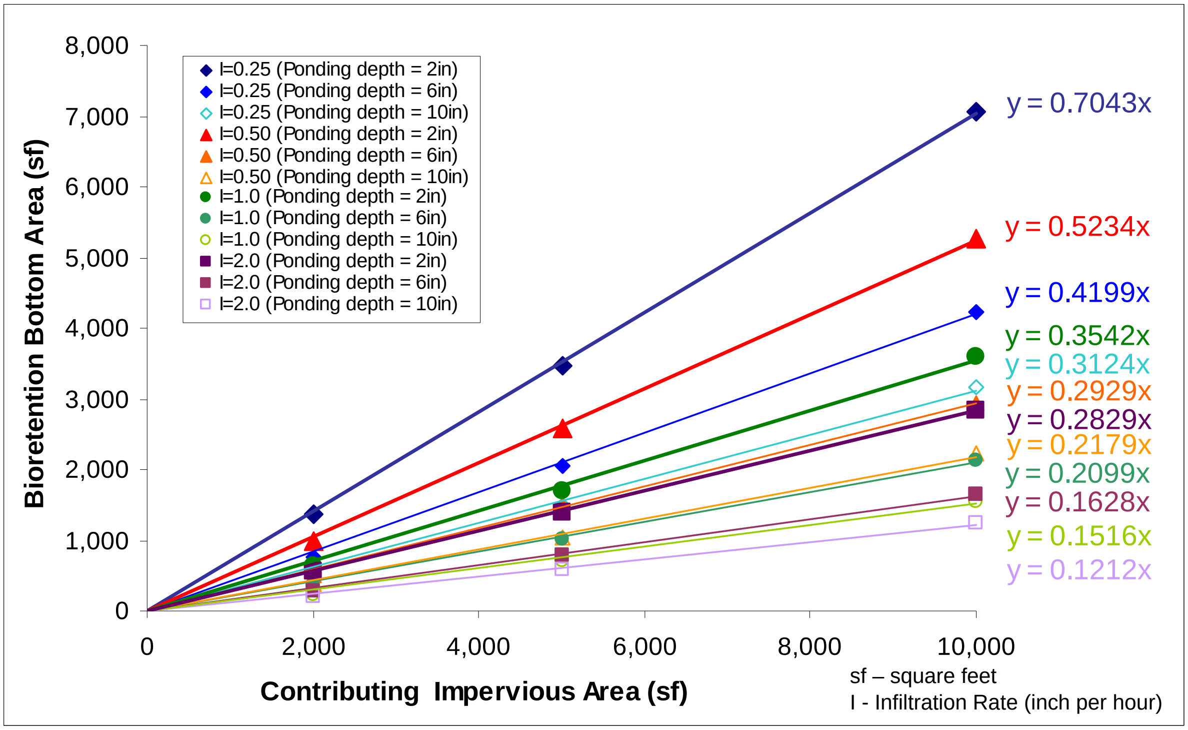


Figure 2. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (mean annual precipitation of 52 inches).

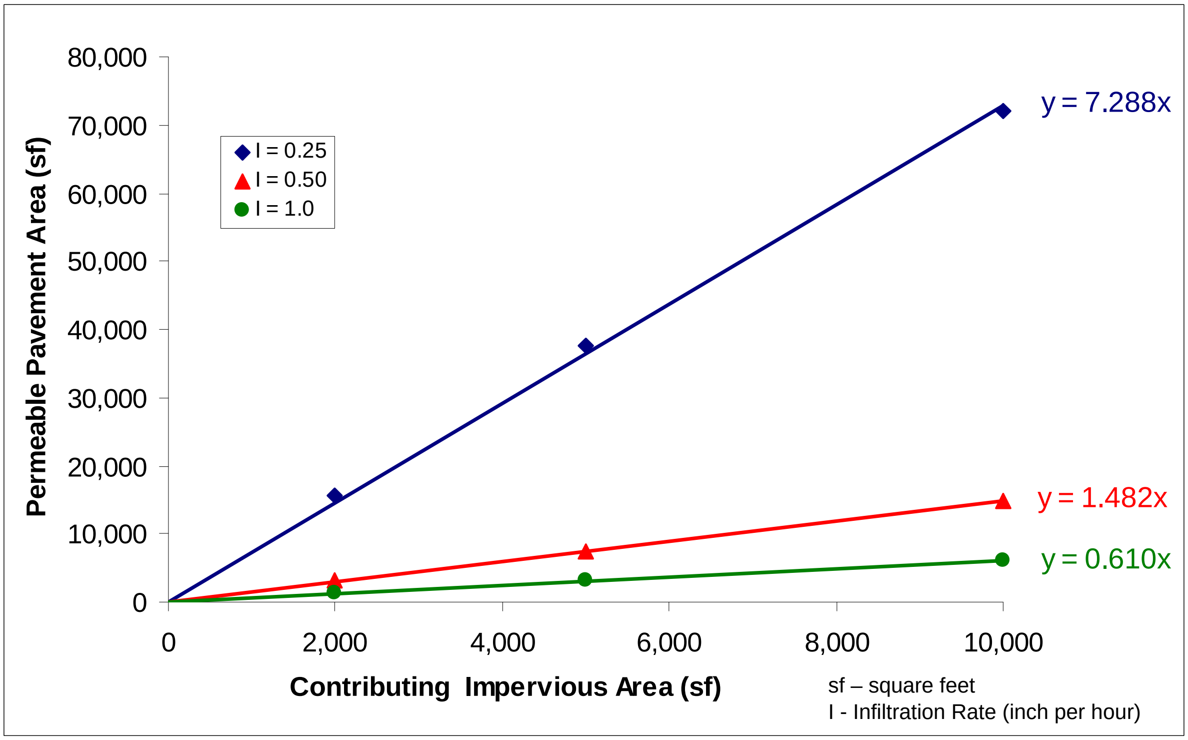


Figure 3. Permeable pavement facility sized for flow control as a function of contributing impervious area (mean annual precipitation of 52 inches).

method of least squares to determine the best fit for the data. For infiltration facilities, the y-axis intercept of the facility sizing graph is very close to zero (and was set to zero for the regression analysis). For all scenarios, the relationship between the size of the BMP and the area of contributing impervious surface is linear with an "R^2" value of at least 0.99. The R^2 value, or coefficient of determination, is an indicator of how well the regression analysis equation explains the relationship among the variables. A value of 1 indicates a perfect correlation.

Because the relationship is linear and the y-intercept is zero, the slope of the line can be used as a sizing factor to calculate the BMP size as a function of the impervious area draining to it:

BMP Area (square feet) = Impervious Area (square feet) x Sizing Factor (%)/100, or

BMP Length (feet) = Impervious Area (square feet) x Sizing Factor (%)/100

Sizing factors are provided for combinations of mean annual precipitation and design soil infiltration rate in Table 3. As an example, the size of a bioretention cell with 6 inches of ponding storage depth at a site with a native soil design infiltration rate of 0.5 inches per hour and a mean annual precipitation depth of 52 inches (Figure 2) would be calculated as 29.3 percent of the impervious area draining to it. Similarly, the size of a permeable pavement facility where the native soil design infiltration rate is 0.5 inches per hour and the site mean annual precipitation depth is 52 inches (Figure 3) would be calculated as 148 percent of the impervious area draining to it. In this case, the facility is larger than the contributing drainage area, such as roof runoff mitigated by a larger permeable parking lot facility.

To use the sizing factors in Table 3, the facilities must meet the specific design requirements (e.g., side slopes, ponding or gravel depth) presented in the "Stormwater BMPs" section above. Designers may linearly interpolate between the design depths evaluated, but may not extrapolate beyond the design parameters used in the pre-sizing calculations. To be conservative, design infiltration rates for the native soils must be rounded down to the nearest rate evaluated (e.g., for a site with a design rate of 0.75 inches per hour, the sizing factors for 0.5 inches per hour should be used).

Sizing Equations for Detention Pipe

Unlike infiltration BMPs, detention facilities are not capable of achieving the Ecology pre-developed forest standard at smaller sites. The minimum allowable orifice diameter for projects in Kitsap County is 0.5 inches for belowground detention systems. For smaller sites, the 0.5-inch bottom orifice diameter is too large to meet the flow control standard release rates, even with minimal hydraulic head. In this case, Ecology recommends that the designer iteratively increase detention area and decrease live storage depth until the performance criteria are met. However, Ecology does not require that the live storage depth be reduced to less than 3 feet in an attempt to meet the flow control standard.

Table 3. BMP sizing factors by mean annual precipitation.

BMP	Mean Annual Precipitation	Native Soil Design Infiltration Rate (inches/hour)	Sizing Factor (% of contributing impervious area)	
			Flow Control [a]	Water Quality [b]
Bioretention Cell [c,d]—2 inch ponding depth	32 inches	0.25	39.2%	—
		0.5	34.3%	—
		1.0	25.6%	—
		2.0	21.4%	—
	36 inches	0.25	45.2%	—
		0.5	37.3%	—
		1.0	27.8%	—
		2.0	23.0%	—
	44 inches	0.25	56.7%	—
		0.5	43.5%	—
		1.0	30.7%	—
		2.0	25.6%	—
	52 inches	0.25	70.4%	—
		0.5	52.3%	—
		1.0	35.4%	—
		2.0	28.3%	—
Bioretention Cell [c,d]—6 inch ponding depth	32 inches	0.25	23.5%	5.3%
		0.5	19.2%	3.7%
		1.0	14.4%	2.5%
		2.0	11.1%	2.1%
	36 inches	0.25	27.5%	6.0%
		0.5	21.4%	4.1%
		1.0	15.1%	2.8%
		2.0	12.0%	2.3%
	44 inches	0.25	34.3%	7.4%
		0.5	25.9%	5.0%
		1.0	18.4%	3.4%
		2.0	14.0%	2.8%
	52 inches	0.25	42.0%	8.9%
		0.5	29.3%	6.1%
		1.0	21.0%	4.1%
		2.0	16.3%	3.4%

Table 3 (continued). BMP sizing factors by mean annual precipitation.

BMP	Mean Annual Precipitation	Native Soil Design Infiltration Rate (inches/hour)	Sizing Factor (% of contributing impervious area)	
			Flow Control [a]	Water Quality [b]
Bioretention Cell [c,d,e] — 10 inch ponding depth	32 inches	0.25	17.8%	4.1%
		0.5	13.8%	2.7%
		1.0	10.5%	1.8%
		2.0	8.6%	1.4%
	36 inches	0.25	20.3%	4.6%
		0.5	15.1%	3.1%
		1.0	11.2%	2.0%
		2.0	9.3%	1.6%
	44 inches	0.25	25.4%	5.7%
		0.5	18.2%	3.8%
		1.0	13.1%	2.5%
		2.0	10.7%	2.0%
	52 inches	0.25	31.2%	7.0%
		0.5	21.8%	4.6%
		1.0	15.2%	3.0%
		2.0	12.1%	2.4%
Permeable Pavement Facility [c] (with 6 inch average ponding depth in aggregate storage reservoir)	32 inches	0.25	247%	—
		0.5	110%	—
		1.0	51.4%	—
	36 inches	0.25	291%	—
		0.5	117%	—
		1.0	52.2%	—
	44 inches	0.25	426%	—
		0.5	130%	—
		1.0	55.1%	—
	52 inches	0.25	729%	—
		0.5	148%	—
		1.0	61.0%	—
Rock Trench [f]	32 inches	0.13	27.5%	—
		0.25	17.2%	—
		0.5	10.8%	—
		2.0	4.5%	—
	36 inches	0.13	41.6%	—
		0.25	25.8%	—
		0.5	15.6%	—
		2.0	6.4%	—

Table 3 (continued). BMP sizing factors by mean annual precipitation.

BMP	Mean Annual Precipitation	Native Soil Design Infiltration Rate (inches/hour)	Sizing Factor (% of contributing impervious area)	
			Flow Control [a]	Water Quality [b]
Rock Trench [f] (cont'd)	44 inches	0.13	56.4%	—
		0.25	30.8%	—
		0.5	17.8%	—
		2.0	6.7%	—
	52 inches	0.13	78.4%	—
		0.25	38.2%	—
		0.5	22.0%	—
		2.0	7.5%	—
Gravelless Chamber [f]	32 inches	0.13	10.3%	—
		0.25	7.4%	—
		0.5	5.0%	—
		2.0	2.3%	—
	36 inches	0.13	14.7%	—
		0.25	10.3%	—
		0.5	7.1%	—
		2.0	3.2%	—
	44 inches	0.13	18.0%	—
		0.25	12.6%	—
		0.5	8.1%	—
		2.0	3.6%	—
	52 inches	0.13	22.4%	—
		0.25	15.4%	—
		0.5	9.6%	—
		2.0	3.9%	—

%-percent

— not evaluated as part of this study

[a] Sizing factors developed to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a pre-developed till/forest condition. Infiltration facilities sized for flow control also meet water quality treatment standards when native or imported soil meets Ecology treatment soil requirements (e.g., 18 inches of imported bioretention soil per Seattle specifications).

[b] Sizing factors developed to infiltrate 91 percent of the runoff file.

[c] BMP area is calculated as a function of impervious area draining to it: BMP Area (square feet) = Impervious Area (square feet) x Sizing Factor (%)/100

[d] Sizing factors are for bioretention facility bottom area. Total footprint area may be calculated based on side slopes (3H:1V), ponding depth, and freeboard.

[e] Surface pool drawdown time exceeds 24 hours for 0.25 inch per hour infiltration rate.

[f] BMP length is calculated as a function of impervious area draining to it: BMP Length (feet) = Impervious Area (square feet) x Sizing Factor (%)/100.

To maximize the flow control benefit in these cases, detention pipes were sized with a low flow orifice of minimum diameter (0.5 inches) and a 3-foot live storage depth such that no overflows occur during the simulated period of record. Using this method, detention pipe was sized for the following scenarios:

- Contributing impervious surface drainage area: 2,000 up to at least 20,000 square feet
- Mean annual precipitation depth: 32, 36, 44, and 52 inches per year

The pipe length under each scenario is plotted against contributing impervious surface area in Figure 4. The type of relationships between contributing drainage area and pipe length depend upon the size of the contributing drainage area. For all scenarios, the relationship between the detention pipe length and the area of contributing impervious surface has an R^2 value of at least 0.99. The sizing equations are presented in Table 4 by mean annual precipitation.

For larger contributing drainage areas the Ecology pre-developed forest standard can be achieved and the relationships are linear. Unlike the relationships for infiltration facilities, the y-axis intercept of the regression line is not zero. Because the relationship is linear and the y-intercept is an integer, the slope of the line (“Factor”) and the y-intercept (“Integer”) can be used to calculate the pipe length as a function of the impervious surface area draining to it:

Pipe Length (feet) = [Factor x Impervious Area (square feet)] + Integer

As an example, for a site with 44 inches of mean annual precipitation and more than 21,250 square feet of contributing impervious surface area, the length of the pipe would be calculated by multiplying the contributing impervious surface area (in square feet) by 0.1579 and then subtracting 1,862.

For smaller contributing drainage areas the Ecology pre-developed forest standard cannot be achieved. In these situations the pipe is sized to maximize the flow control benefit as described above. This results in a power relationship and the pipe length is calculated as:

Pipe Length (feet) = Factor x [Impervious Area (square feet)^Integer]

As an example, for a site with 44 inches of mean annual precipitation and less than 19,000 square feet of contributing impervious surface area, the length of the pipe would be calculated by raising the contributing impervious area (in square feet) to a power of 1.657 and then multiplying the result by 0.00012.

For contributing drainage areas in the transition zone between the power and linear relationships a horizontal line was established to bridge the relationships and the pipe length is equal to a constant value. As an example, for a site with 44 inches of mean annual precipitation and a contributing impervious surface area between 19,000 and 21,250 square feet, the length of the pipe would be equal to 1,500 square feet.

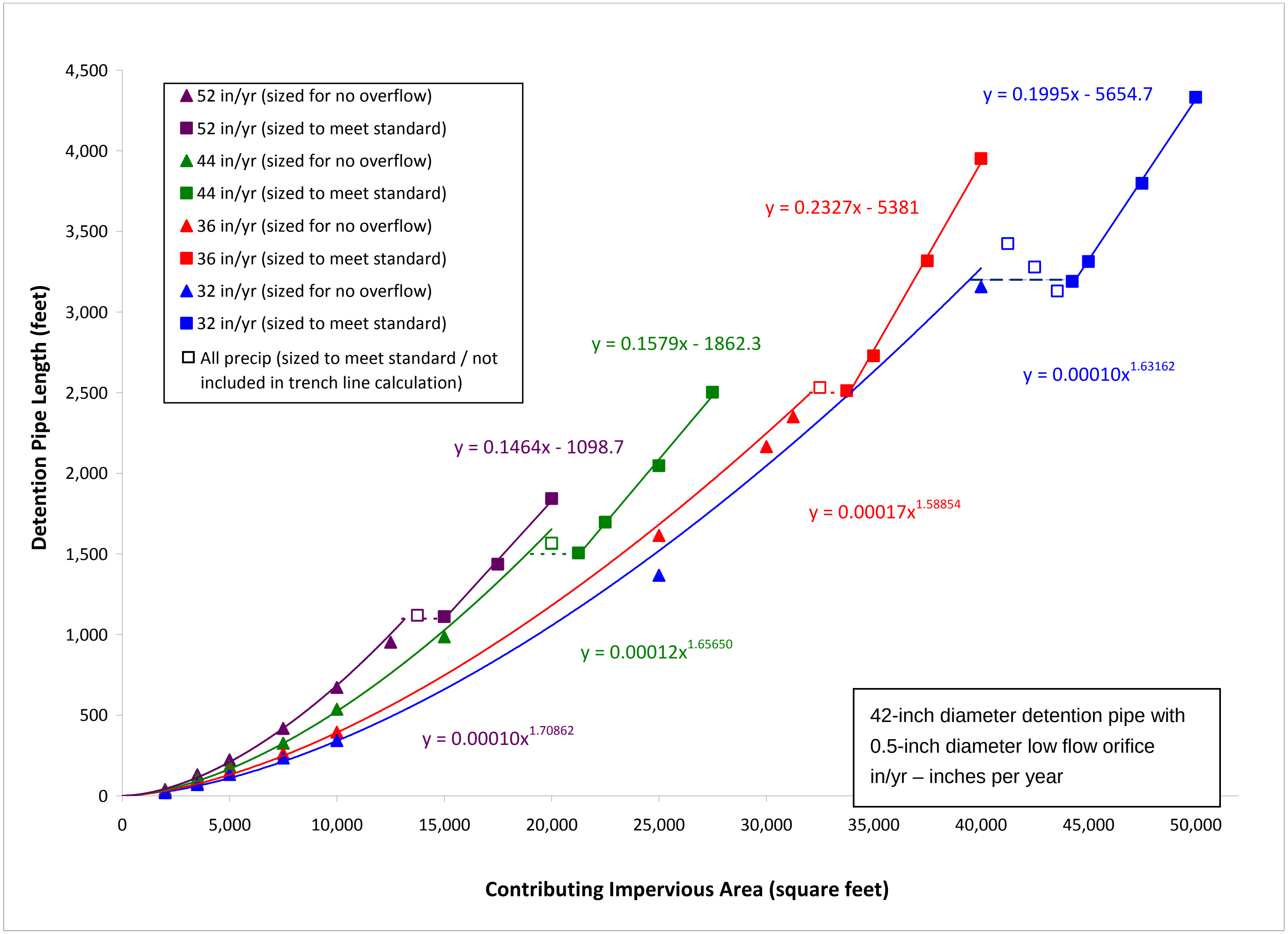


Figure 4. Detention pipe sized for flow control as a function of contributing impervious area (mean annual precipitation of 52, 44, 36, and 32 inches).

