APPENDIX

C

SIZING OF LID FACILITIES

C.1 Sizing LID BMPs

This appendix presents guidelines for sizing LID BMPs using approved modeling methods provided in the 2004 SWMMEW. The first part of this section provides step-by-step processes for hydrologic modeling to size LID BMPs to meet 1) flow control requirements for Core Element #6 and 2) runoff treatment requirements for Core Element #5.

Following the step-by-step process overview, two hypothetical example problems are provided. Sizing Example #1 demonstrates sizing of a bioretention swale (without under-drain) for the Spokane area, with explicit accounting for snowmelt in the sizing calculations. Sizing Example #2 provides a comparison of LID BMP sizing for bioretention (without under-drain), flow-through planters, and permeable pavement (without under-drains) for all 4 eastern Washington Climatic Regions to show how results may vary as a function of BMP type, climate, and infiltration rates.

C1.1 Step-by-step hydrologic modeling process

The following provides a 16-step process for hydrologic modeling to size and demonstrate the performance of infiltration facilities for meeting **flow control requirements** for Core Element #6, adapted from Section 4.4.2 of the 2004 SWMMEW:

Step 1. Review Core Element #6 in Chapter 2 of the 2004 SWMMEW to determine all flow control requirements that apply to the proposed project.

Step 2. Identify the climate region and average annual precipitation from Figure 4.3.1 of the 2004 SWMMEW

Step 3. Identify the design rainfall depths from Figures 4.3.3 through 4.3.7 of the 2004 SWMMEW.

Step 4. Select storm hyetograph and analysis time steps. Verify that the analysis time step is appropriate for use with the input storm hyetograph time step.

Step 5. Account for rain-on-snow and snowmelt, as appropriate. See discussion of rain-on-snow and snowmelt considerations below and Sizing Example #1.

Step 6. Determine the pre-developed and proposed-development drainage basin areas, and identify pervious and impervious area for each condition.

Step 7. Classify existing site soils types and hydrologic soil groups (A, B, C, or D) using best available soils data, maps, and reports.

Step 8. Determine times of concentration for both pre-developed and proposed-development conditions. Some computer models will perform these calculations based on model input length, slope, roughness, and flow type. See Section 4.4.3 of the 2004 SWMMEW for further guidance on this step.

Step 9. Input data obtained from the steps above into the computer model for both the pre-developed and proposed-development conditions. See Table 4.1.1 of the 2004 SWMMEW for applicability of hydrologic analysis methods for runoff treatment and flow control facility design. For sizing of flow control facilities:.

a. Compute the design hydrographs for the pre-developed and proposed-development conditions using the selected computer model.

b. Review the modeled peak flow rates for the pre-developed condition. The Ecology-allowed release rate for the entire volume of the 2-year storm is 50 percent of the pre-developed or existing 2-year peak flow rate. The allowed release rate for the 25-year storm (or other recurrence interval(s) required by the local jurisdiction) may vary by local jurisdiction. Some local jurisdictions may also require retaining the 10-year, 24-hour storm on-site. In these situations, the 2-year proposed-development flow volume and/or 10-year, 24-hour proposed development flow volume must be retained to allow for storage, infiltration, and/or evaporation.

c. Review the modeled proposed-development condition peak flow rates for the 2-year and 25-year (or other recurrence interval(s) required by the local jurisdiction) storms. Determine whether the designs meet the allowed release rates and if a flow control facility is therefore required.

Step 10. Enter initial assumptions for the overall site and LID BMP designs into the computer model.

Step 11. If using level-pool routing, develop a stage-storage-discharge table to define the relationship between BMP geometry, available storage volume, and discharge as a function of stage, or water surface elevation. The stage-storage-discharge relationship must be accurately defined, as this relationship controls the modeled performance of the BMP. See Sizing Example #1 below for an example definition of a stage-storage-discharge table for a bioretention swale.

