REVIEW DRAFT
VOLUME 3 –
PROJECT STORMWATER CONTROL

Prepared for
City of Seattle

Prepared by
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CHAPTER 1 – INTRODUCTION

1.1. Purpose of this Volume

Volume 3 (*Project Stormwater Control*) of the City of Seattle Stormwater Manual presents approved methods, requirements, criteria, details, and general guidance for analysis and design of on-site stormwater management, flow control, and water quality treatment pursuant to the Seattle Municipal Code (SMC), Chapter 22.800 – 22.808, the Stormwater Code.

This volume describes and provides technical requirements for selecting, designing, constructing, and maintaining best management practices (BMPs) required by the Stormwater Code. These BMPs are designed to reduce the flow rates or volumes of stormwater runoff, reduce the level of pollutants contained in that runoff, and convey stormwater runoff. In accordance with provisions of the Stormwater Code, additional BMPs beyond those specified in this volume may be required.

1.2. How to Use this Volume

- *Chapter 1* (this chapter) outlines the purpose and content of this volume.
- *Chapter 2* describes the BMP categories.
- *Chapter 3* describes the steps required to select appropriate BMPs after the minimum requirements for on-site stormwater management, flow control, and/or water quality treatment have been determined using *Volume 1*.
- *Chapter 4* provides general design guidance on the following:
    - On-site list approach, pre-sized approach, and modeling approach
    - Information pertinent to bypass and conveyance design
    - Pretreatment requirements
- *Chapter 5* provides detailed descriptions and design criteria for BMPs outlined in *Chapter 2*

Several appendices also support the information contained in this volume. These appendices include:

- *Appendix A* – Definitions
- *Appendix C* – On-site Stormwater Management Infeasibility Criteria
- *Appendix D* – Subsurface Characterization and Infiltration Testing for Infiltration Facilities

- *Appendix E* – Additional Design Requirements
- *Appendix F* – Hydrologic Analysis and Design
- *Appendix G* – Stormwater Control Operations and Maintenance Requirements

CHAPTER 2 – BMP CATEGORIES

2.1. Introduction

BMPs are designed to reduce the flow rates or volumes of stormwater runoff, reduce the level of pollutants contained in that runoff, and convey stormwater runoff. BMPs include structural stormwater facilities that provide long-term management of stormwater at developed sites. This volume covers four primary categories:

- On-site stormwater management includes measures designed to reduce runoff volume and pollutants from development using infiltration, dispersion, and retention of stormwater runoff on-site.

- Flow control (FC) measures typically detain, retain, or infiltrate stormwater runoff to control the flow rate, frequency, duration, and sometimes the volume of stormwater runoff leaving the site.

- Water quality (WQ) treatment measures remove pollutants through one or more of the following processes: gravity settling of particulate pollutants, filtration, biological processes, and/or adsorption. Target pollutants include:

    - Sand, silt, and other suspended solids
    - Metals such as copper, lead, and zinc
    - Nutrients (e.g., nitrogen and phosphorus)
    - Certain bacteria and viruses
    - Organic contaminants such as petroleum hydrocarbons and pesticides

    Water quality treatment in this volume is divided into the following four categories based on the type of pollutant removal provided: basic treatment, enhanced treatment, oil treatment, or phosphorus treatment. Additional details on these treatment categories are provided in *Section 3.3*.

- Conveyance measures are designed to transport stormwater and can incorporate additional functions such as flow control or water quality treatment.

Note that some BMPs fall under more than one category. Determining which BMPs to use for a given application will depend on the applicable Stormwater Code requirements (refer to *Volume 1*), as well as site-specific factors such as available land surface and infiltration capacity of the soils. Additional requirements for conveyance are described in the side sewer code and associated rules.

To help further differentiate among the many functions, applications, and design requirements presented in this volume, the following sections describe eight subcategories of BMPs. BMPs are placed in one of the following subcategories based on their primary function:

1. Soil amendment
2. Tree planting and retention
3. Dispersion BMPs
4. Infiltration BMPs
5. Rainwater harvesting BMPs
6. Alternative surface BMPs
7. Detention BMPs
8. Non-infiltrating BMPs

Each section contains a chart identifying the categories to which the BMP can be applied and a reference to the section within this volume containing additional information.

2.2. Soil Amendment

Site soils must meet the minimum quality and depth requirement at project completion. Requirements may be achieved by either retaining and protecting undisturbed soil or restoring the soil (e.g., amending with compost) in disturbed areas.

BMP	On-site	FC	WQ	Conveyance	Reference
Soil amendment BMP	✓	✓			*Section 5.1*

2.3. Tree Planting and Retention

Tree planting and retention provides flow control through interception and evapotranspiration of stormwater.