Table 4. Sizing equations for detention pipe (42-inch diameter) by mean annual precipitation.

Mean Annual Precipitation Depth	Contributing Area (sf)	Relationship	Sizing Equations [a] (function of contributing impervious area)	Standard Achieved? [b]
32 inches	<39,500	Power	0.00010 x (A^1.632)	No
	39,500-44,000	Constant	3,200 ft	No
	>44,000	Linear	(0.1995 x A) – 5,655	Yes
36 inches	<32,000	Power	0.00017 x (A^1.589)	No
	32,000-33,750	Constant	2,500 ft	No
	>33,750	Linear	(0.2327 x A) – 5,381	Yes
44 inches	<19,000	Power	0.00012 x (A^1.657)	No
	19,000-21,250	Constant	1,500 ft	No
	>21,250	Linear	(0.1579 x A) – 1,862	Yes
52 inches	<13,000	Power	0.00010 x (A^1.709)	No
	13,000-15,000	Constant	1,100 ft	No
	>15,000	Linear	(0.1464 x A) – 1,099	Yes

A contributing impervious area; sf-square feet; ft – feet.

[a] Pipe length is calculated as a function of impervious area draining to it (A) using one of the following equations:
Pipe Length (feet) = Factor x [A (square feet)^Integer].
Pipe Length (feet) = Constant.
Pipe Length (feet) = [Factor x A (square feet)] + Integer.
Length values must be in units of feet and area values must be in units of square feet.

[b] If "yes", detention pipe sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a pre-developed till/forest condition. If "no", detention pipe not capable of meeting the flow control standard for the contributing drainage area with the assumed orifice diameter.

BMP Flow Control Credits

For LID BMPs that do not fully meet the Ecology pre-developed forest flow control standard, flow control credits were developed instead of sizing factors or sizing equations. The flow control credit values are based on the extent to which these facilities achieve the flow control standard. Flow control performance was evaluated by various methods including literature review and continuous simulation hydrologic modeling as summarized below.

Retained and New Trees

Runoff reduction credits are provided as a function of the canopy area of protected trees or the number of newly planted trees (Table 5). These credits were developed based on a literature review of infiltration, evapotranspiration, and interception of evergreen and deciduous trees (Herrera 2008) and discussions with the City of Seattle and the Department of Ecology. To receive the flow control credit, the tree(s) must be within 20 feet of ground-level impervious surfaces. The total tree credit shall not exceed 25 percent of impervious surface area requiring mitigation.

Table 5. Flow control credits for retained trees.

BMP	Tree Type	Flow Control Credit
Retained Tree	Evergreen	20% canopy area (min 100 sf / tree)
	Deciduous	10% canopy area (min 50 sf / tree)
New Tree	Evergreen	50 sf / tree
	Deciduous	20 sf / tree

% percent
sf square feet
min minimum

The impervious area mitigated by a tree is calculated as the product of the flow control credit and either the existing tree canopy or number of new trees planted:

Impervious Area Mitigated = Σ Existing Canopy Area x Credit (%)/100.

Impervious Area Mitigated = Σ Number of New Trees x Credit (%)/100.

Downspout or Sheet Flow Dispersion

The flow control benefits of downspout and sheet flow dispersion were evaluated using continuous simulation hydrologic modeling. Per Ecology's guidelines, the impervious surface area from which runoff is dispersed was modeled as lawn over till (see Attachment D). The flow control performance for dispersion is listed based on mean annual precipitation in Table 6. The reductions in peak flow (for the 2-, 25-, and 50-year recurrence interval flows) and flow duration (for half the 2- to the 50-year recurrence interval flows) were calculated. The average reductions were compared to those required to meet the Ecology pre-developed forest standard. Depending upon location in Kitsap County with respect to mean annual precipitation depth, dispersion is predicted to achieve between approximately 74 and 82 percent of the Ecology goal. For a site with 52 inches of mean annual precipitation, the impervious surface area mitigated is calculated using this flow credit as follows:

Area Mitigated = 74 % x Impervious Area Dispersed

Vegetated Roof

Modeling was performed as described in the "Modeling Methods" section and detailed in Attachment D. Flow control credits were calculated as the percent of the goal achieved (as explained for dispersion) and are presented in Table 6. Vegetated roofs in Kitsap County are predicted to achieve between approximately 42 and 47 percent of the Ecology goal depending upon mean annual precipitation and growth media depth.

Table 6. BMP flow control performance by mean annual precipitation.

BMP	Mean Annual Precipitation	Peak and Duration Reduction Goal (to Meet Standard) [a]	Reduction Achieved	Flow Control Credit (Goal Achieved)
Partial Dispersion (downspout or sheet flow)	32 inches	94.4%	77.3%	81.6%
	36 inches	93.1%	76.8%	80.2%
	44 inches	91.3%	73.4%	77.5%
	52 inches	89.6%	69.7%	74.0%
Vegetated Roof (4 inches of growth media depth)	32 inches	94.4%	39.7%	42.0%
	36 inches	93.1%	40.0%	42.5%
	44 inches	91.0%	39.2%	42.3%
	52 inches	89.6%	38.3%	41.9%
Vegetated Roof (8 inches of growth media depth)	32 inches	94.4%	45.2%	47.1%
	36 inches	93.1%	44.7%	46.9%
	44 inches	91.0%	42.6%	45.5%
	52 inches	89.6%	41.2%	44.7%
Permeable Pavement Surface (2-5% slope)	32 inches	93.7%	40.7%	43.4%
	36 inches	92.1%	40.2%	43.5%
	44 inches	90.1%	38.3%	42.2%
	52 inches	88.2%	36.4%	40.8%

[a] Flow control standard matches peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a pre-developed till/forest condition.

Permeable Pavement Surfaces (2 percent or less subgrade slope)

Unlike permeable pavement facilities, the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir. Therefore, the performance of permeable pavement surfaces will vary depending upon subgrade slope. Installations on a sloped subgrade have an increased potential for lateral flow through the aggregate storage reservoir along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system. For sites with a subgrade slope of less than 2 percent, it is reasonable to assume that the effect of slope is negligible. For these low-slope configurations, the system was explicitly modeled as a gravel-filled trench with infiltration to underlying soil (the same method used for permeable pavement facilities) (see Attachment D). The aggregate storage reservoir depth was sized to meet flow control standards for a 5,000 square foot area with a native soil design infiltration rate of 0.13 and 0.25 inches per hour. Table 7 provides the minimum storage reservoir depth for each mean annual precipitation scenario evaluated. For example, a permeable pavement surface would require a minimum aggregate storage reservoir thickness of 2.5 inches where mean annual precipitation is 32 inches and the native soil design infiltration rate is 0.25 inches per hour.

Table 7. Permeable pavement surface aggregate storage reservoir depth by mean annual precipitation (for installations up to 2 percent slope).

	Minimum Aggregate Storage Reservoir Depth for Flow Control [a] (inches)	
Mean Annual Precipitation	I = 0.13 inch/hour	I = 0.25 inch/hour
32 inches	5.8	2.5
36 inches	6.2	2.6
44 inches	7.6	3.5
52 inches	9.7	4.0

I Native Soil Design Infiltration Rate

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a pre-developed till/forest condition.

Permeable Pavement Surfaces (2 to 5 percent subgrade slope)

For permeable pavement surfaces with higher subgrade slopes, a different approach was taken. The method of modeling the system as a gravel-filled trench does not explicitly represent the lateral flow in sloped facilities. Therefore, as recommended in the Ecology Manual (Ecology 2005), the performance of permeable pavement surfaces at slopes between 2 and 5 percent was approximated by modeling the area as 50 percent lawn over till and 50 percent impervious surface (see Attachment D). Flow control credits were calculated as the percent of the goal achieved (as explained for dispersion) and are presented in Table 6. Permeable pavement installations in Kitsap County on slopes between 2 and 5 percent are predicted to achieve between approximately 41 to 43 percent of the Ecology goal depending upon mean annual precipitation depth.

County-Wide BMP Sizing Tool

Sizing Equations

The sizing factors presented in Table 3 are applicable to sites where mean annual precipitation is equal to 32, 36, 44, or 52 inches. Given the wide variability of mean annual precipitation across Kitsap County, a more functional tool was developed that can be used for any location in the County, with intermediate, higher or lower precipitation depths. This tool allows BMP sizing as a function of contributing impervious surface area, site infiltration rate, and mean annual precipitation depth specific to a particular site location.

To develop such a relationship, sizing factors outlined previously were plotted against mean annual precipitation values. This provided a graphical representation of the changes in sizing factors as a result of varying mean annual precipitation. The relationships for bioretention facilities sized to meet flow control and water quality treatment standards are presented in Figures 5 and 6, respectively. Based on a regression analysis, the resulting relationships are linear with R^2 values of 0.99 or greater.

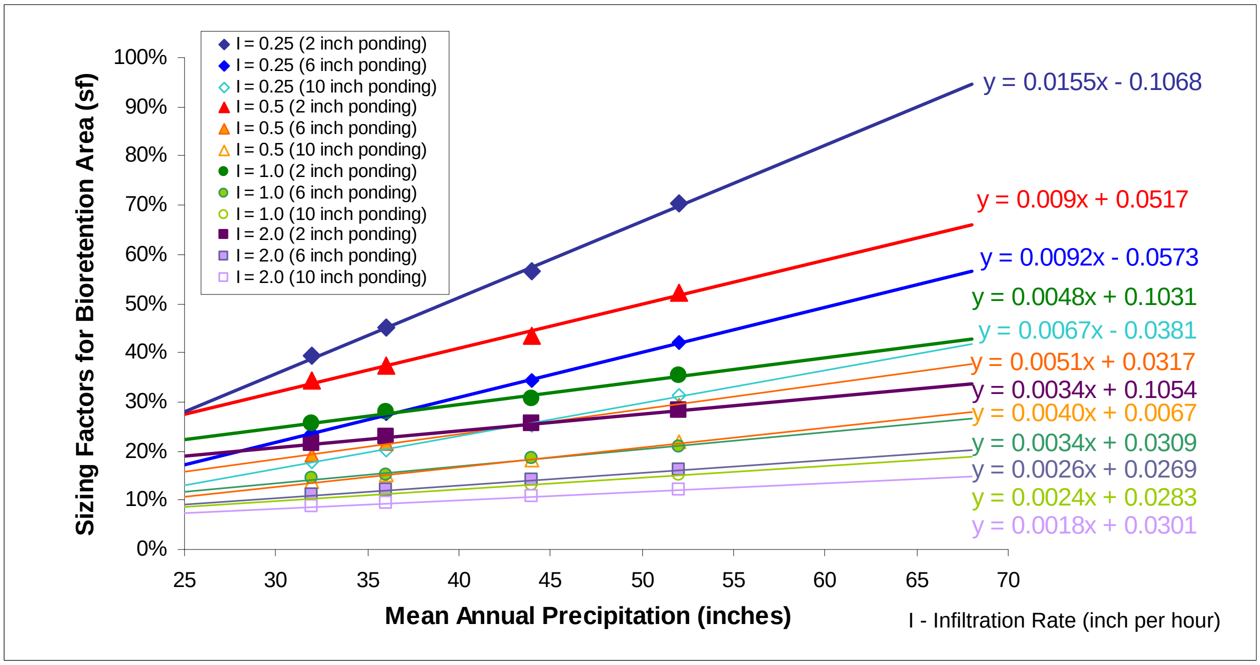


Figure 5. Bioretention flow control sizing factors for Kitsap County as a function of mean annual precipitation.

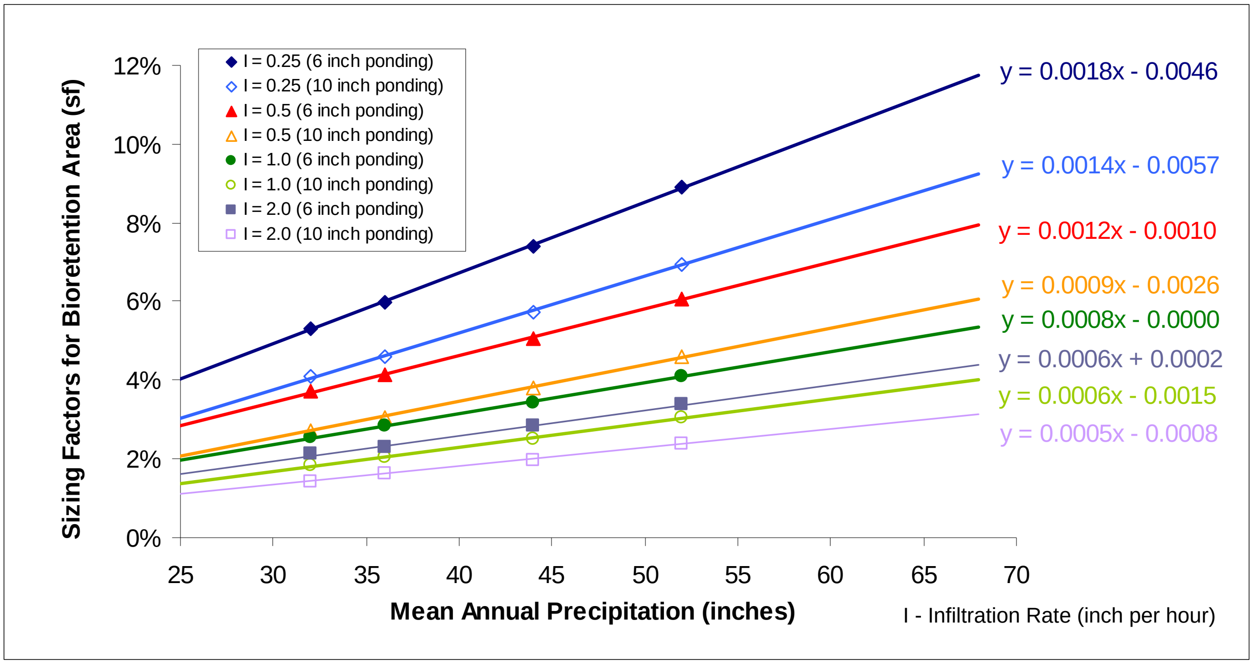


Figure 6. Bioretention water quality sizing factors for Kitsap County as a function of mean annual precipitation.

A plot for permeable pavement facilities sized to meet the flow control standard is presented in Figure 7. The best fit relationship is exponential with R^2 values of 0.99, 1.0 and 0.96 for infiltration rates of 0.25, 0.5 and 1.0 inches per hour, respectively. However, the plot is also well represented by a linear relationship (shown in Figure 7) for infiltration rates of 0.5 and 1.0 inches per hour under all precipitation conditions and for an infiltration rate of 0.25 inches per hour for mean annual precipitation depths up to 37 inches (R^2 values are 0.95 or greater). This covers most scenarios. For other scenarios, modeling would be required.

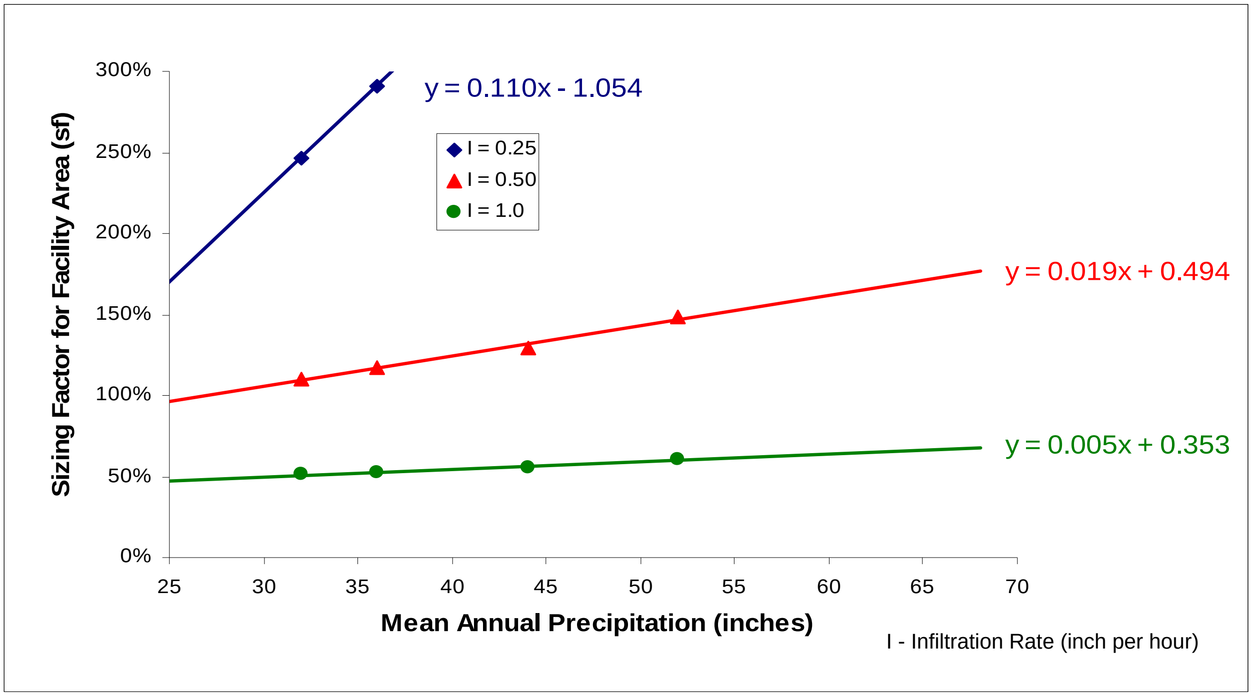


Figure 7. Permeable pavement facility flow control sizing factors for Kitsap County as a function of mean annual precipitation.

Plots for rock trenches and graveless chambers sized to meet the flow control standard are presented in Figures 8 and 9. Based on a regression analysis, the relationships between BMP sizing factors and mean annual precipitation depth are linear with R^2 values ranging from 0.8 to 0.99. As shown in Figures 8 and 9, it is clear that the sizing factors associated with a mean annual precipitation depth of 36 inches are high relative to the trend. When the sizing factors for 36 inches of annual precipitation are not included in the data set, the R^2 values increase significantly, ranging from 0.93 to 1.0.

It is unclear why BMPs sized for the 36-inch precipitation depth are consistently higher. However, the inclusion of these data shifts the trend line up, making the resultant BMP size requirements more conservative for all precipitation values. Therefore, inclusion of the results for 36 inches of precipitation depth is recommended.