Step 12. If orifices are included in the designs to control discharge rates, consult the local jurisdiction design requirements to determine the minimum allowable orifice diameter. An important consideration for cold climate regions is that orifices should be large enough to prevent frozen water from clogging the orifice. Similarly, the orifice structure should be designed to minimize or prevent clogging from sediments, organic debris, etc.

Step 13. Use computer model to route the proposed development hydrographs through the LID BMPs.

Step 14. Compare the proposed-development peak outflow rates to the allowable release rates.

Step 15. If the proposed-development peak outflow rates exceed the allowable release rates, adjust the site and LID BMP designs. Continue iterations utilizing the computer model and adjusting the parameters until the proposed-development outflow rates are less than or equal to the allowable release rates.

Step 16. Calculations are complete. Prepare hydrologic modeling documentation as required by local jurisdiction.

The following step-by-step process for hydrologic modeling to size and demonstrate the performance of bioretention facilities for meeting **runoff treatment** requirements for Core Element #5, adapted from Section 4.4.2 of the 2004 SWMMEW:

Step 1. Review Core Element #5 in Chapter 2 of the 2004 SWMMEW to determine all runoff treatment requirements that will apply to the proposed project.

Step 2. Identify the climate region and average annual precipitation from Figure 4.3.1 of the 2004 SWMMEW.

Step 3. Identify the precipitation map from Figure 4.3.2 or 4.3.3 of the 2004 SWMMEW to be used based on the type of runoff treatment BMP being designed:

   a. 2-year, 2-hour for flow-rate-based treatment BMPs

   b. 2-year, 24-hour for volume-based treatment BMPs (recommended for infiltration-based LID BMPs)

Step 4. Multiply the rainfall by the appropriate coefficient to convert the 2-year to the 6-month precipitation depth:

   a. See Table 4.2.11 of the 2004 SWMMEW for 6-month, 3-hour precipitation for flow-rate-based LID BMPs

   b. See Table 4.2.9 of the 2004 SWMMEW for 6-month, 24-hour precipitation for volume-based BMPs (recommended for infiltration-based LID BMPs)

Step 5. Determine the proposed-development drainage basin areas and identify the pervious and impervious areas that contribute flow to the proposed treatment BMPs.

Step 6. Classify existing site soils types and hydrologic soil groups (A, B, C, or D) using best available soils data, maps, and reports.

Step 7. Determine the time of concentration for the proposed-development conditions. Some computer models will do this calculation if the designer enters length, slope, roughness, and flow type. See Section 4.4.3 of the 2004 SWMMEW for further guidance on this step.

Step 8. If modeling the short- or long-duration storm hyetograph, select the 3-hour short-duration storm hyetographs (see Table 4.2.4 of the 2004 SWMMEW) or regional long-duration storm hyetographs for the climate region (see either Table 4.2.2 or Tables 4.2.5 to 4.2.8 of the 2004 SWMMEW) and analysis time step. Check to be certain that the analysis time step is appropriate for use with the storm hyetograph time step.

Step 9. Account for rain-on-snow and snowmelt considerations as appropriate. See additional discussion on this topic in the text below and in Sizing Example #1.Account for rain-on-snow and snowmelt as appropriate. See additional discussion on this topic in the text below and in Sizing Example #1.

Step 10. Input data obtained from the steps above into the computer model for the proposed-development conditions and storm event. Section 4.1.2 of the 2004 SWMMEW describes allowable options for hydrologic analysis, including for runoff treatment facilities:

   a. Single event hydrograph methods:

      i. Soil conservation Service (SCS) Curve Number Equations.

      ii. Santa Barbara Urban Hydrograph (SBUH).

   b. SCS Curve Number Equations (not single event).

   c. Level-Pool Routing.

   d. Rational Method.

Step 11. Use computer model to evaluate the proposed-development hydrograph and route the hydrograph through the LID BMPs.

Step 12. To design flow-rate-based treatment BMPs, use the computed peak flow from the 6-month, 3-hour hydrograph.

Step 13. To design volume-based treatment BMPs, use the computed volume from the 6-month, 24-hour (or long-duration design) hydrograph. This option is recommended for infiltration-based LID BMPs.