BMP	On-site	FC	WQ	Conveyance	Reference
Tree planting and retention	✓	✓			*Section 5.2*

2.4. Dispersion BMPs

Dispersion is a simple method of flow control that uses surface grading to avoid concentrating flows or to disperse flows over vegetation.

The dispersion BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Full dispersion	✓	✓			*Section 5.3.2*
Splashblock downspout dispersion	✓	✓			*Section 5.3.3*
Trench downspout dispersion	✓	✓			*Section 5.3.4*
Sheet flow dispersion	✓	✓			*Section 5.3.5*
Concentrated dispersion	✓	✓			*Section 5.3.6*

2.5. Infiltration BMPs

Infiltration BMPs are designed to facilitate percolation of stormwater into the ground. Infiltration is feasible only where sufficiently porous soils are available, and where other site constraints are not limiting (e.g., steep slopes, high groundwater) as detailed under *Section 5.4.1*.

The infiltration BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Infiltration trenches	✓	✓	✓ [a]		*Section 5.4.2*
Drywells	✓	✓			*Section 5.4.3*
Infiltrating bioretention	✓	✓ [b]	✓	✓ [c]	*Section 5.4.4*
Rain gardens	✓				*Section 5.4.5*
Permeable pavement facilities	✓	✓	✓ [a]		*Section 5.4.6*
Perforated stub-out connections	✓				*Section 5.4.7*
Infiltration basins		✓	✓ [a]		*Section 5.4.8*

[a] If soil suitability criteria (SSC) are met (refer to *Section 5.4.1*).

[b] Bioretention cells with underdrains may be designed to meet the Peak Control Standard, but cannot achieve the pre-developed pasture standard.

[c] Bioretention cells, planters, or rain gardens may be connected in series, with the overflows of upstream cells directed to downstream cells to provide conveyance.

2.6. Rainwater Harvesting BMPs

Rainwater harvesting BMPs capture and store rainwater for beneficial use. Roof runoff may be routed to cisterns for storage and nonpotable uses such as irrigation, toilet flushing, and cold water laundry; however, additional treatment is required for use of collected rainwater

indoors. Design plans for indoor use of harvested rainwater must be prepared by a licensed engineer. This volume focuses on rainwater harvesting and use for nonpotable outdoor uses.

The rainwater harvesting BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Rainwater harvesting	✓	✓		✓	*Section 5.5.1*
Single Family Residential (SFR) cisterns	✓	✓		✓	*Section 5.5.2*

2.7. Alternative Surface BMPs

Alternative surface BMPs convert a conventional impervious surface to a surface that reduces the amount of stormwater runoff and also provides flow control.

The alternative surface BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Vegetated roofs	✓	✓			*Section 5.6.1*
Permeable pavement surfaces[a]	✓	✓	✓ [b]		*Section 5.6.2*

[a] While similar to permeable pavement "facilities" (refer to *Section 2.5*), permeable pavement "surfaces" are designed to function as a permeable land surface and not intended to receive runoff from other surfaces. Therefore, they are not considered infiltration facilities and have less onerous design requirements.

[b] If soil suitability criteria (SSC) are met (refer to *Section 5.4.1*).

2.8. Detention BMPs

Detention BMPs are designed to collect and temporarily store runoff, and then release it over a period of time at a reduced rate. Detention BMPs have an outlet control structure designed to release flows at an attenuated rate to meet flow control standards.

The detention BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Detention ponds		✓		✓	*Section 5.7.1*
Detention pipes		✓		✓	*Section 5.7.2*
Detention vaults		✓		✓	*Section 5.7.3*
Detention cisterns		✓		✓	*Section 5.7.4*
Other detention options		✓		✓	*Section 5.7.5*

2.9. Non-Infiltrating BMPs

Non-infiltrating BMPs are designed to remove pollutants contained in stormwater runoff. Some non-infiltrating BMPs may provide low levels of flow control as a secondary benefit.

Subcategories of non-infiltrating BMPs are presented below:

Non-infiltrating Bioretention is similar to infiltrating bioretention (*Section 5.4.4*) except that facilities are designed with an impervious bottom and sidewalls preventing infiltration to underlying soil. After percolating through the bioretention soil, the water is discharged via an underdrain. Non-infiltrating bioretention provides the following functions:

BMP	On-site	FC	WQ	Conveyance	Reference
Non-infiltrating Bioretention	✓	✓[a]	✓[b]	✓[c]	*Section 5.8.2*

[a] Bioretention cells with underdrains may be designed to meet the Peak Control Standard, but cannot achieve the pre-developed pasture standard.