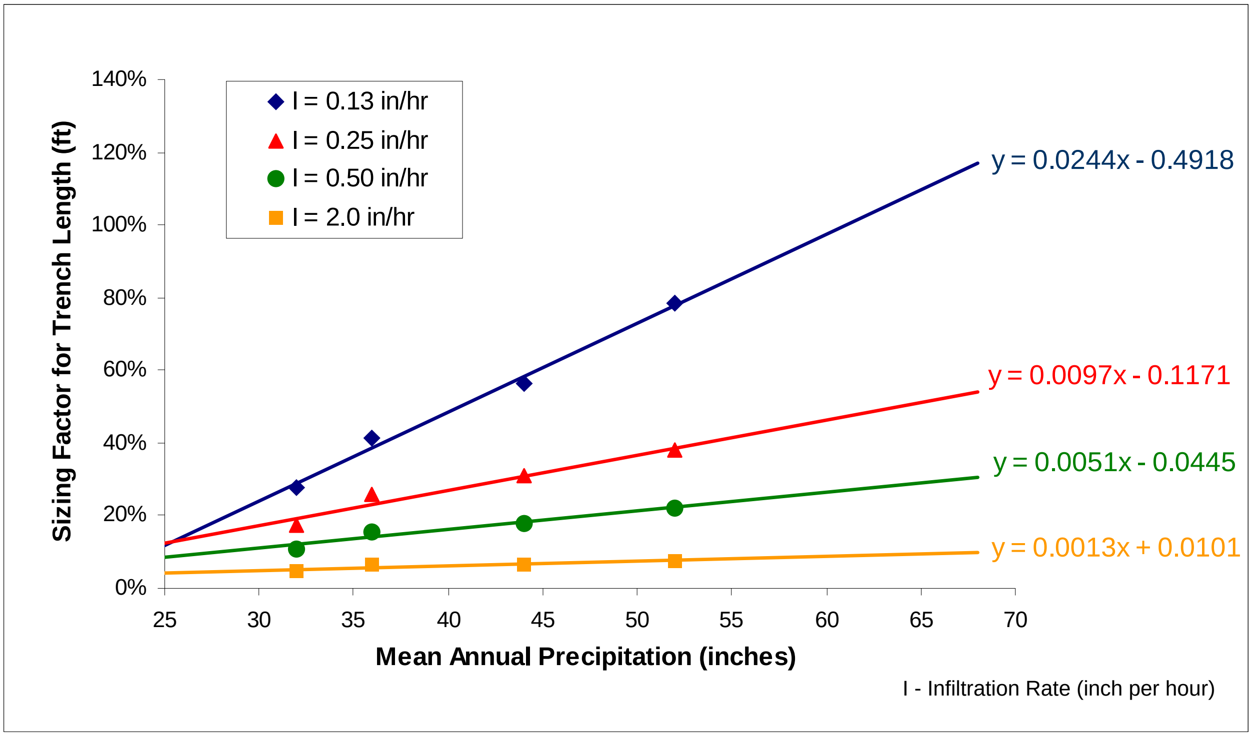


Figure 8. Rock trench flow control sizing factors for Kitsap County as a function of mean annual precipitation.

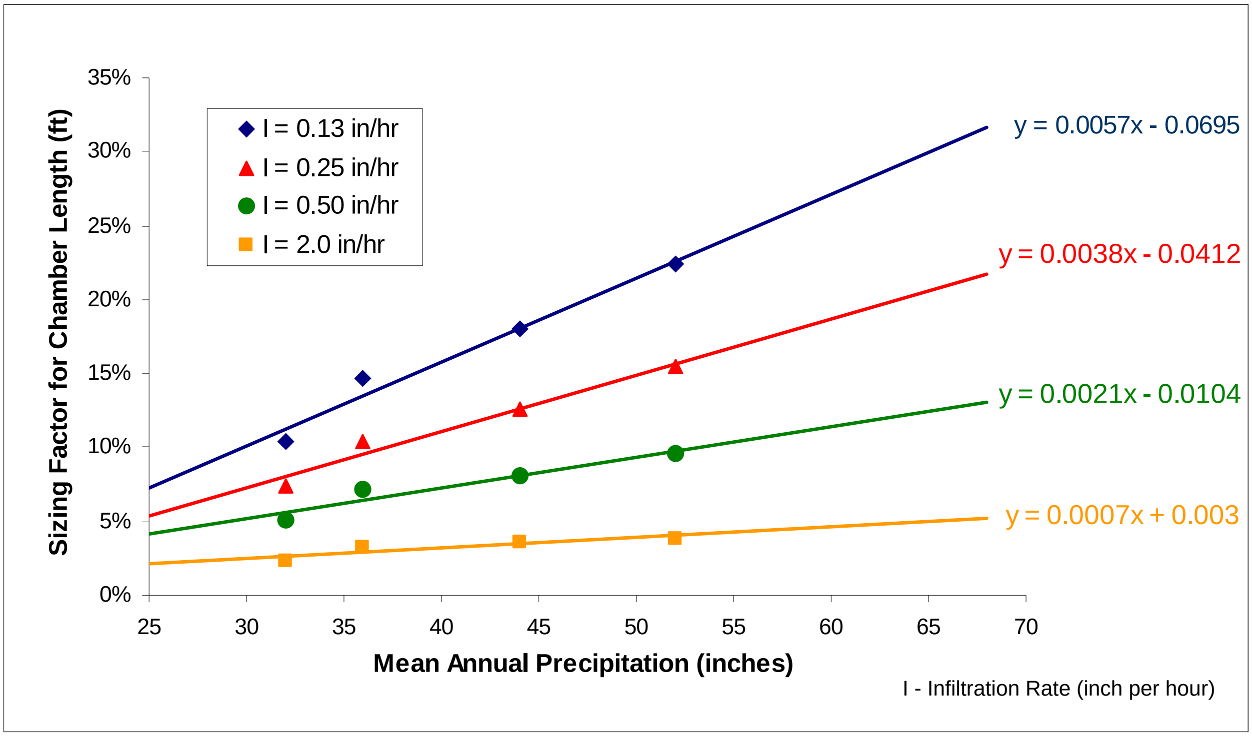


Figure 9. Gravelless chamber flow control sizing factors for Kitsap County as a function of mean annual precipitation.

Using these linear relationships, the slope of the line (M) and the y-intercept (B) (see Table 8) can be used to calculate the BMP size as a function of the impervious surface area draining to it and the mean annual precipitation as follows:

> BMP Area or Length (square feet or feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a bioretention cell with 10 inches of ponding storage depth receiving runoff from 1,000 square feet of impervious surface area at a site with a native soil design infiltration rate of 1.0 inches per hour and a mean annual precipitation depth of 40 inches would be calculated (based on Figures 5 and 6 and Table 8) as:

> Bioretention Bottom Area (square feet) for flow control = 1,000 square feet x [0.0024 x 40 inches + 0.0283] = 124 square feet.
>
> Bioretention Bottom Area (square feet) for water quality treatment = 1,000 square feet x [0.0006 x 40 inches - 0.0015 square feet] = 23 square feet.

Similarly, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious surface area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches would be calculated (based on Figure 7 and Table 8) as:

> Permeable Pavement Facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531 square feet] = 545 square feet.

Note that although the regression equations presented in this study were only developed for mean annual precipitation depths between 32 and 52 inches, the resulting relationships may be extrapolated to lower (as low as 26 inches per year) and higher (up to 68 inches per year) mean annual precipitation values. Based on discussion with MGS Engineering Consultants, the extent of Kitsap County covered by MGS' extended time series was limited not by applicability but by the scope of their project. Therefore, it is anticipated that the relationships are valid across Kitsap County. However, confirming this would require further modeling and is outside of the scope of this study.

Flow Control Credits

The flow control performance of partial dispersion, vegetated roofs, and higher slope permeable pavement surfaces vary somewhat with mean annual precipitation (see Table 6). To be conservative, the County-wide flow control credits presented in Table 9 are based on the minimum predicted benefit (associated with 52 inches of mean annual precipitation).

Table 8. Regression factors for BMP sizing in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors: Flow Control [a] M	Flow Control [a] B	Water Quality [b] M	Water Quality [b] B	Regression Equation
Bioretention Cell [c]—2 inch ponding depth	0.25	0.0155	- 0.1068	—	—	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.5	0.0090	0.0517	—	—	
	1.0	0.0048	0.1031	—	—	
	2.0	0.0034	0.1054	—	—	
Bioretention Cell [c]—6 inch ponding depth	0.25	0.0092	- 0.0573	0.0018	- 0.0046	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.5	0.0051	+ 0.0317	0.0012	- 0.001	
	1.0	0.0034	+ 0.0309	0.0008	- 0.00005	
	2.0	0.0026	+ 0.0269	0.0006	+ 0.0002	
Bioretention Cell [c,d]—10 inch ponding depth	0.25	0.0067	- 0.0381	0.0014	- 0.0057	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.5	0.0040	+ 0.0067	0.0009	- 0.0026	
	1.0	0.0024	+ 0.0283	0.0006	- 0.0015	
	2.0	0.0018	+ 0.0301	0.0005	- 0.0008	
Permeable Pavement Facility — 6 inch Aggregate Storage Reservoir and Overflow	0.25	0.1100	- 1.0536	—	—	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.5	0.0187	+ 0.4945	—	—	
	1.0	0.0048	+ 0.3531	—	—	
Rock Trench	0.13	0.0244	- 0.4918	—	—	Rock Trench Length (feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.25	0.0097	- 0.1171	—	—	
	0.5	0.0051	- 0.0445	—	—	
	2.0	0.00130	+ 0.0101	—	—	
Gravelless Chamber	0.13	0.0057	- 0.0695	—	—	Gravelless Chamber Length (feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B]
	0.25	0.0038	- 0.0412	—	—	
	0.5	0.0021	- 0.0104	—	—	
	2.0	0.00072	- 0.00303	—	—	

[a] Regression factors developed to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a pre-developed till/forest condition. Facilities sized for flow control also meet water quality treatment standards when imported or native underlying soil meets Ecology treatment soil requirements (e.g., 18 inches of bioretention soil per Seattle specifications).

[b] Regression factors developed to infiltrate 91 percent of the runoff file.

[c] Regression constants are for bioretention facility bottom area. Total footprint area may be calculated based on side slopes (3H:1V), ponding depth, and freeboard.

[d] Surface pool drawdown time exceeds 24 hours for 0.25 inch per hour infiltration rate.

— not evaluated as a part of this study

M slope of regression equation

B y-intercept of regression equation

Table 9. Flow control credits for BMPs in Kitsap County.

BMP	Design Configuration	Flow Control Credit [a] (%)
Retained Tree	Evergreen	20% canopy area (min 100 sf / tree)
	Deciduous	10% canopy area (min 50 sf / tree)
New Tree	Evergreen	50 sf / tree
	Deciduous	20 sf / tree
Partial Dispersion	Downspout or sheet flow dispersion	74%
Vegetated Roof	4 inch depth growth medium	42%
	8 inch depth growth medium	45%
Permeable Pavement Surface (may not receive run-on)	Slope up to 2%	100% [b]
	Slope 2% to 5%	40% [b, c]

sf square feet

% percent

min minimum

[a] Impervious area mitigated by a BMP is calculated as: [Flow Control Credit (%)/100] x [Existing Tree Canopy Area, Number New Trees Planted, Green Roof Area, Dispersed Area, or Pavement Area]. Note that some of the BMPs do not achieve full credit (i.e., 100 percent credit) and as such the site design would require additional flow control measures to meet the flow control standard.

[b] Aggregate subbase depth must be sized using the equation in Table 10.

[c] If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate storage reservoir. In this case, the permeable pavement facility sizing equations may be used.

Table 10. Permeable pavement surface aggregate storage reservoir depth for Kitsap County.

Native Soil Design Infiltration Rate (in/hr)	Regression Factor (M)	Regression Equation
0.13	0.2	Minimum Aggregate Storage Reservoir Depth (inches) = M x Mean Annual Precipitation Depth (inches)
0.25	0.1	

in/hr – inch per hour

The impervious surface area mitigated by a runoff reduction BMP is calculated as the product of the flow control credit and either the existing tree canopy, the number of new trees planted, the impervious surface area from which runoff is dispersed, the vegetated roof area, or the permeable pavement facility area. As an example, for a vegetated roof with an 8 inch depth of growth medium the area mitigated is calculated as follows:

Area Mitigated = 45% x Vegetated Roof Area

Note that full credit (i.e., 100 percent credit) is not achieved and the site design would require additional flow control measures to meet the flow control standard. The effective impervious surface area (area used to size a downstream flow control facility) is thus calculated as 55 percent of the vegetated roof area.

To use flow control credits, the facilities must meet the specific design requirements (e.g., tree protection methods, dispersion distances, aggregate characteristics, etc.) presented in the "Stormwater BMPs" section above. In addition, the use of the credits for permeable pavement surfaces requires that the aggregate storage reservoir depth be determined as explained below.

For lower slope permeable pavement surfaces (up to 2 percent), the aggregate storage reservoir depth required to achieve the Ecology predeveloped forest standard for native soil design infiltration rates of 0.13 and 0.25 is provided by mean annual precipitation in Figure 10. Based on a regression analysis, the resulting relationships are linear with R^2 values of at least 0.97. To establish a conservative County-wide equation for aggregate storage reservoir depth, the regression slope was rounded up to 0.2 and 0.1 for design infiltration rates of 0.13 and 0.25 inches per hour, respectively (see Table 10).

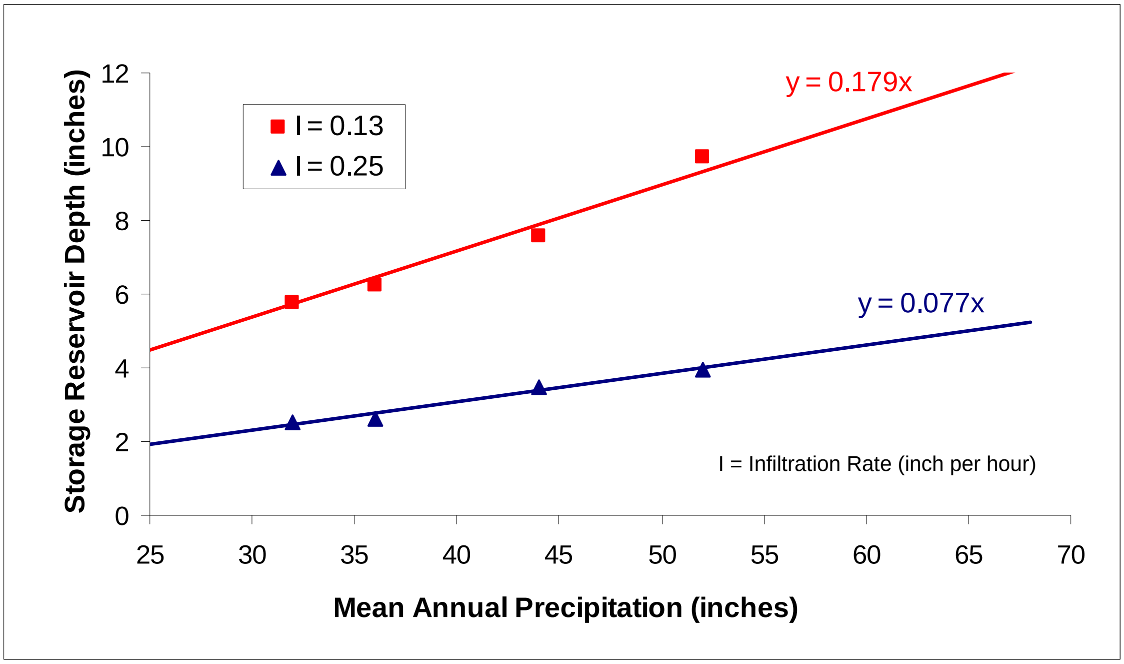


Figure 10. Permeable pavement surface aggregate depth sizing factors for Kitsap County as a function of mean annual precipitation.

Using these conservative factors, the minimum aggregate storage reservoir depth for a site with a design infiltration rate of 0.13 inches per hour is calculated as:

> Aggregate Storage Reservoir Depth (inches) = 0.2 x Mean Annual Precipitation (inches).

Lower-slope permeable pavement surfaces designed with the minimum aggregate storage reservoir depth achieve 100 percent flow control credit (i.e., 100 percent of the permeable pavement surface is mitigated). For higher-slope permeable pavement surfaces (2 to 5 percent), the minimum aggregate storage reservoir depth is calculated as shown above and the area mitigated is calculated as follows:

Area Mitigated = 40% x Permeable Pavement Area

Conclusions

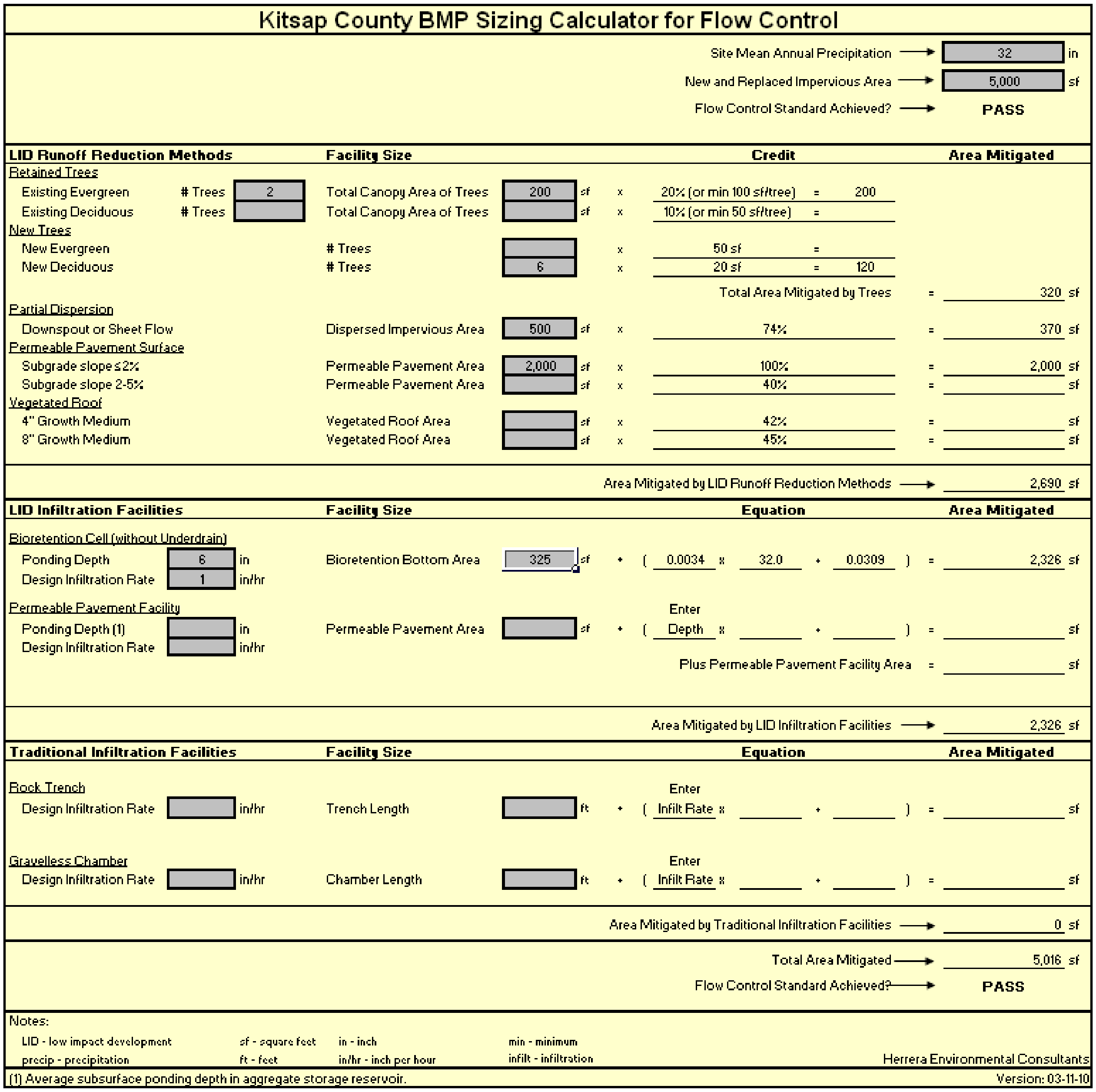
The equations and flow control credits presented in Tables 8, 9, and 10 can be used as a BMP sizing tool for most areas within Kitsap County. The tool is appropriate for use in Kitsap County where site soils are comprised of glacial till (hydrologic group C) and native soil design infiltration rates are between 0.13 and 2.0 inches per hour. Facilities sized using this tool must meet the design requirements (e.g., side slopes, ponding depth, soil or gravel depth) presented in the “Stormwater BMPs” section of this report. Guidance for using this tool should specify that facilities be sited and designed per the requirements presented in the Ecology Manual. In addition, guidance should be clear that the infiltration rate used to determine the applicable BMP sizing equation for a given site (i.e., 0.13, 0.25, 0.5, 1.0, and 2.0 inches per hour) is the *design* rate, rounded down to the nearest pre-sizing value, and should be derived using correction factors (safety factors) per the Ecology Manual.