Step 14. If the proposed LID BMP design does not accommodate the design flow rate or volume, adjust the design. Continue iterations utilizing the computer model and adjusting the parameters until the proposed design provides the required level of treatment.

Step 15. Calculations are complete. Prepare hydrologic modeling documentation as required by local jurisdiction.

RAIN-ON-SNOW AND SNOWMELT CONSIDERATIONS

Rain-on-snow and snowmelt can be an important design consideration in many eastern Washington regions. Although the size of rainfall events typically used in BMP design may or may not produce a significant amount of snowmelt, runoff produced by these events is high because of frozen and saturated ground conditions beneath the snow cover. Section 4.2.7 of the 2004 SWMMEW provides a step-by-step procedure for calculating rain-on-snow volume and snow melt to be factored into sizing as appropriate. Note that because the ground is generally frozen during snowmelt or rain-on-snow events, the difference between pre- and proposed-project discharges are often small. However, snowmelt and rain-on-snow events should be included in calculations if runoff from these events will be routed to the LID BMP facilities.

In dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. The 2004 SWMMEW recommends oversizing the facility when average annual snowfall depth is greater than or equal to the annual precipitation depth, assuming snow is approximately 10% water. See Section 4.2.7 of the 2004 SWMMEW for guidance on designing BMPs for rain-on-snow and snowmelt.

C.2.2 Hypothetical Sizing Examples

This section presents two hypothetical examples to illustrate the above-described LID BMP sizing process. In the first example, a bioretention swale (without under-drain) is sized for a 15,000-square-foot site in Spokane to provide runoff treatment and flow control in accordance with Core Elements #5 and #6. In the second sizing example, several BMPs are sized to manage stormwater runoff from 10,000 square feet of impervious surface area for hypothetical sites in each of the 4 climatic regions of eastern Washington. The results allow for comparison of resulting BMP sizes that would be required as a function of BMP type, sizing goal, climate, and infiltration rate.

SIZING EXAMPLE #1 – SIZE BIORETENTION SWALE (WITHOUT UNDER-DRAIN) FOR 15,000-SQUARE-FOOT SITE IN SPOKANE, WA TO TREAT AND RETAIN THE 10-YEAR, 24-HOUR STORM ON-SITE

The following assumptions apply to the hypothetical project site:

- Location: Spokane, WA (Climatic Region 3).
- 10-year, 24-hour rain fall depth: 1.9 inches.
- Proposed site land use:
  - » 8,500 sf building (Curve Number 98).
  - » 5,000 sf pavement (Curve Number 98.
  - » 1,500 sf compost amended landscaped area (Curve Number 74).
  - » 15,000 sf total.
- Long-term design native soil infiltration rate: 1.2 inch/hour (measured rate. Because the native soils are protected

from fouling when a deep layer of bioretention soil mix is place on top, no correction factor need be applied).

A bioretention swale (without under-drain) will be used to meet runoff treatment and flow control requirements with the following assumptions for design (see Figure C.1):

- Bottom width (swale): 4 feet.
- Bottom width (excavation): 12 feet.
- Freeboard: 1 foot.
- Side slopes (swale): 3 Horizontal:1 Vertical.
- Side slopes (excavation): 1 Horizontal:1 Vertical.
- Bioretention soil mix depth: 1.5 feet.
- Bioretention soil mix porosity: 40%.
- Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors).
- Overflow riser diameter: 1 foot (unrestricted flow based on drainage area).
- Overflow riser height (maximum ponding depth): 1 foot.
- ***Sizing target: Treat and retain the 10-year, 24-hour storm on-site.***

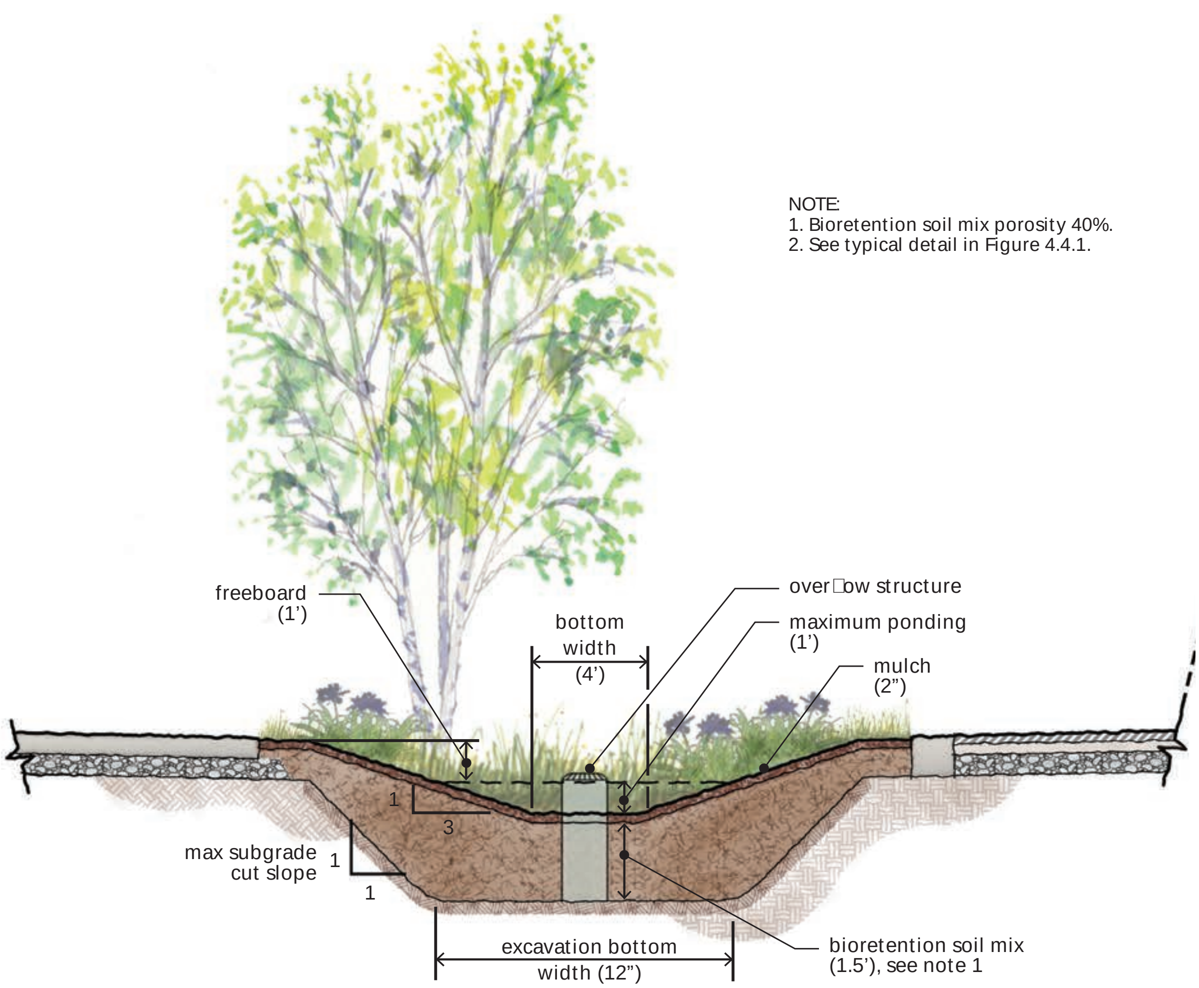

FIGURE **C.1**
Schematic illustration of bioretention geometry parameters input to hydrologic model for sizing.
Source: AHBL,Inc. and HDR Engineering

The hydrologic modeling methods and assumptions used to size the bioretention swale for this hypothetical project example are as follows:

- Design storm: 24-hour SCS Type 1A.
- Hydrologic modeling method: SCS Curve Number.
- Model timestep: 6-minute (to match the input storm hyetrograph).
- Time of concentration: 5 minutes.
- Snowmelt (M_s) in inches per day calculated using Method 2 (Section 4.2.7 of the 2004 SWMMEW):
  - » $M_s = C_m (T_{air} – T_{base})$, where:
    - T_{air} is the average daily air temperature (°F), assumed for this example to be 50°F during the melt season.
    - T_{base} is the base temperature (32 °F).
    - C_m selected from Table 4.2.14 based on light rain, windy conditions; value of .163 inches/°F used.
  - » M_s = 2.93 inches.
  - » This value for M_s was added to the 10-year, 24-hour rainfall depth, for a total influent moisture depth of 4.83 inches (1.90 inches + 2.93 inches = 4.83 inches).
- Routing method: Level-pool routing.

Level-pool routing is used to route stormwater runoff generated by the developed site through the bioretention facility. To do this, we must develop a stage-storage-discharge relationship defined by the bioretention geometry, overflow control structures, and native soil infiltration rate. For this example, the stage-storage-discharge relationship is defined to include the bioretention soil mix and surface ponding layer of the bioretention facility, so that storage can be explicitly represented in the ponding zone and in the voids of the bioretention soil mix layer. For purposes of defining the infiltration component of discharge, the smaller of the native soil infiltration rate and bioretention soil mix infiltration rate was used.

Given these assumptions, the minimum bioretention swale length needed to treat and retain the 10-year, 24-hour storm event including snowmelt is 202 feet. The corresponding top width, based on the 4-foot bottom width, 1-foot ponding depth, 1-foot freeboard, and 3:1 side slopes, is 16 feet. While the bottom width is important to track for sizing and construction purposes, the top width is also important to track during design iterations to quickly gauge whether there is adequate room for the facility given available space and feasibility constraints of the site. Figure C.2 shows the model input rainfall + snowmelt distribution along the top X-axis and the modeled inflow to the bioretention facility, overflow, and infiltration to native soils along the bottom X-axis. Since the facility was designed to retain the 10-year, 24-hour storm on-site, the modeled overflow is zero for the entire length of the simulation. The stage-storage-discharge table that represents this design, used in the level pool routing calculations, is shown in Table C.1.