While the sizing tool was developed to provide adequate flow control and water quality treatment for an impervious drainage area, it may be applied for other drainage scenarios:

- If a drainage area consists of a mix of impervious and pervious surface areas, and the pervious area *requires mitigation*, a stormwater management facility may be sized using the equations for the total contributing area (including pervious areas). In this case, the facility size will be conservatively large (because there is less runoff from pervious areas than impervious areas).

- If a drainage area does not allow for bypass of flow from an additional area that *does not require mitigation*, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the stormwater management facility shall be twice the contributing drainage area for which it is sized. No flow control or water quality credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

In a related effort, an electronic calculator was developed to automate BMP sizing calculations. This spreadsheet tool guides the designer through the selection and sizing of the pre-designed BMPs presented in this report. A screen shot of this tool is provided in Figure 11.



Kitsap County BMP Sizing Calculator for Flow Control

Site Mean Annual Precipitation → 32 in
New and Replaced Impervious Area → 5,000 sf
Flow Control Standard Achieved? → PASS

LID Runoff Reduction Methods			Facility Size				Credit				Area Mitigated
Retained Trees											
Existing Evergreen	# Trees	2	Total Canopy Area of Trees	200	sf	x	20% (or min 100 sf/tree)	=	200		
Existing Deciduous	# Trees		Total Canopy Area of Trees		sf	x	10% (or min 50 sf/tree)	=			
New Trees											
New Evergreen			# Trees			x	50 sf	=			
New Deciduous			# Trees	6		x	20 sf	=	120		
							Total Area Mitigated by Trees			=	320 sf
Partial Dispersion											
Downspout or Sheet Flow			Dispersed Impervious Area	500	sf	x	74%			=	370 sf
Permeable Pavement Surface											
Subgrade slope ≤2%			Permeable Pavement Area	2,000	sf	x	100%			=	2,000 sf
Subgrade slope 2-5%			Permeable Pavement Area		sf	x	40%			=	sf
Vegetated Roof											
4" Growth Medium			Vegetated Roof Area		sf	x	42%			=	sf
8" Growth Medium			Vegetated Roof Area		sf	x	45%			=	sf

Area Mitigated by LID Runoff Reduction Methods → 2,690 sf

LID Infiltration Facilities			Facility Size			Equation	Area Mitigated
Bioretention Cell (without Underdrain)							
Ponding Depth	6	in	Bioretention Bottom Area	325	sf	÷ (0.0034 x 32.0 + 0.0309) =	2,326 sf
Design Infiltration Rate	1	in/hr					
Permeable Pavement Facility							
Ponding Depth (1)		in	Permeable Pavement Area		sf	÷ (Enter Depth x +) =	sf
Design Infiltration Rate		in/hr					
						Plus Permeable Pavement Facility Area =	sf

Area Mitigated by LID Infiltration Facilities → 2,326 sf

Traditional Infiltration Facilities			Facility Size			Equation	Area Mitigated
Rock Trench							
Design Infiltration Rate		in/hr	Trench Length		ft	÷ (Enter Infilt Rate x +) =	sf
Gravelless Chamber							
Design Infiltration Rate		in/hr	Chamber Length		ft	÷ (Enter Infilt Rate x +) =	sf

Area Mitigated by Traditional Infiltration Facilities → 0 sf

Total Area Mitigated → 5,016 sf
Flow Control Standard Achieved? → PASS

Notes:
LID - low impact development; sf - square feet; in - inch; min - minimum
precip - precipitation; ft - feet; in/hr - inch per hour; infilt - infiltration
Herrera Environmental Consultants
(1) Average subsurface ponding depth in aggregate storage reservoir.
Version: 03-11-10

Figure 11. Kitsap County BMP Sizing Calculator.

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Seattle, City of. 2009. Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual. Seattle Public Utilities and Department of Planning and Development. December 2009.

WSU. 2005. Low Impact Development Technical Guidance Manual for Puget Sound. Washington State University (WSU) Pierce County Extension and Puget Sound Action Team. January 2005.

ATTACHMENT A

Seattle Public Utilities Draft Bioretention Soil Specification (January 2010)

1-05.5 CONSTRUCTION STAKES

Supplement the third paragraph of this section with the following:

4.

SECTION 2-03 ROADWAY EXCAVATION AND EMBANKMENT

2-03.3(19) BIORETENTION CELLS AND EARTH BERMS (New Section)

Bioretention cells and earth berms shall be constructed as shown on the Drawings.

2-03.3(19)A GRADING FOR BIORETENTION CELLS

The Contractor shall not start bioretention cell construction until the Project Site draining to the bioretention area has been stabilized and authorization is given by Engineer.

The Engineer will provide the Contractor with a Drawing indicating subgrade points that will be used to identify final grading prior to construction. Each Drawing will include horizontal and vertical control for bioretention cell construction.

All bioretention cells, conveyance swales, and associated drainage features shown on the Drawings shall be constructed to an accuracy of 0.25 feet in location and 0.08 feet in elevation unless otherwise noted. All other remaining drainage features shall be constructed to an accuracy of 0.50 feet for location and 0.17 feet for elevation.

Finish grades at all the subgrade points shall be reported to the Engineer for approval prior to the placement of bioretention soil or Type 26 aggregate and prior to subgrade soil scarification.

The Contractor shall scarify the subgrade soil to a minimum depth of 2 inches prior to placement of bioretention soil.

Following placement and compaction of the bioretention soil (see Section 7-21.3(2)), the Engineer shall verify the bioretention soil has been placed at a consistent uniform depth as specified on the Drawings.

Following placement of mulch, the Engineer shall verify the mulch has been placed at a consistent and uniform depth as specified on the Drawings.

Grading within root zones of existing trees to be protected shall be under the direction of the Engineer. Trees shall be protected per 1-07.16(2) and 8-02.3(7). Should grading conflict with existing Project Site conditions, the Contractor shall consult with the Engineer prior to proceeding with the Work.

No heavy equipment shall operate within the cell or earth berm perimeter during excavation, subsurface pipe placement, backfilling, tree pit preparation, or mulching.

Excavation within 6-inches of final native soil grade shall not be permitted if Project Site soil is frozen, has standing water, or has been subjected to more than ½ inch of precipitation within 48 hours..

No Materials or substances shall be mixed or dumped within the cell or earth berm area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations.

Relocation and/or adjustments of water meters shall be coordinated per Section 7-15 Water Service Connection Transfers.

Bioretention cells with a utility crossing through the swale soil or a side sewer within 18-inches from the bottom of the swale or rain garden soil shall require a clay trench dam to be constructed within the existing utility trench to prevent migration of water along the utility service. A clay trench dam shall be placed and constructed at locations shown on the Drawings or as directed by the Engineer. Payment for cell liner will be made at the unit price bid for "Dam, Clay Trench".

Prior to finishing cell excavation, the Engineer will inspect swale native soil to establish if there are any soil lenses that might direct significant volumes of water to a private property or other area of concern. If such a soil lens is identified the Engineer shall determine if a swale liner is necessary.

Prior to placement of bioretention soil or type 26 aggregate in each cell, the Contractor shall notify the Engineer to inspect the bioretention cell. If any sediment laden runoff has entered the cell, the sediment deposition shall be removed by overexcavating the cell by a 3-inch minimum. An additional 3-inches of bioretention soil shall be imported at the Contractor's expense.

Prior to placement of bioretention soil in each cell when an underdrain in is place, the Contractor shall notify the Engineer to inspect the bioretention cell and top of underdrain bedding. If the bedding is not free of fines, the Contractor shall remove the top 6 inches and replace with material per design at the Contractor's expense.

Prior to placement of mulch in each cell, the Contractor shall notify the Engineer to inspect the bioretention cell. If any sediment laden runoff has entered the cell, the Contractor shall remove the top 3 inches of bioretention soil and replace with bioretention soil per design, at the Contractor's expense.

The finished elevation shall be flush with walks, curbs, pavements and driveways, unless adjacent to a bermed area, as verified by the Engineer. Upon completion of finish grading work, all excess Material shall be removed from the Project Site and disposed of accordingly.

2-03.3(19)B GRADING FOR EARTH BERM

The upper one foot of soil used for any bermed areas shall be turf bioretention soil, the lower portion of the berm shall be landscape bioretention soil (as defined in Section 7-21 Bioretention Soil) or native soil.

Finish grades at all the Grading Points shall be reported to the Engineer prior to the placement of mulch. Earth berm elevations shall meet the accuracy as described in Section 2-03.3(19)A. If design elevations are not met, the Engineer will require the Contractor to rework the soil to meet the design requirements, solely at the Contractor's expense. Following placement of mulch, the Engineer shall verify a consistent uniform mulch depth of 3-inches.

2-03.4 MEASUREMENT

Supplement this Section with the following:

No measurement for finish grading will be made.

2-03.5 PAYMENT

Supplement item 10. with the following:

Payment for Bioretention Cells & Earth Berms shall be made using the applicable bid items listed in the Bid Form.

No separate payment will be made for finish grading work required to hand grade Bioretention Cells and Earth Berms to final shape as specified.

No separate payment will be made for connection of private drain pipes to the cells.

7-21 NATURAL DRAINAGE SYSTEMS

Delete this Section and Title and replace with the following Section and Title:

7-21 BIORETENTION SOIL

7-21.1 DESCRIPTION

Section 7-21 describes work consisting of the installation of Bioretention Soil in bioretention cells intended to receive surface runoff for infiltration.

7-21.2 MATERIALS

Materials for bioretention soil will be specified in the Contract and consist of one or more of the following:

Landscape Bioretention Soil	9-14.1(3)B
Turf Bioretention Soil	9-14.1(3)C

7-21.3 CONSTRUCTION REQUIREMENTS

7-21.3(1) GENERAL

Bioretention soil shall be protected from all sources of additional moisture at the Supplier's site, in covered conveyance, and at the Project Site until incorporated into the Work. Soil placement and compaction shall not occur when the ground is frozen or excessively wet (3% above optimum moisture content), or when the weather is too wet as determined by the Engineer.

When the Contract specifies testing by a Contractor provided testing laboratory, the laboratory must be an STA, AASHTO or ASTM or other designated recognized standards organization accredited laboratory with current and maintained certification. The testing laboratory shall be capable of performing all tests to the standards specified, and shall provide test results with an accompanying Manufacturer's Certificate of Compliance.

7-21.3(1)A SUBMITTALS

At least 10 Working Days prior to placement of Bioretention Soil, the Contractor shall submit to the Engineer and the SPU Materials Laboratory, (insert address), for approval:

1. Grain size analysis results of Mineral Aggregate performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils;
2. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 9-14.4(9);
3. Organic content test results of mixed bioretention soil. Organic content test shall be performed in accordance with Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method";
4. Modified Proctor compaction testing of mixed bioretention soil, performed in accordance with ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort;
5. A description of the equipment and methods to mix the Mineral Aggregate and compost to produce bioretention soil;
6. Permeability or hydraulic conductivity testing of the bioretention soil, performed in accordance with ASTM D 2434, Standard Test Method for Permeability of Granular Soils. For the landscape bioretention soil assume a relative compaction of 85 percent of modified maximum dry density (ASTM D 1557); and

7. Provide the following information about the testing laboratory(ies):
    1. name of laboratory(ies) including contact person(s),
    2. address(es),
    3. phone contact(s),
    4. e-mail address(es);
    5. qualifications of laboratory and personnel including date of current certification by STA, ASTM, AASHTO, or approved equal.

7-21.3(2) BIORETENTION SOIL PLACEMENT

The Contractor shall not place bioretention soil until the Project Site draining to the bioretention area has been stabilized and authorization is given by Engineer.

Mixing or placing bioretention soil shall not be allowed if the area receiving bioretention soil is wet or saturated or has been subjected to more than ½-inch of precipitation within 48-hours prior to mixing or placement. The Engineer will have final authority to determine if wet or saturated conditions exist.

Place landscape bioretention soil loosely. Final soil depth shall be measured and verified only after the soil has been water compacted, which requires filling the cell with water, without creating any scour or erosion, to at least 1 inches of ponding. If water compaction is not an option, final soil depth shall be measured at X inches above the grade specified on the plans to allow for settling after the first storm. X shall be calculated by depth of soil x 0.15 and rounded up to the nearest whole number.

Place turf bioretention soil in loose lifts not exceeding 12 inches. Compact turf bioretention soil to a relative compaction of 85 percent of modified maximum dry density (ASTM D 1557), where slopes allow, as determined by the Engineer. Where turf bioretention soil is placed in the 2-foot road shoulder, compact to a relative compaction of 90 percent of modified maximum dry density (ASTM D 1557). Final soil depth shall be measured and verified only after the soil has been compacted.

7-21.4 MEASUREMENT

Bid items of Work completed pursuant to the Contract will be measured as provided in Section 1-09.1, Measurement of Quantities, unless otherwise provided for by individual measurement paragraphs here in this Section.

Measurement for bioretention soil placement will be by per cubic yard.

7-21.5 PAYMENT

Compensation for the cost necessary to complete the Work described in Section 7-21 will be made at the Bid item prices Bid only for the Bid items listed or referenced as follows:

1. "Bioretention Soil Placement" per cubic yard.

The Bid item price for "Bioretention Soil Placement" shall include all costs for the work necessary to furnish, place, compact, excavate, grade, shape, mix, and dispose of bioretention soil.

9-03.2 AGGREGATES FOR NATURAL DRAINAGE SYSTEMS

Delete this Section and Title and replace with the following Section and Title:

9-03.2 MINERAL AGGREGATES FOR BIORETENTION SOIL

9-03.2(1) GENERAL

Mineral Aggregate shall be free of wood, waste, coating, or any other deleterious material. All Mineral Aggregate passing the No. 200 sieve size shall be non-plastic.

9-03.2(2) MINERAL AGGREGATE FOR TURF AND LANDSCAPE BIORETENTION SOIL

Mineral Aggregate for turf and landscape bioretention soils shall be analyzed by an accredited lab using the sieve sizes noted below, and shall meet the following gradation:

Sieve Size	Percent Passing
1 inch	100
No. 4	60 - 100
No.10	40 - 100
No. 40	15 - 50
No. 200	2 - 5

Efforts should be made to have the Mineral Aggregate for turf and landscape bioretention soils meet the following gradation coefficients: Coefficient of Uniformity ($C_u = D_{60}/D_{10}$) equal to or greater than 6; and Coefficient of Curve ($C_c = D_{30}^2/D_{60}D_{10}$) greater than or equal to 1 and less than or equal to 3.

9-14.1(3) NATURAL DRAINAGE SYSTEM SOILS

Delete this Section and Title and replace with the following Section and Title:

9-14.1(3) BIORETENTION SOIL

9-14.1(3)A GENERAL

Bioretention soil shall be a well blended mixture of Mineral Aggregate and compost measured on a volume basis.

9-14.1(3)B LANDSCAPE BIORETENTION SOIL

Landscape bioretention soil shall consist of two parts compost (approximately 35 to 40 percent) by volume meeting the requirements of Section 9-14.4(9) and three parts Mineral Aggregate (approximately 60 to 65 percent), by volume meeting the requirements of Section 9-03.2(3). The mixture shall be well blended to produce a homogeneous mix. Organic matter content shall be 8 to 10 percent, with the final mix to be determined by the Engineer based on samples and test results submitted.

9-14.1(3)C TURF BIORETENTION SOIL

Turf bioretention soil shall consist of one part compost by volume (approximately 30 to 35 percent), meeting the requirements of Section 9-14.4(9) and two parts mineral aggregate (approximately 65 to 70 percent) by volume meeting the requirements of Section 9-03.2(3). The mixture shall be well blended to produce a homogeneous mix. Organic matter content shall be 4 to 6 percent, with the final mix to be determined by the Engineer based on samples and test results submitted.

9-14.4(9) COMPOSTED MATERIAL

Delete this Section and replace with the following:

Compost products shall be the result of the biological degradation and transformation of Type I or III feedstocks under controlled conditions designed to promote aerobic decomposition, per WAC 173-350-220, which is available at http://www.ecy.wa.gov/programs/swfa/compost. Compost shall be stable with regard to oxygen consumption and carbon dioxide generation. Compost shall be mature with regard to its suitability for serving as a soil amendment or an erosion control BMP as defined below. The compost shall have a moisture content that has no visible free water or dust produced when handling the material.

Compost production and quality shall comply with Chapter 173-350 WAC, and meet the following physical criteria:

1. Compost material shall be tested in accordance with Testing Methods for the Examination of Compost and Composting (TMECC) Test Method 02.02-B, "Sample Sieving for Aggregate Size Classification".

   Compost shall meet the following:

	Min.	Max.
Percent passing 1"	99%	100%
Percent passing 5/8"	90%	100%
Percent passing 1/4"	40%	90%

2. The pH shall be between 5.5 and 8.0 when tested in accordance with TMECC 04.11-A, "1:5 Slurry pH".

3. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0 percent by weight as determined by TMECC 03.08-A "percent dry weight basis".

4. Organic matter content should be between 45 and 65 percent dry weight basis as determined by TMECC 05.07A, "Loss-On-Ignition Organic Matter Method".

5. Soluble salt contents shall be less than 6.0 mmhos/cm tested in accordance with TMECC 04.10-A, "1:5 Slurry Method, Mass Basis".

6. Maturity shall be greater than 80% in accordance with TMECC 05.05-A, "Germination and Vigor".

7. Stability shall be 7 or below in accordance with TMECC 05.08-B, Carbon Dioxide Evolution Rate"

8. The compost product must originate a minimum of 65 percent by volume from recycled plant waste as defined in WAC 173-350-100 as "Type 1 Feedstocks." A maximum of 35 percent by volume of other approved organic waste as defined in WAC 173-350-100 as "Type III", including post-consumer food waste, but not including biosolids, may be substituted for recycled plant waste. The supplier shall provide written verification of feedstock sources.

9. Carbon to nitrogen ratio shall be less than 25:1 as determined using TMECC 04.01 "Total Carbon" and TMECC 04.02D "Total Kjeldhal Nitrogen". The Engineer may specify a C:N ratio up to 35:1 for projects where the plants selected are entirely Puget Sound native species.