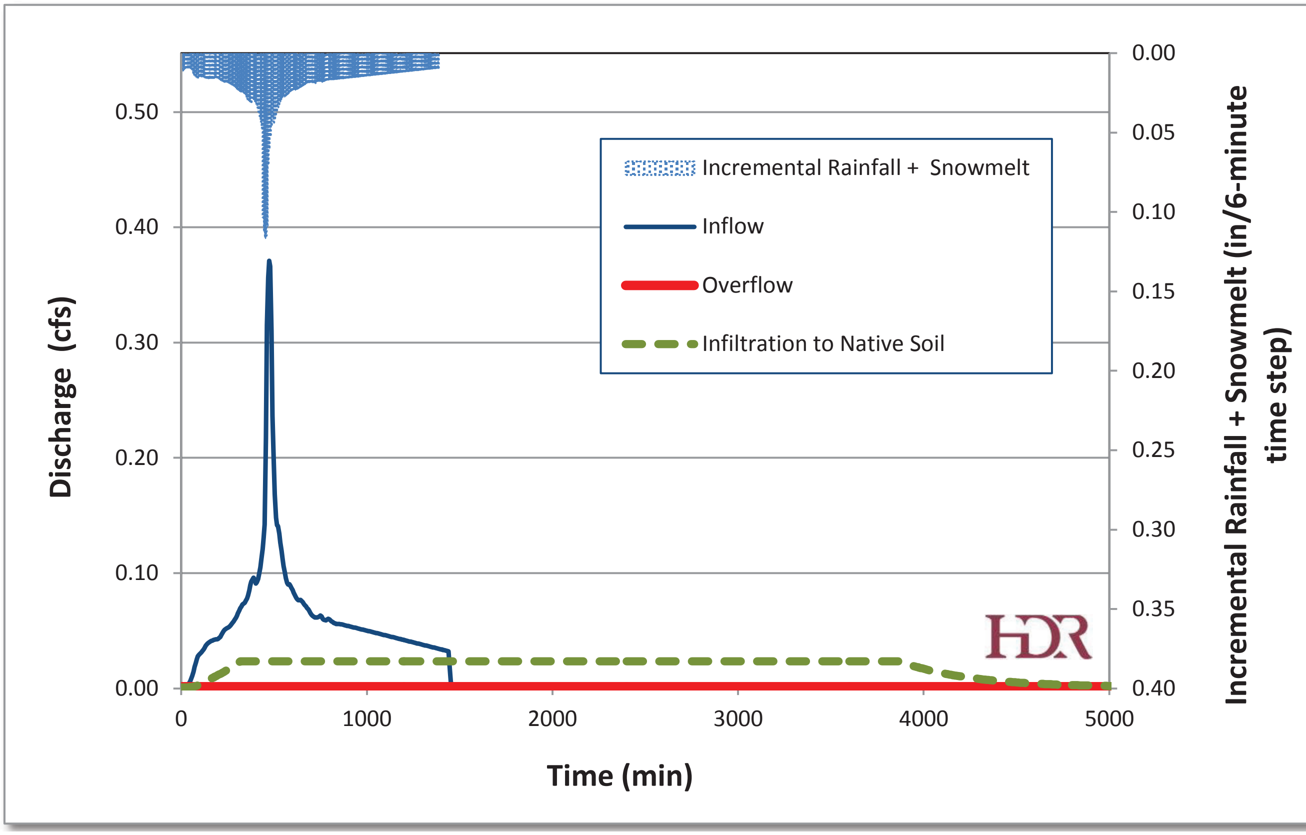

FIGURE **C.2**
Model input incremental rainfall plus snowmelt and resulting modeled inflow to the bioretention facility, overflow, and infiltration to native soils.
Source: HDR Engineering

TABLE C.1 STAGE-STORAGE-DISCHARGE RELATIONSHIP FOR LEVEL POOL ROUTING THROUGH BIORETENTION BMP FOR HYPOTHETICAL PROJECT EXAMPLE #1

Stage[a] (ft)	Storage[b] (cf)	$Q_{infiltration}$[c] (cfs)	$Q_{overflow}$[d] (cfs)	Q_{total}[e] (cfs)	COMMENTS
0	0	0.00	0.00	0.00	0 stage represents bottom of bioretention soil mix layer.
0.5	505	0.02	0.00	0.02	$Q_{infiltration}$ begins for stage > 0, calculated as the product of the long-term design native soil infiltration rate and the swale bottom area.
1	1,050	0.02	0.00	0.02	
1.5	1,727	0.02	0.00	0.02	Top of bioretention soil mix layer, bottom of surface ponding layer. Storage volume includes 1.5 foot bioretention soil mix with 40% porosity.
2	2,596	0.02	0.00	0.02	
2.5	3,777	0.02	0.00	0.02	Top of overflow riser.
3	5,181	0.02	2.67	2.70	$Q_{overflow}$ begins for stage > 2.5 feet (overflow structure elevation), calculated as the lower value based on the weir and orifice equations.
3.5	6,807	0.02	3.78	3.80	Top of effective storage depth, includes 1.5 feet of bioretention soil mix, 1 foot ponding, and 1 foot freeboard. Storage volume accounts for porosity of bioretention soil mix (40%) and ponded zone (100%).

Notes:

cf Cubic feet
cfs Cubic feet per second
ft Feet

a. Stage represents the water surface elevation in the bioretention facility, measured from the bottom of the BSM.