10. The Engineer may also evaluate compost for maturity using the Solvita Compost Maturity Test at time of delivery. Compost shall score a number 6 or above on the Solvita Compost Maturity Test.

The compost supplier shall test all compost products within 90 Calendar Days prior to application. Samples shall be collected using the Seal of Testing Assurance (STA) sample collection protocol. The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org. The sample shall be sent to an independent STA Program approved laboratory. The compost supplier shall pay for the test. A copy of the approved independent STA Program laboratory test report shall be submitted to the Engineer prior to initial application of the compost. Seven days prior to application, the Contractor shall submit a sample of each type of compost to be used on the project to the Engineer.

Compost not conforming to the above requirements or taken from a source other than those tested and accepted shall be immediately removed from the project and replaced at no cost to the Owner.

The Contractor shall submit the following information to the Engineer for approval:

1. A copy of the Solid Waste Handling Permit issued to the supplier by the Jurisdictional Health Department as per WAC 173-350 (Minimum Functional Standards for Solid Waste Handling).

2. The supplier shall verify in writing, and provide lab analyses that the Materials comply with the processes, testing, and standards specified in WAC 173-350 and these Specifications. An independent STA Program certified laboratory shall perform the analysis.

3. A list of the feedstock by percentage present in the final compost product.

4. A copy of the producer's STA certification as issued by the U.S. Composting Council.

Acceptance shall be based upon a satisfactory Test Report from an independent STA program certified laboratory and the sample(s) submitted to the Engineer.

ATTACHMENT B

Rock Trench Design

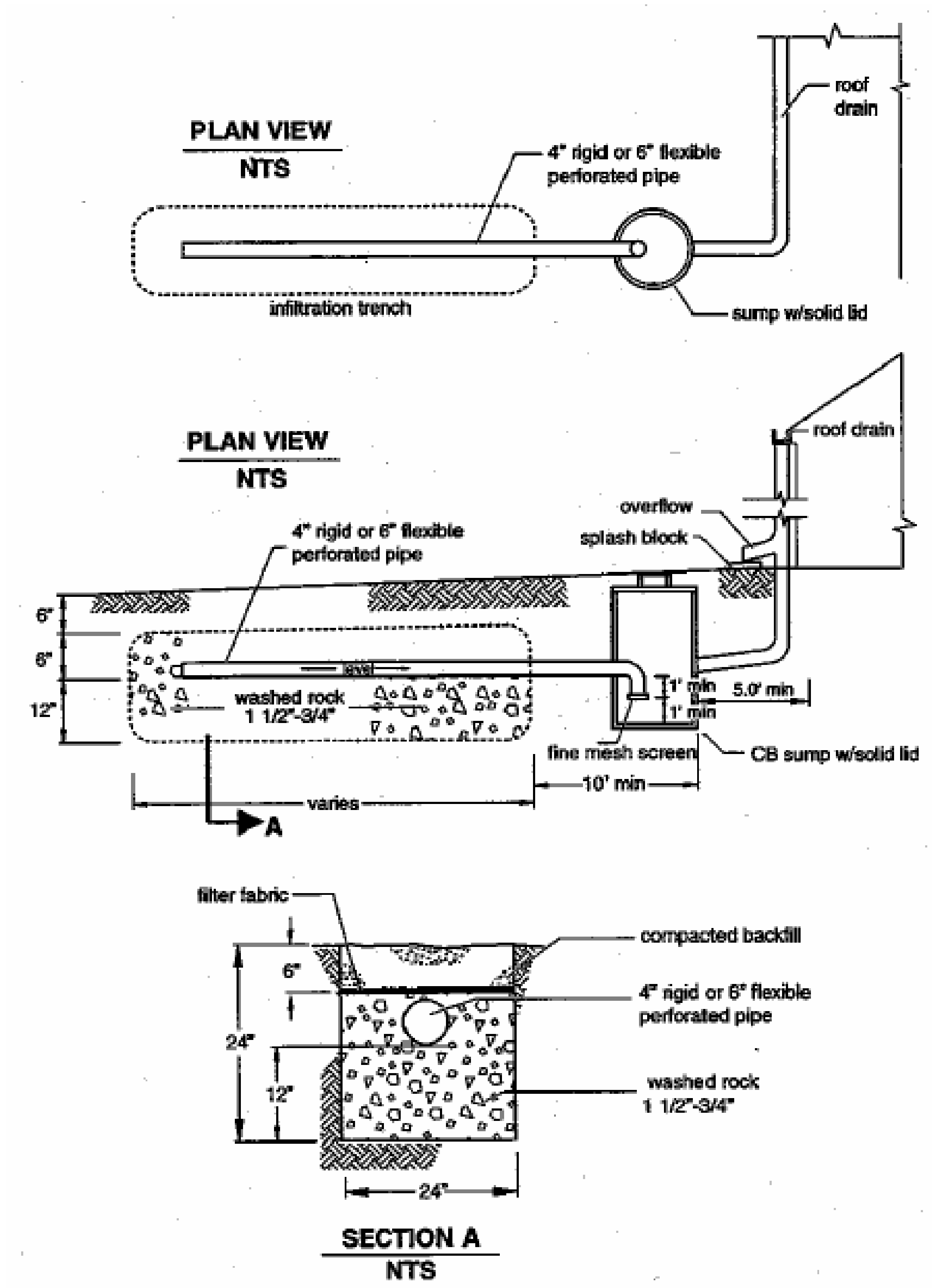


Figure 3.2 Typical Downspout Infiltration Trench

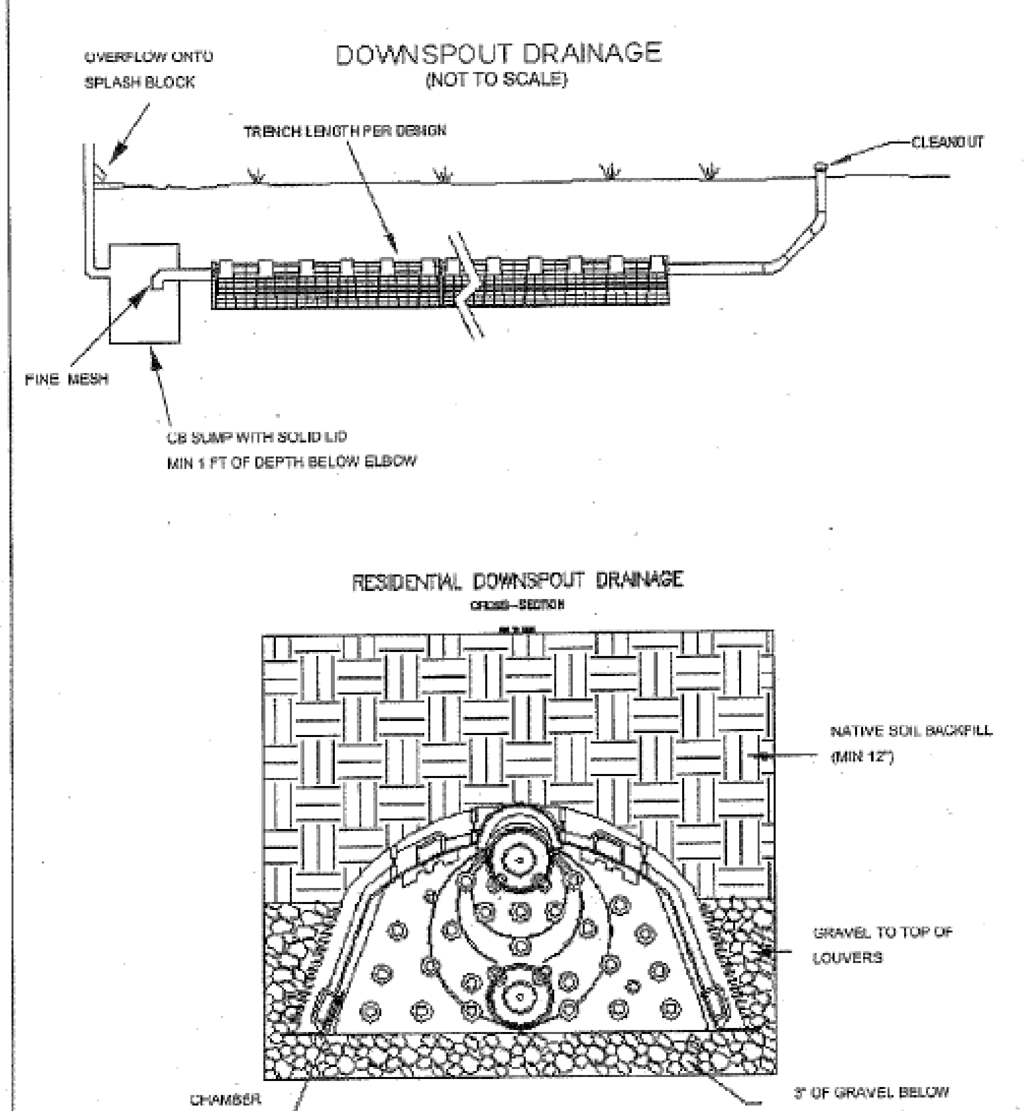
Source: King County

Figure 3.2 in "Volume III– Hydrologic Analysis and Flow Control BMPs" of Washington State Department of Ecology's *Stormwater Management Manual for Western Washington*

ATTACHMENT C

Gravelless Chamber Design

Figure 5-27 Gravelless Trench



A gravelless infiltration chamber trench designed per figure 5-27. The Void space per linear foot shall be at least 2.6 cubic feet. The infiltrative surface per linear foot shall be at least 2.8 sq ft.

The following products are known to meet these gravelless chamber criteria

Infiltrator© High Capacity by Infiltrator Systems, Inc.
EnviroChamber© High Capacity by Hancor, Inc.
Stormtech© SC-310 by Infiltrator Systems, Inc

Figure 5.27 in Appendix 5A of the Kitsap County Stormwater Management Design Manual (Kitsap County 1997).

jr /09-04247-000 attach-c - chamber design.doc

ATTACHMENT D

BMP Modeling Methods, Assumptions and Inputs Table

Table D-1. BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Downspout or Sheet Flow Dispersion	None/modeled as basin	• Downspout or sheet flow dispersion to compost amended lawn or landscape • Till soil, moderate slope • Impervious area dispersed modeled as lawn over till and performance evaluated relative to standard	• Lawn, till (class C) soil • Moderate slope
Vegetated Roof	Eco-roof	• Soil depth (in) = 4/8 • Impervious area modeled as vegetated roof and performance evaluated relative to standard	• Soil type – GREEN/ECO/ROOF • Green area (ac) – equal to roof size • Depth of material (in) – 4/8 • Slope of rooftop (ft/ft) – 0.001 • Vegetative cover – ground cover • Length of rooftop (ft) – length of one side of square roof • Groundwater – box must be checked in order to account for subsurface flow
Permeable Pavement Surface at slope 0 to 2% (may not receive run-on)	Gravel-filled trench with infiltration	• Base course depth (in) – varied • Base course porosity – 0.2 • Pervious wearing course not modeled (storage neglected) • Facility assumed to be square (notch width set equal to the length of one side of the facility) • Facility size set equal to permeable pavement area and performance evaluated relative to standard	• Pavement length and bottom width (ft) – set to impervious area • Bottom elevation (ft) – 0 • Total effective depth (ft) – base course depth (varied) + 0.333 (notch height) • Bottom slope of pavement base course (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft) – 0.333 + base course depth • Riser diameter (in) – 10,000 • Notch height (ft)/width (ft) – 0.333/one side of square facility (riser overflows at top of storage reservoir) • Orifice height (ft)/diameter (in) – none • Native soil infiltration rate (in/hr) – 0.13, 0.25 • Infiltration reduction factor – 1 (design infiltration rate used) • Use wetted surface area – no (infiltration across bottom only) • Underdrain used – no • Aggregate thickness (ft) – varied • Aggregate porosity – 0.2 • Rain and evaporation applied to trench – no (raining on impervious area routed to trench)

Table D-1 (continued). BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Permeable Pavement Surface at slope 2 to 5% (may not receive run-on)	None/modeled as basin	• Permeable pavement surface area equal to total impervious area • Permeable pavement area modeled as mix of lawn and impervious cover and performance evaluated relative to standard	• 50% lawn, till (class C) soil • 50% impervious • Moderate slope
Bioretention Cell	Bioretention swale with infiltration and overflow (without underdrain)	• Ponding depth (in) – 2/6/10 • Bioretention soil depth (ft) – 1 [a] • Bioretention soil porosity – 0.4 • Infiltration rate into bioretention soil (in/hr)– 2.5 • Side slopes (ft/ft) – 3:1 • Facility bottom area increased until runoff from contributing impervious area mitigated	• Swale length and bottom width (ft) – varied • Swale bottom elevation (ft) – 0 • Effective depth (ft) – 2.167/2.5/2.833 (soil, ponding, & over-road flooding depth) • Bottom slope of swale (ft/ft) – 0.001 • Side slopes (ft/ft) – 3:1 • Freeboard (ponding depth) (ft) – 0.167/0.5/0.833 • Over-road flooding (ft) – 1 • Width of over-road flooding (ft) – one side of square facility • Vertical orifice diameter (in)/elevation (in) – 0/0 • Bioretention soil infiltration rate (in/hr) – 2.5 • Native soil infiltration rate (in/hr) – 0.25, 0.5, 1.0, 2.0 • Infiltration reduction factor – 1 (design infiltration rate used) • Use wetted surface area – yes • Underdrain used – no • Bioretention soil thickness (ft) – 1 • Bioretention soil porosity – 0.4 • Rain and evaporation applied to cell – yes

Table D-1 (continued). BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Pervious Pavement Facility (may receive run-on)	Gravel-filled trench with infiltration	• Base course depth (in) – 6 • Base course porosity – 0.2 • Pervious wearing course was not modeled (storage neglected) • Facility assumed to be square (notch width was equal to the length of one side of the facility) • Facility area increased until runoff from contributing impervious area was mitigated	• Pavement length and bottom width (ft) – varied • Bottom elevation (ft) – 0 • Total effective depth (ft) –0.5 (storage reservoir) + 0.333 (notch height) = 0.833 • Bottom slope of pavement base course (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft) – 0.833 • Riser diameter (in) – 10,000 • Notch height (ft)/width (ft) – 0.333/one side of square facility (riser overflows at top of storage reservoir) • Orifice height (ft)/diameter (in) – none • Native soil infiltration rate (in/hr) – 0.25, 0.5, 1.0 • Infiltration reduction factor – 1 (design infiltration rate used) • Use wetted surface area – no (infiltration across bottom only) • Underdrain used – no • Aggregate thickness (ft) & porosity – 0.5/0.2
Rock Trench	Gravel-filled trench with infiltration	• Trench aggregate depth before overflow (ft) – 1.5 • Trench width (ft) – 2 • Gravel porosity – 0.3 • Trench length increased until runoff from contributing impervious area was mitigated	• Trench length (ft) – varied • Trench bottom width (ft) – 2 • Bottom elevation (ft) – 0 • Total effective depth (ft) – 1.6 (includes 0.1’ freeboard for uncontrolled overflow) • Bottom slope of trench (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft)/diameter (in) – 1.5/36 • Notch / orifice – NA • Infiltration rate (in/hr) – 0.13, 0.25, 0.5, 2.0 • Infiltration reduction factor – 1 (design infiltration rate used) • Use wetted surface area – no (infiltration across trench bottom only) • Aggregate thickness (ft) & porosity – 1.5/0.30 • Rain applied to trench- yes • Evaporation applied to trench – no

Table D-1 (continued). BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Graveless Chamber	Gravel-filled trench with infiltration	• Void space provided by chamber shall be at least 2.6 cubic feet per linear foot and infiltrative surface under chamber footprint shall be at least 2.8 square feet per linear foot • Trench bottom width of 2.8 feet selected to result in a infiltrative surface of 2.8 square feet per linear foot • Gravel layer thickness of 2 feet and porosity of 0.4646 selected to result in an effective water depth of 0.92 feet (when this depth is multiplied by a width of 2.8 feet the void space is 2.6 cubic feet per linear foot) • Additional storage in gravel layer below unit neglected • Trench length increased until runoff from contributing impervious area was mitigated	• Trench length (ft) – varied • Trench bottom width (ft) – 2.8 • Bottom elevation (ft) – 0 • Total effective depth (ft) – 2.1 (includes 0.1’ freeboard for uncontrolled overflow) • Bottom slope of trench (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft)/diameter (in) – 2/36 • Notch / orifice – NA • Infiltration rate (in/hr) – 0.13, 0.25, 0.5, 2.0 • Infiltration reduction factor – 1 (design infiltration rate used) • Use wetted surface area – no (infiltration across trench bottom only) • Gravel thickness (ft) & porosity – 2/0.4646 • Rain applied to trench- yes • Evaporation applied to trench – no
Detention Pipe	Tank with low flow orifice and overflow	• Pipe diameter (in) – 42 • Low flow orifice diameter (in) – 0.5 • Dead storage at pipe bottom (ft) – 0.5	• Tank diameter (ft) – 3.5 • Tank bottom elevation (ft) – 0 • Tank length (ft) – varied • Riser (flat) head (ft) – 3.45 • Riser diameter (in) – 9 • Orifice height (ft) – 0.5 • Orifice diameter (in) –0.5 • Infiltration – no • Rain and evaporation applied to pipe – no

BMP – best management practice; ft – feet; in – inch; hr – hour; % – percent

[a] A bioretention soil depth of 18 inches is required to provide water quality treatment. Modeling was performed using 12 inches, resulting in a conservative size for treatment facilities (additional storage in 6 inches of bioretention soil is neglected).

ATTACHMENT E

BMP Sizing Plots by Precipitation Depth

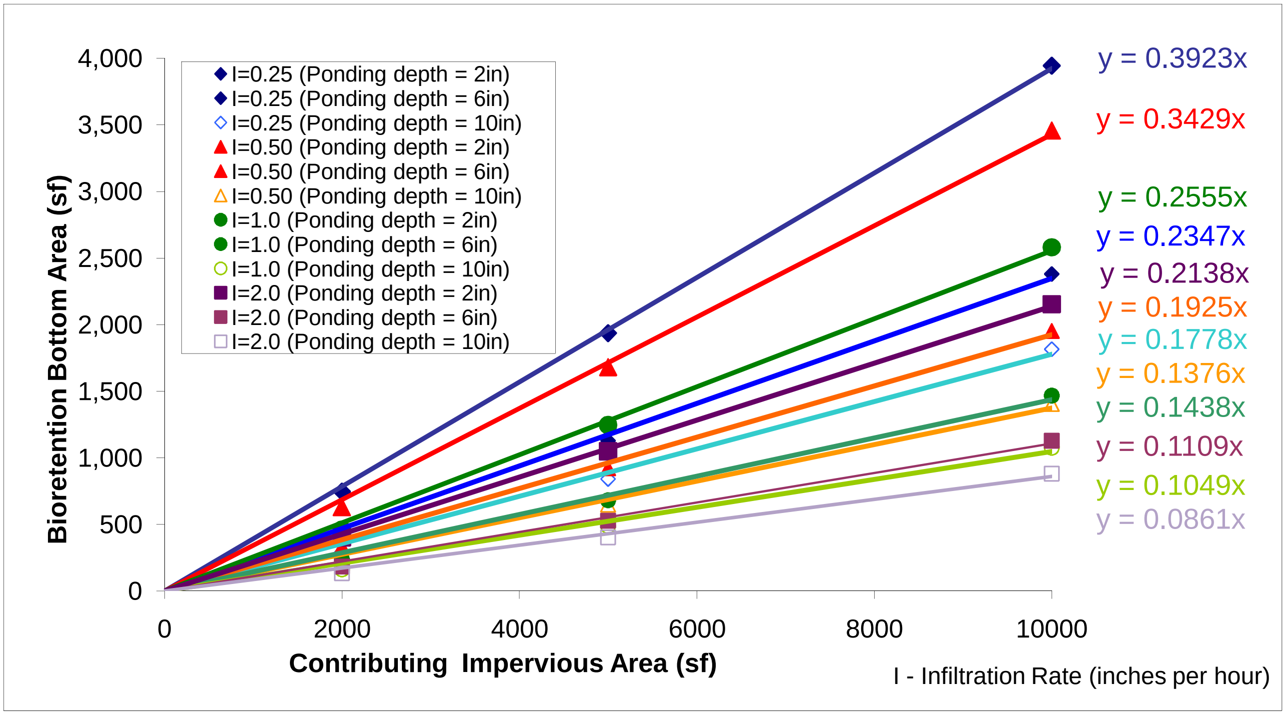


Figure E1. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

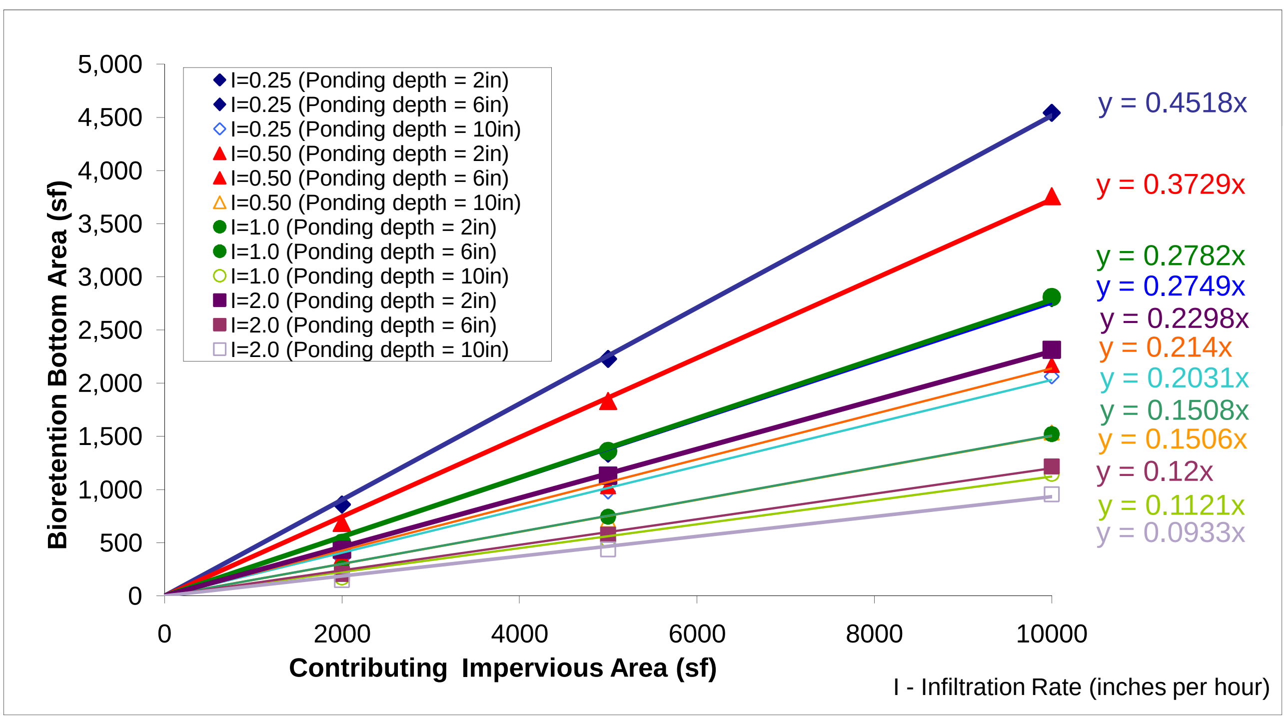


Figure E2. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

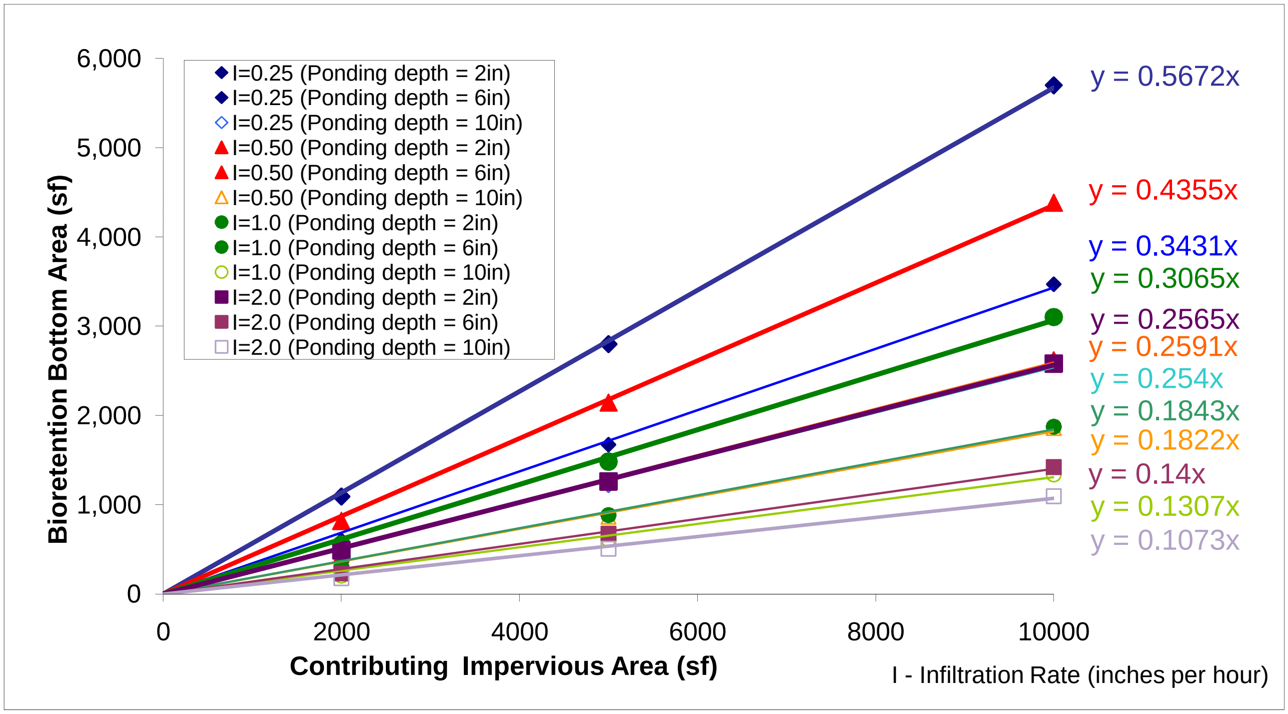


Figure E3. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

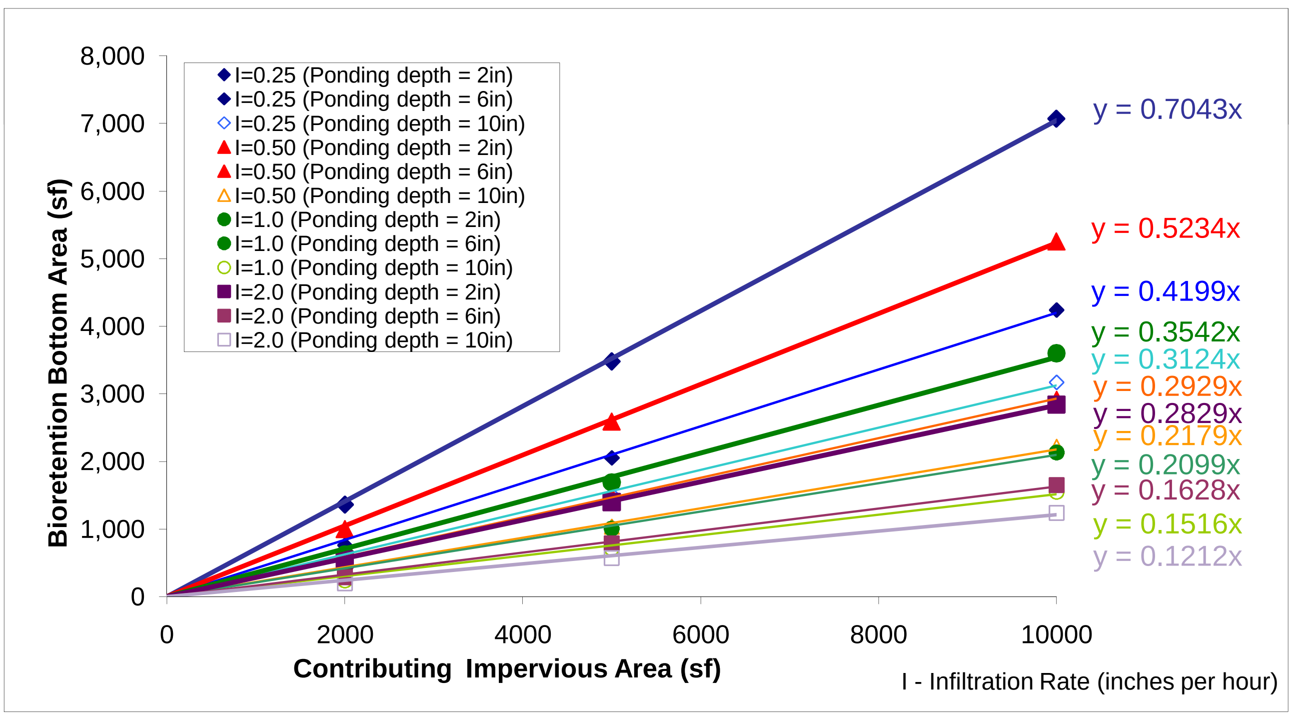


Figure E4. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).

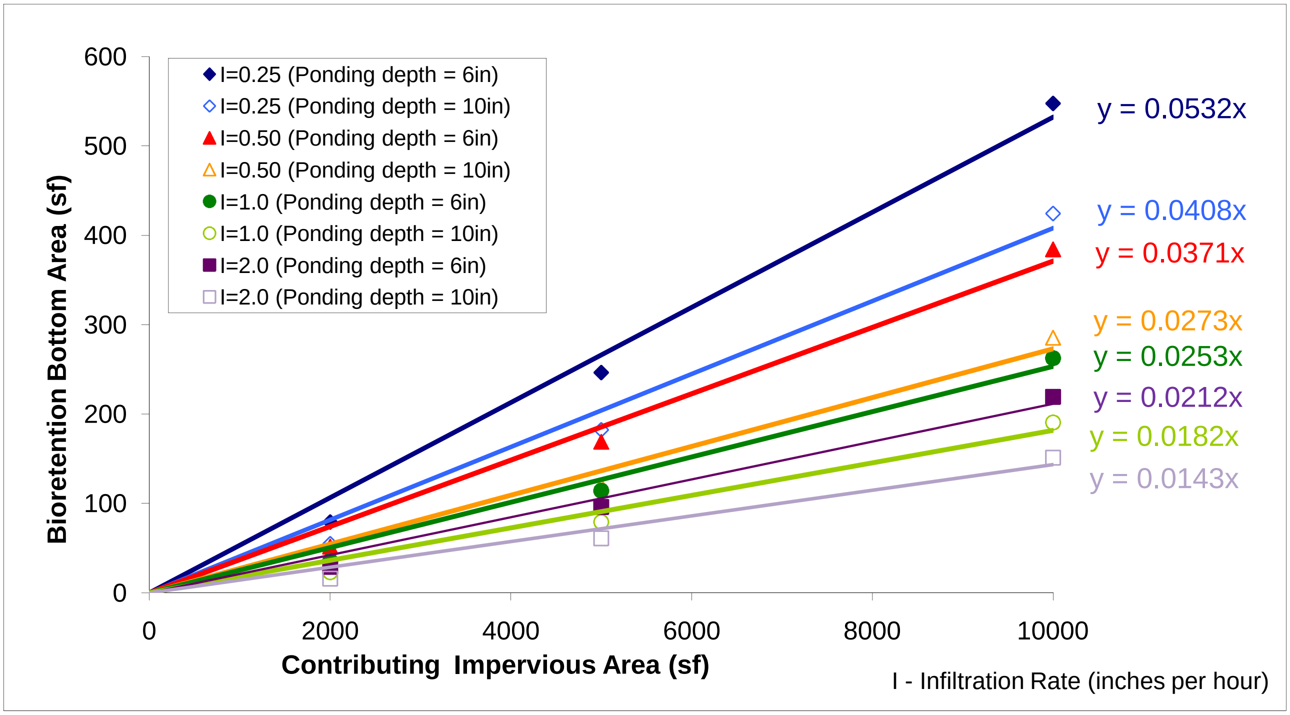


Figure E5. Bioretention facility (bottom area) sized for treatment as a function of contributing impervious area (annual precipitation of 32 inches).

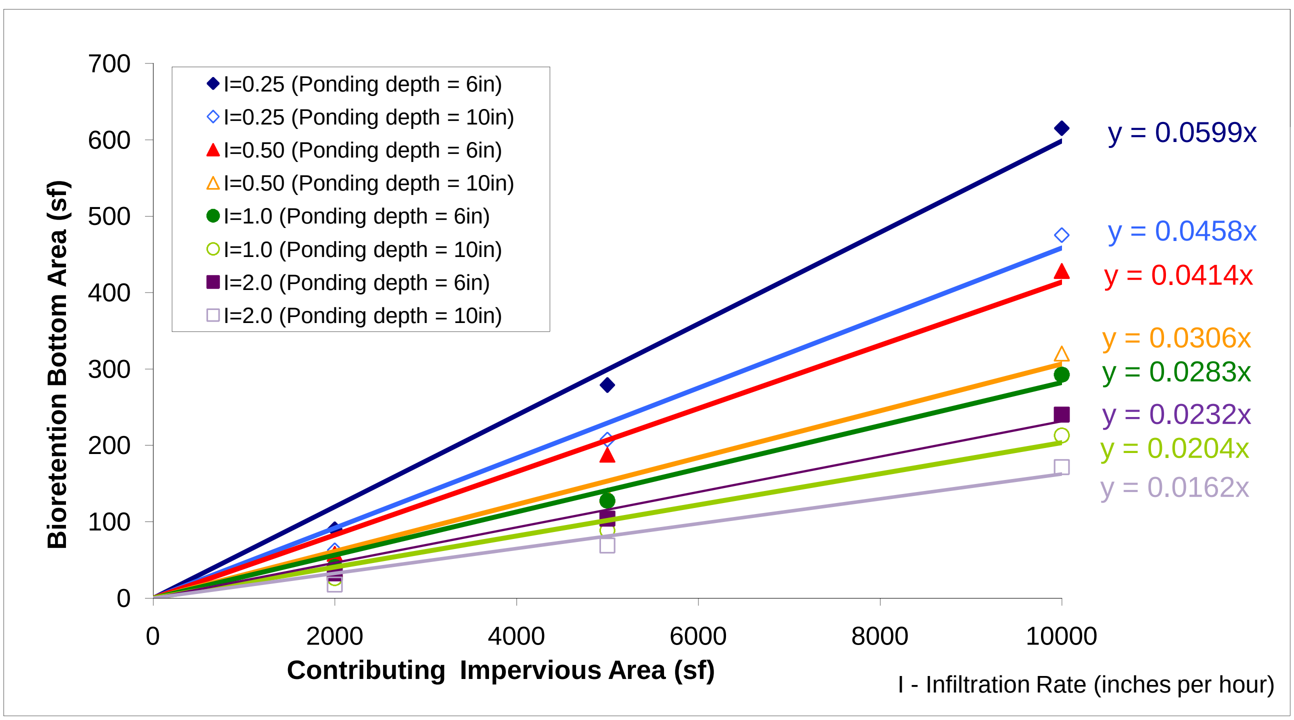


Figure E6. Bioretention facility (bottom area) sized for treatment as a function of contributing impervious area (annual precipitation of 36 inches).

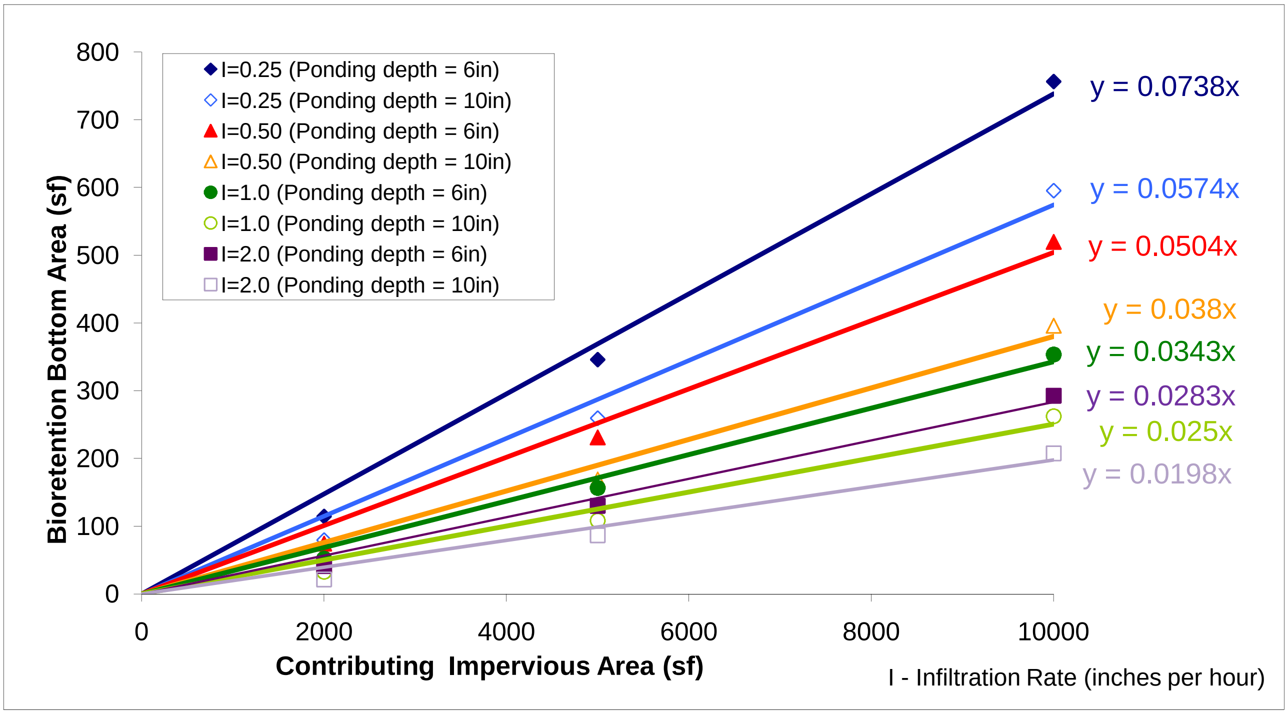


Figure E7. Bioretention facility (bottom area) sized for treatment as a function of contributing impervious area (annual precipitation of 44 inches).