b. Storage represents the total effective storage volume available in the bioretention facility, calculated for each stage level as the sum of the available pore volume in the bioretention soil mix plus the available live storage volume in the ponding zone.
For example, for the 1-foot stage level, which is below the ponding level, storage was calculated as follows:
Storage = Available Bioretention Soil Void Volume
Storage = (Bioretention Soil Mix Cross-Sectional Area)*(Swale Length)*(Bioretention Soil Mix Porosity)
Storage = (1 ft * (12 ft + 14 ft)/2)*(202 ft)*(40%) = 1,050 cf
Where 12 ft and 14 ft are the bottom and top widths, respectively of the bioretention soil mix layer at the 1-foot stage level, based on the geometry assumptions provided above and shown in Figure C.1.
As another example, for the 2-foot stage level, which is above the ponding level, storage was calculated as follows:
Storage = Available Bioretention Soil Mix Void Volume + Available Ponding Storage Volume
Available Bioretention Soil Mix Void Volume = ((2 ft*(12 ft + 16 ft)/2)-(0.5 ft * (4 ft+7 ft)/2))*(202 ft) * (40%) = 2,040 cf
Where 12 ft and 16 ft are the bottom and top widths, respectively, of the bioretention soil mix layer at the 2-foot stage level, based on the geometry assumptions provided above and shown in Figure C.1.
Available Ponding Storage Volume = (0.5 ft * (4 ft + 7 ft)/2) * (202 ft) = 556 cf
Where 4 ft and 7 ft are the bottom and top widths, respectively, of the ponding zone based on the geometry assumptions provided above and shown in Figure C.1.
Storage = 2,040 cf + 556 cf = 2,596 cf.

c. $Q_{infiltration}$ represents infiltration from the bioretention soil mix to the underlying native soil, calculated for all stage levels > 0 as the smaller of the long-term design native soil infiltration rate and the bioretention soil mix multiplied by the bottom area of the swale. In this example, the infiltration capacity of the native soil is limiting, since 1.2 in/hr < 1.5 in/hr.
$Q_{infiltration}$ = (1.2 in/hr) * (4 ft * 202 ft) * (43,200 ft-hr/in-s) = 0.02 cfs.

d. $Q_{overflow}$ represents discharge through the overflow pipe, calculated as the minimum value based on the weir and orifice equations.

e. Q_{total} represents the sum of $Q_{infiltration}$ and $Q_{overflow}$.

SIZING EXAMPLE 2 – REGIONAL BMP SIZING COMPARISON FOR BIORETENTION, FLOW-THROUGH PLANTER, AND PERMEABLE PAVEMENT

This section illustrates a BMP sizing comparison for three LID BMP types: bioretention swale (without under-drain), flow-through planters, and permeable pavement. The purpose of this example is to provide a high-level comparison of how sizes may vary for various BMP types as a function of climate region, sizing goals, and infiltration rates.

Bioretention and permeable pavement facilities were sized to retain the 10-year, 24-hour runoff from 10,000 square feet of impervious area on-site to meet flow control requirements for Core Element #6. For permeable pavement, runoff from the 10,000-square-foot impervious area was assumed to be routed onto the permeable pavement facility. Thus, the modeled BMP footprint area for permeable pavement represents the size needed to manage runoff from the contributing impervious area.

Note that routing excessive amounts of stormwater runoff from impervious surfaces onto permeable pavement could cause clogging and may necessitate more intense and frequent maintenance. For purposes of this exercise, two size values are provided for permeable pavement. The first value represents the minimum permeable pavement footprint area needed to meet the applicable standards based on hydrologic modeling alone. The second value represents the minimum footprint area needed based on an assumed maximum ratio of contributing impervious surface area to permeable pavement surface area of 50%. See Chapter 4: LID BMPs for design guidelines for permeable pavement and consult local jurisdiction requirements.

Flow-through planters are lined and do not provide infiltration. While flow-through planters may offer some flow control benefits through storage and evapotranspiration, only treatment benefits were evaluated for this exercise.

For runoff treatment, all BMPs were sized to retain the 6-month, 24-hour storm volume. Regional design storms were used for Regions 1 and 4 and the Type 1A storm was used for Regions 2 and 3, with rainfall depths selected based on location. Snowmelt was not included in the calculations to allow for comparison of results based on regional design storm differences alone.

Two long-term design native soil infiltration rates were evaluated: 0.5 inches per hour and 3.0 inches per hour, with appropriate correction factors applied. Table C.2 provides a summary of design assumptions input to the model for each BMP type and Table C.3 provides a summary comparison of sizing results. The values shown in the table represent the BMP bottom footprint area needed to meet the flow control and runoff treatment targets.