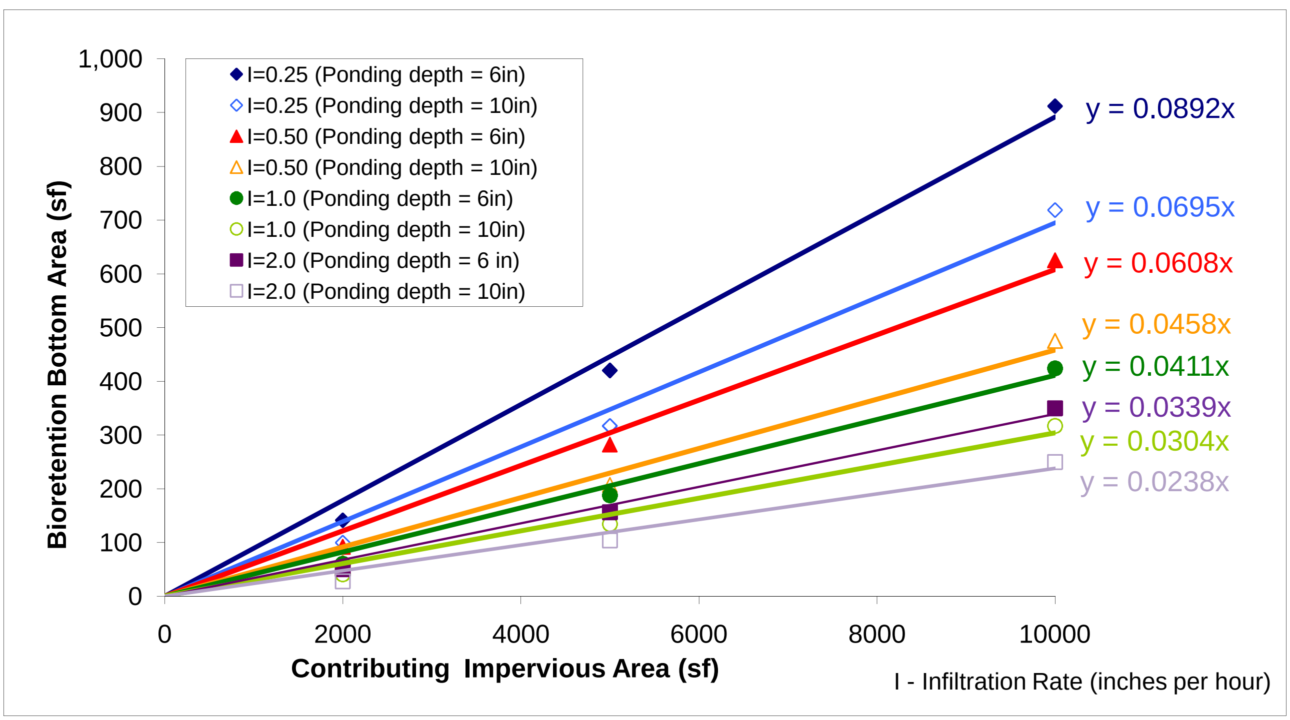


Figure E8. Bioretention facility (bottom area) sized for treatment as a function of contributing impervious area (annual precipitation of 52 inches).

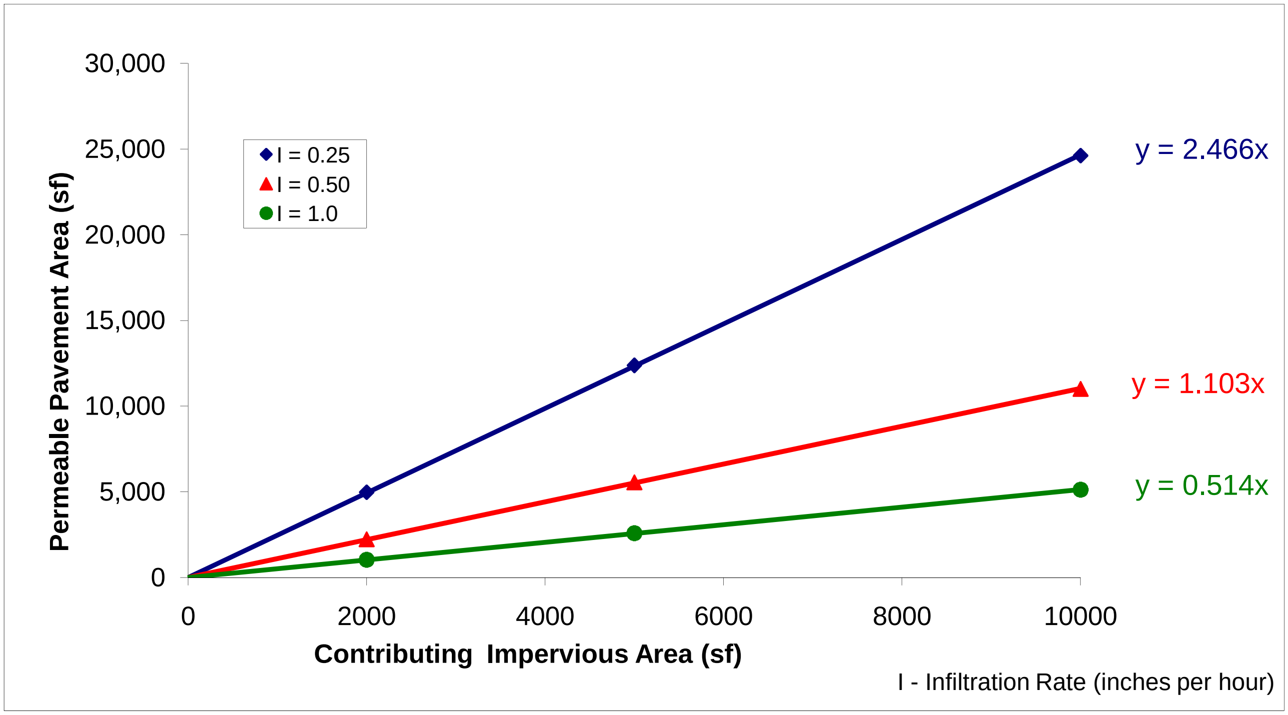


Figure E9. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

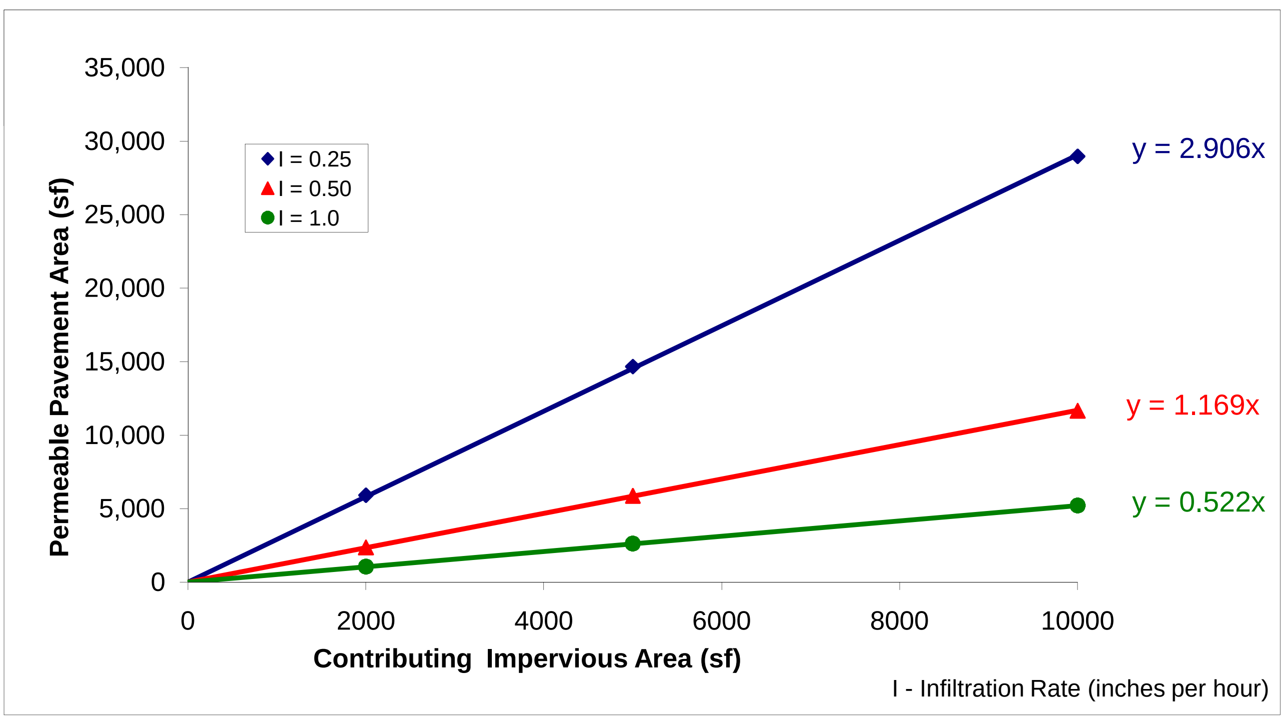


Figure E10. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

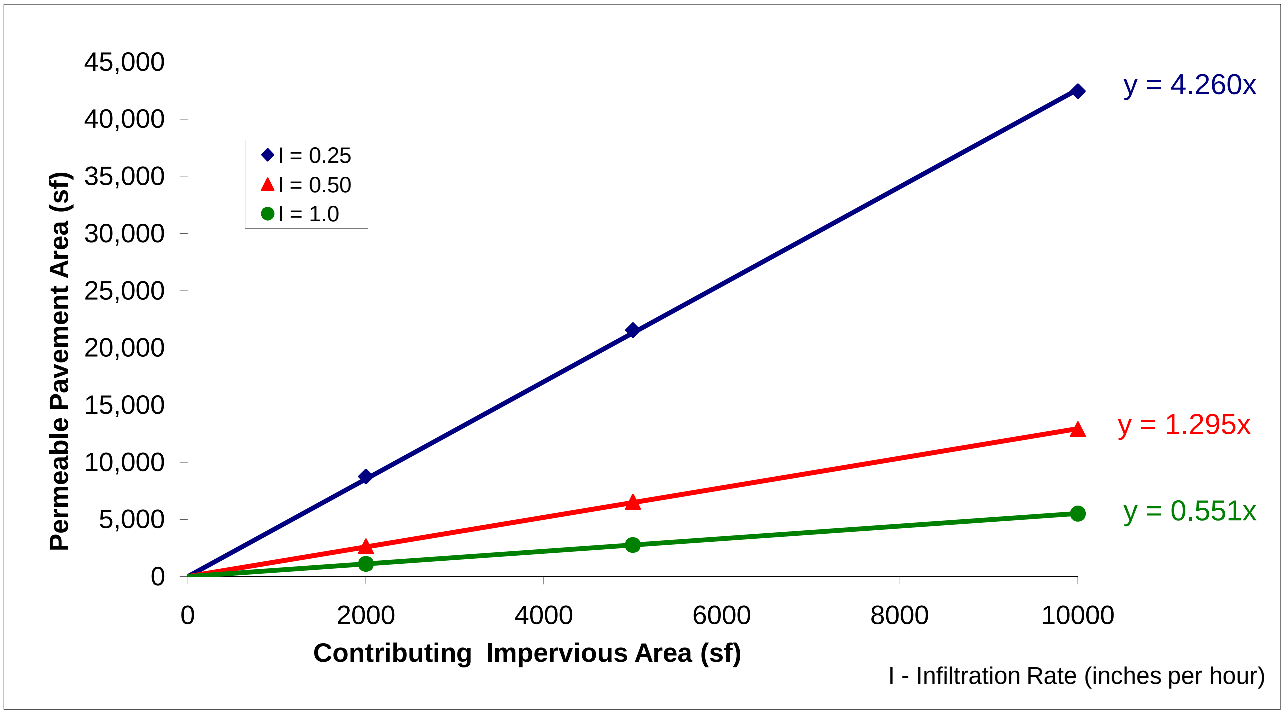


Figure E11. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

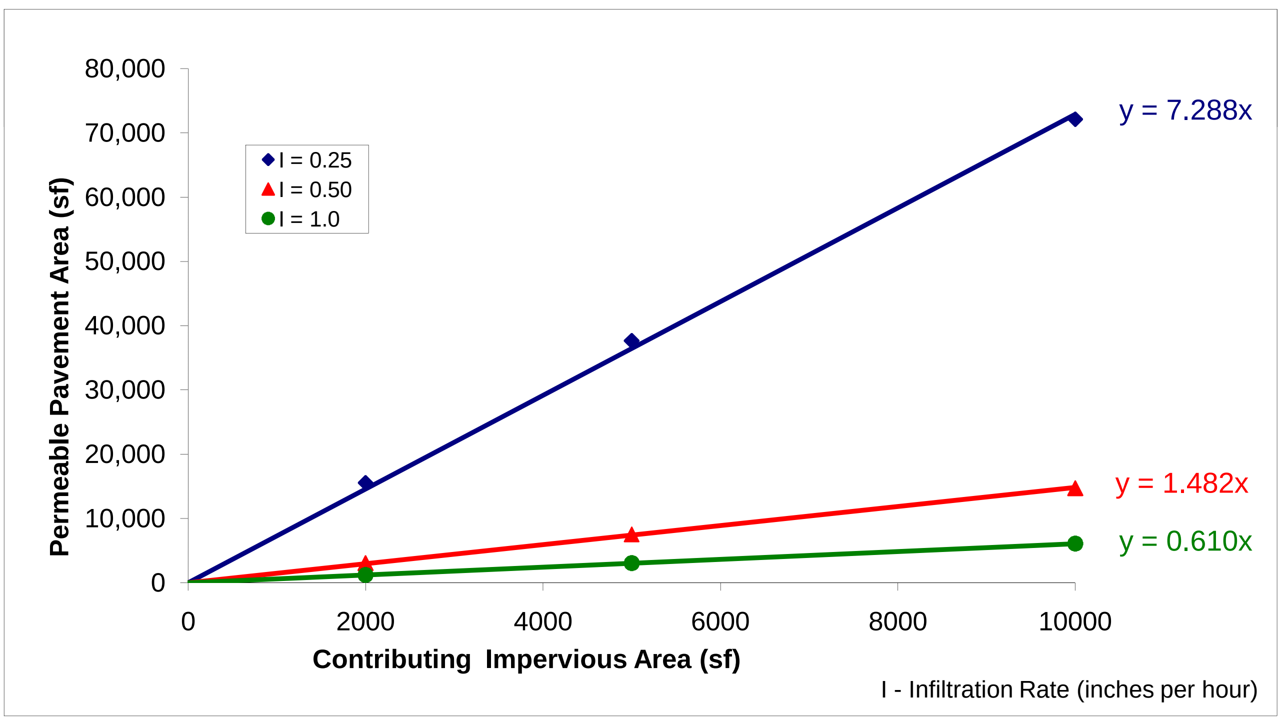


Figure E12. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).