TABLE C.2 SUMMARY OF INPUT BMP DESIGN ASSUMPTIONS USED FOR BMP SIZING COMPARISON EXERCISE

BMP	DESIGN ASSUMPTIONS
Bioretention	• Bottom width: 2 feet • Freeboard: 1 foot • Side slopes (swale): 3 Horizontal:1 Vertical • Side slopes (excavation): 1 Horizontal:1 Vertical • Bioretention soil mix depth: 18 inches • Bioretention soil mix porosity: 40% • Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors) • Overflow riser diameter: 12 inch (unrestricted flow based on drainage area) • Overflow riser height: 1 foot • Native soil infiltration rate: 0.5 and 3.0 inches per hour
Flow-through Planter	• Bottom width: 2 feet • Freeboard: 1 foot • Side slopes: 0 Horizontal:1 Vertical • Bioretention soil mix depth: 18 inches • Bioretention soil mix porosity: 40% • Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors) • Overflow riser diameter: 12 inch (unrestricted flow based on drainage area) • Overflow riser height: 1 foot • Native soil infiltration rate: 0 inches per hour
Permeable Pavement	• Side slopes: 0 Horizontal:1 Vertical • Aggregate subbase depth: 12 inches • Aggregate subbase porosity: 35% • Native soil infiltration rate: 0.5 and 3.0 inches per hour

TABLE C.3 COMPARISON OF REQUIRED BMP BOTTOM AREAS TO MEET RUNOFF TREATMENT AND FLOW CONTROL REQUIREMENTS FOR 10,000 SQUARE FEET OF IMPERVIOUS AREA BY CLIMATE REGION (ALL UNITS IN SQUARE FEET)

CLIMATIC REGION	1		2		3		4	
Location	Cle Elum		Tri-Cities		Spokane		Asotin	
Design Storm Type	Regional		Type 1A		Type 1A		Regional	
10-year, 24-hour rainfall depth (inches)	2.9		1.3		1.9		2.0	
	WQ	FC	WQ	FC	WQ	FC	WQ	FC
Native Soil Infiltration Rate 0.5 inch per hour								
Bioretention	88	250	34	106	76	164	68	170
Flow-Through Planter	483	N/A	179	N/A	395	N/A	362	N/A
Permeable Pavement	576/5,000	1,620/5,000	267/5,000	828/5,000	583/5,000	1,270/5,000	486/5,000	1,225/5,000
Native Soil Infiltration Rate 3 inch per hour								
Bioretention	70	198	30	90	64	138	56	140
Flow-Through Planter	483	N/A	179	N/A	395	N/A	362	N/A
Permeable Pavement	165/5,000	452/5,000	97/5,000	311/5,000	218/5,000	475/5,000	172/5,000	429/5,000

Notes:

FC Flow Control.

N/A Not Applicable.

WQ Water Quality.

a- BMPs sized to meet Core Element #5 (Runoff Treatment) and #6 (Flow Control) by retaining the 10-year, 24-hour storm on-site. BMP sizes provided in the table represent modeled BMP bottom areas (square feet) required to meet the runoff treatment and flow control goals, respectively.

b- Climatic regions based on Figure 4.3.1 of the 2004 SWMMEW.

c- Flow-through planters are lined and do not infiltrate into native soil. While they offer some flow control benefits, only treatment benefits were evaluated for this exercise.

d- Permeable pavement bottom and top areas are the same, assuming vertical side slopes of the installation. Two sizing values are provided in the table for permeable pavement: Value 1/Value 2. Value 1 represents the minimum surface area needed to meet the applicable standard based on hydrologic modeling alone. Value 2 represents the minimum permeable pavement surface area based on an assumed maximum ratio of contributing impervious surface area to permeable pavement facility surface area of 50%. This type of maximum ratio limit may help reduce clogging and maintenance requirements. See Chapter 4 for permeable pavement design guidelines.