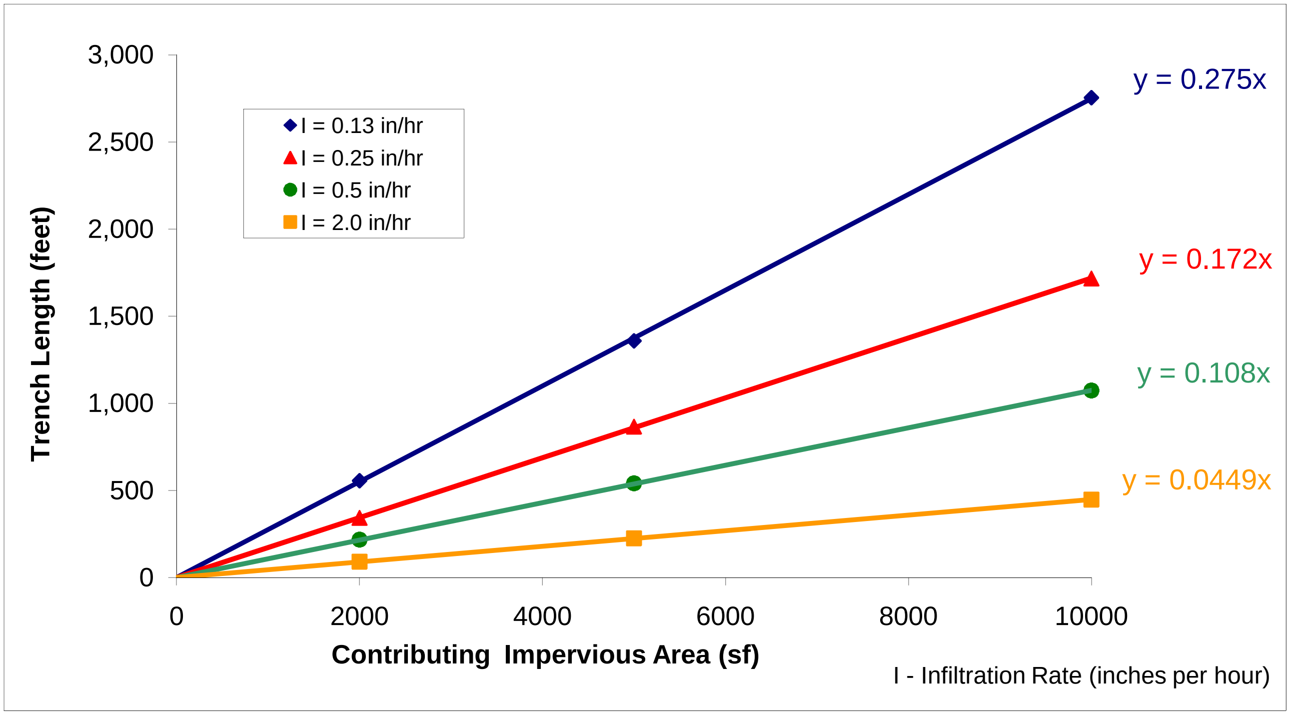


Figure E13. Rock trench sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

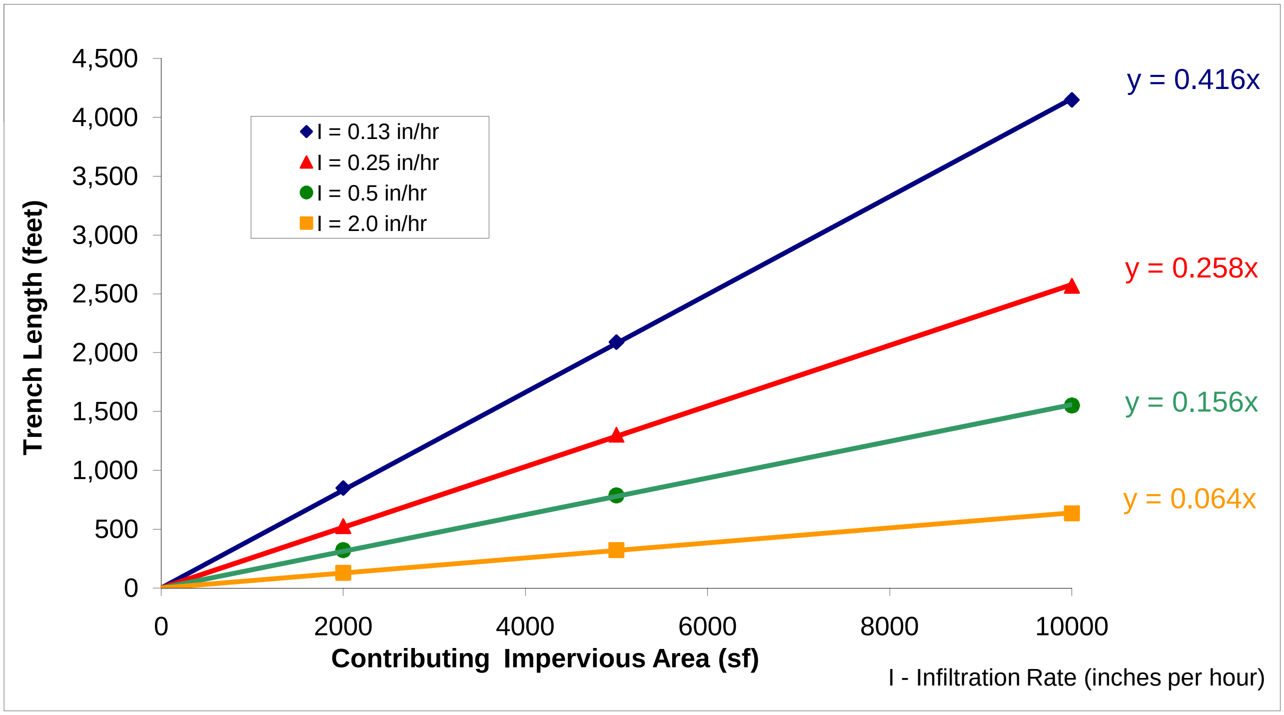


Figure E14. Rock trench sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

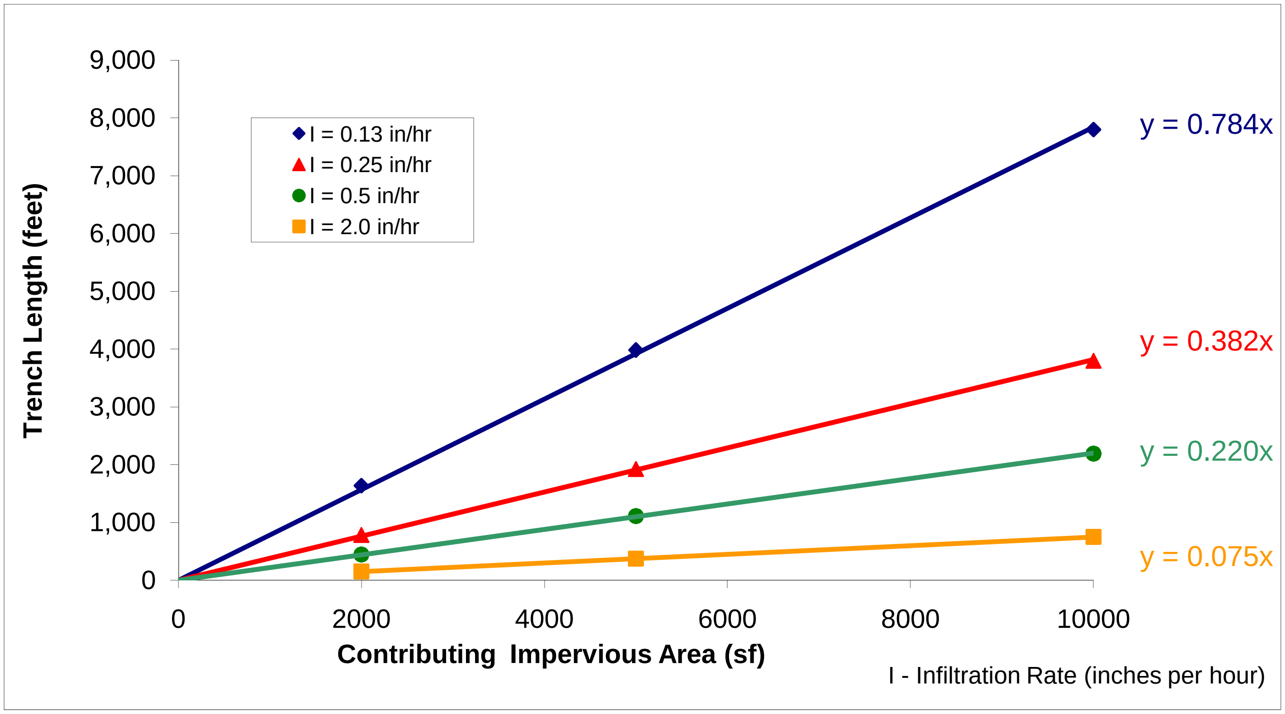


Figure E15. Rock trench sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

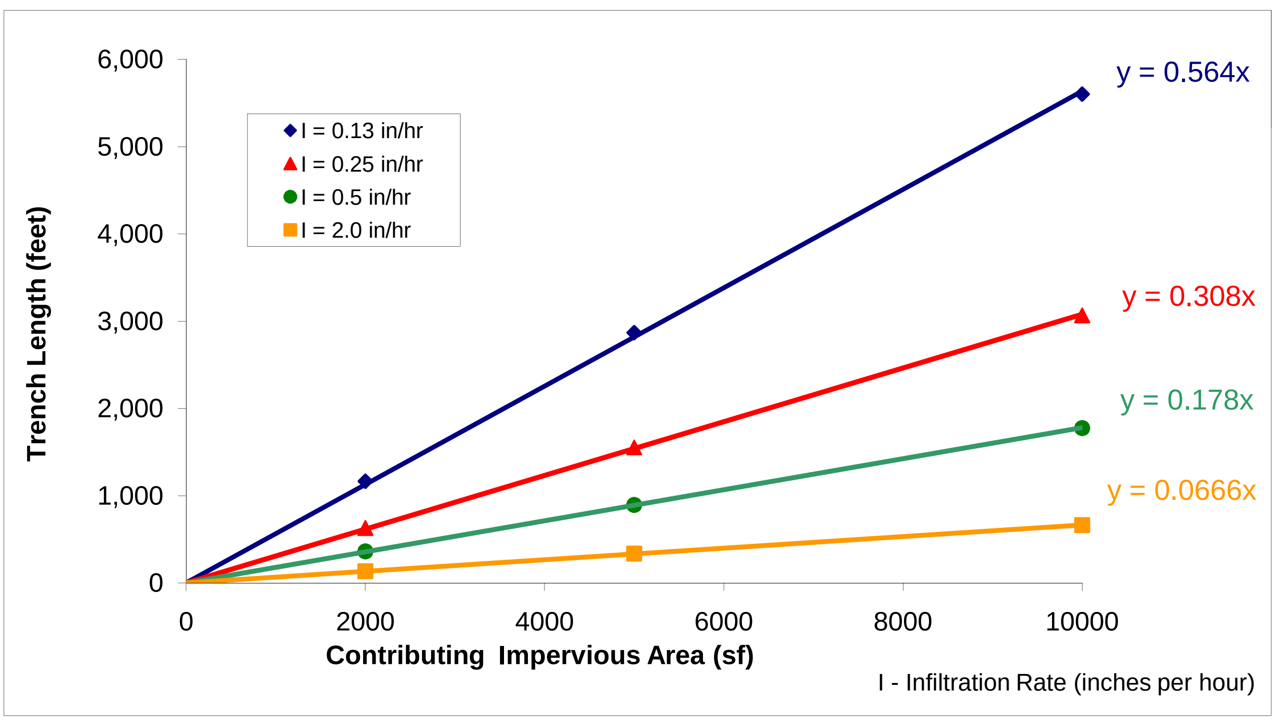


Figure E16. Rock trench sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).

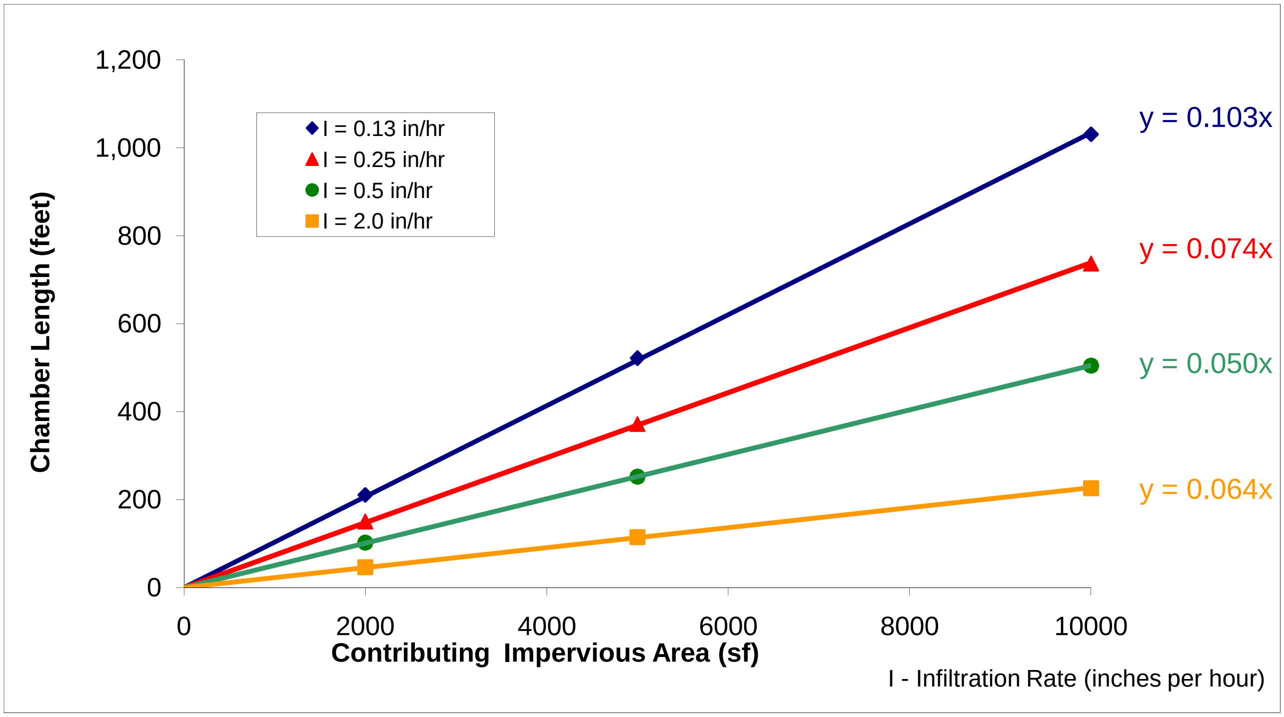


Figure E17. Gravelless chamber sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

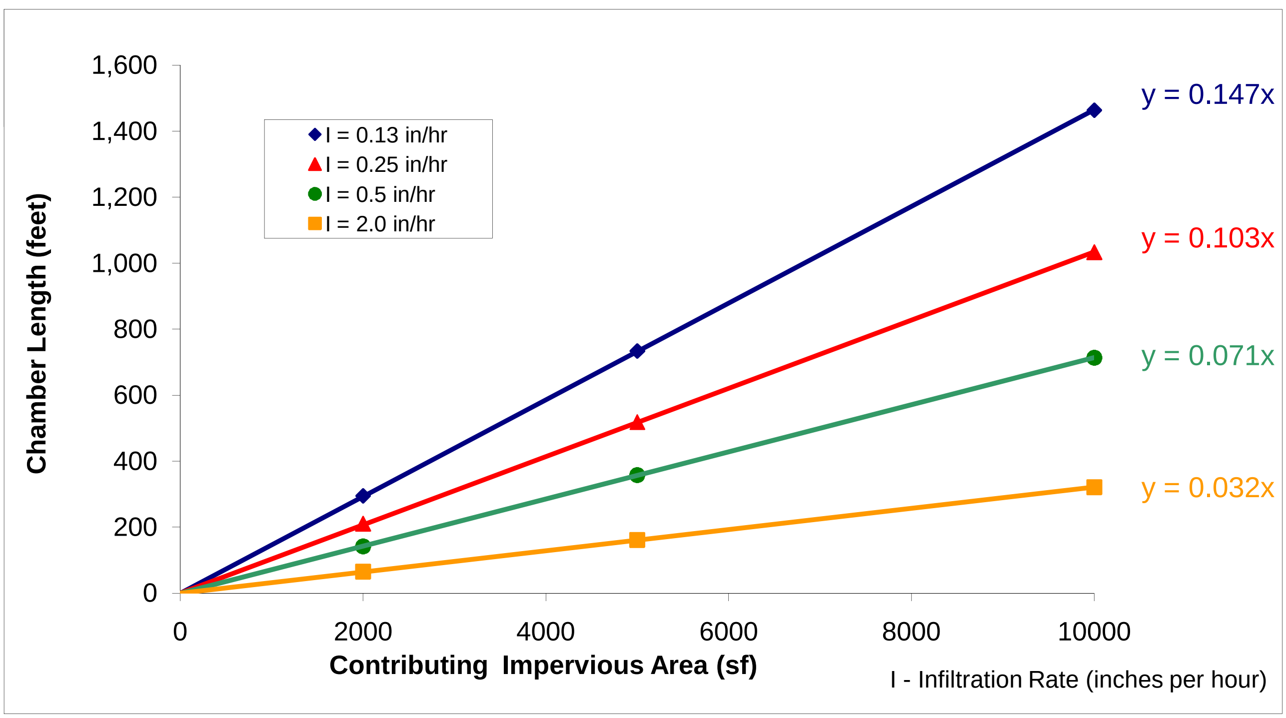


Figure E18. Gravelless chamber sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

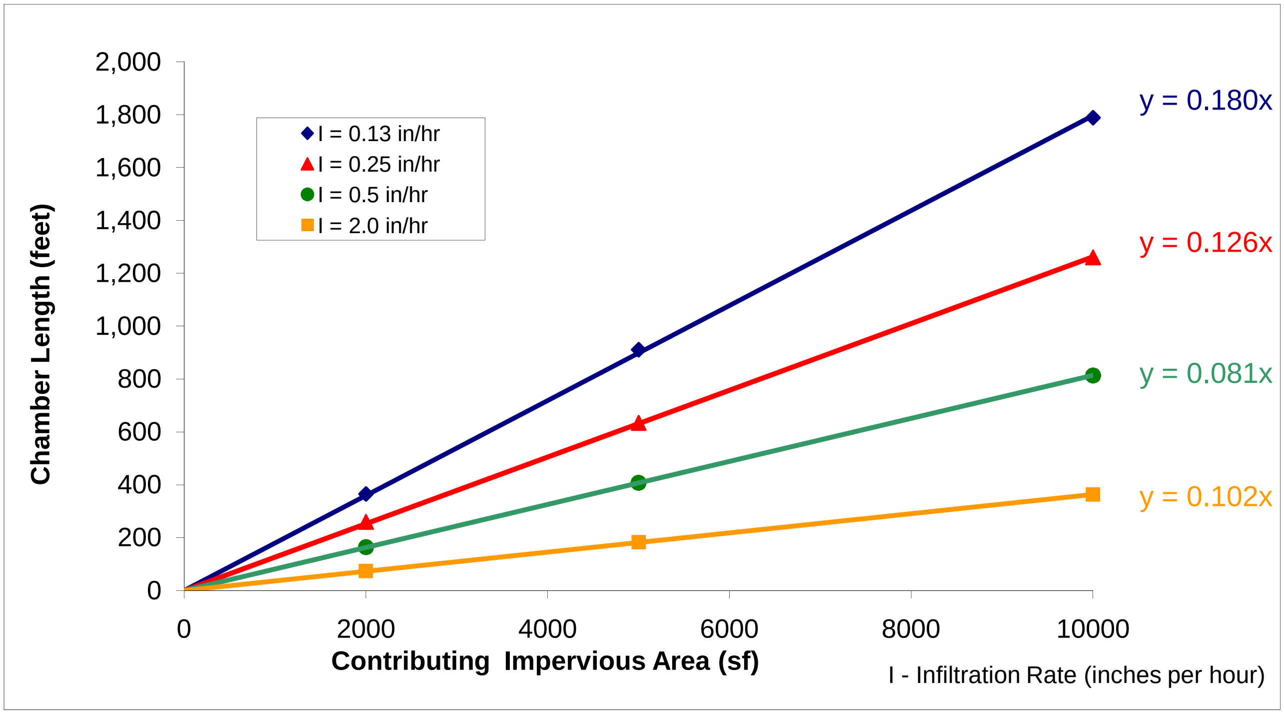


Figure E19. Gravelless chamber sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

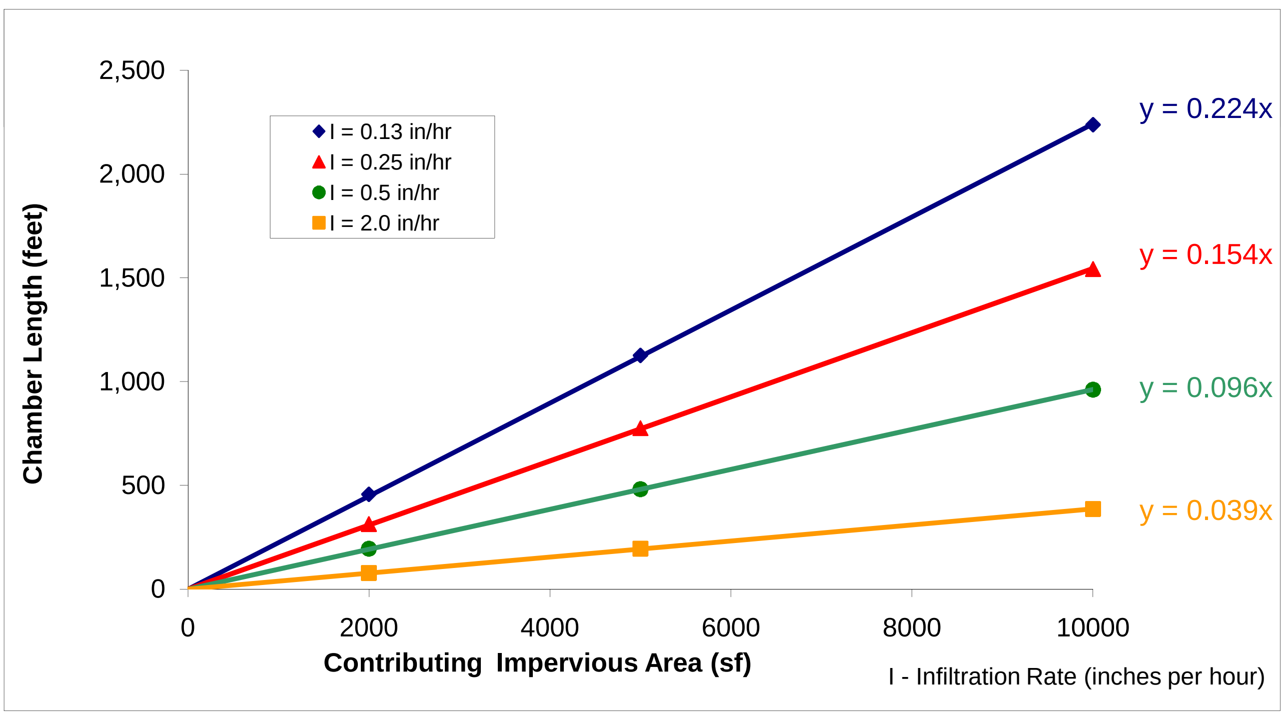


Figure E20. Gravelless chamber sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).