[b] If soil suitability criteria (SSC) are met (refer to *Section 5.4.1*).

[c] Bioretention cells or planters may be connected in series, with the overflows of upstream cells directed to downstream cells to provide conveyance.

Biofiltration Swales use vegetation in conjunction with slow and shallow-depth flow for runoff treatment. Biofiltration swales may also result in some incidental infiltration to underlying native soils. Biofiltration swales described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Basic biofiltration swale			✓	✓	*Section 5.8.3*
Wet biofiltration swale			✓	✓	*Section 5.8.3*
Continuous inflow biofiltration swale			✓	✓	*Section 5.8.3*
Compost-amended biofiltration swale			✓	✓	*Section 5.8.3*

Filter Strips/Drains are grassy slopes that receive unconcentrated runoff from adjacent impervious areas such as a parking lots, driveways, or roadways. Filter strips are graded to maintain sheet flow over their entire width. Compost and other amendments can be incorporated into filter strip designs to provide enhanced treatment. Filter strip/drain BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Basic filter strips			✓	✓	*Section 5.8.4*
Compost-amended vegetated filter strips (CAVFS)			✓	✓	*Section 5.8.4*
Media filter drains			✓	✓	*Section 5.8.4*

Sand Filters are impoundments that temporarily store stormwater runoff so that it can infiltrate, but instead of infiltrating through the native soil, stormwater passes through a constructed sand bed. Sand filters can be sized as either a basic or a large facility to meet different water quality objectives. Sand filter basins are designed with underdrains to collect and route runoff following treatment to the downstream conveyance system. The sand filter BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Basic and large sand filter basins			✓		*Section 5.8.5*
Sand filter vaults			✓		*Section 5.8.5*
Linear sand filters			✓		*Section 5.8.5*
Proprietary and emerging water quality treatment technologies			✓		*Section 5.8.11*

Wet Ponds are constructed stormwater ponds that retain a permanent pool of water (i.e., a wet pool or dead storage) at least during the wet season. The volume required for flow control or "live storage" can be provided above the treatment wet pool. The wet pond BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Wet ponds – basic and large			✓	✓	*Section 5.8.6*

Wet Vaults are drainage facilities that contain permanent pools of water that are filled during the initial runoff from a storm event. They are similar to wet ponds, except the facility is constructed below grade in a concrete (or similar) vault. The wet vault BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Wet vaults			✓	✓	*Section 5.8.7*

Stormwater Treatment Wetlands are similar to wet ponds, but also provide a shallow marsh area to allow the establishment of emergent wetland aquatic plants, which improves pollutant removal. In land development situations, wetlands are usually constructed for two main reasons: to replace or mitigate impacts when natural wetlands are filled or impacted by development (mitigation wetlands) and to treat stormwater runoff (stormwater treatment wetlands). Mitigation wetlands may not be used as stormwater treatment facilities, because stormwater treatment functions are not compatible with normal wetland function. The stormwater treatment wetland BMPs described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Stormwater treatment wetlands			✓	✓	*Section 5.8.8*

Combined Detention and Wet Pool Facilities provide a combination of runoff treatment and flow control. If combined, the wet pool portion of the facility can often be incorporated below the detention facility with little further loss of development area. Combined detention and wet pool facilities described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
Combined detention and wet pond		✓	✓	✓	*Section 5.8.9*
Combined detention and wet vault		✓	✓	✓	*Section 5.8.9*
Combined detention and stormwater wetland		✓	✓	✓	*Section 5.8.9*

Oil/Water Separators remove floating and dispersed oil using gravity. Oil/water separators described in this volume include:

BMP	On-site	FC	WQ	Conveyance	Reference
American Petroleum Institute (API baffle type) oil/water separator			✓		*Section 5.8.10*
Coalescing plate (CP) oil/water separator			✓		*Section 5.8.10*

Proprietary and Emerging Water Quality Treatment Technologies consist of technologies that are monitored in the state of Washington through the Technology Assessment Protocol –

Ecology (TAPE) process. Upon completion of a monitoring program, the monitoring data is evaluated by Ecology and the technology may be approved for use for basic treatment, enhanced treatment, oil treatment, and/or phosphorus treatment. The following technologies have received General Use Level Designations (GULD) approval from Ecology at the time of publication and is provided as a reference. This list is subject to change. Refer to Ecology's website for a list of approved stormwater technologies and technologies currently under review (http://www.ecy.wa.gov/programs/WQ/stormwater/newtech/technologies.html).

BMP	On-site	FC	WQ	Conveyance	Reference
Bay Filter			✓		*Section 5.8.11*
ecoStorm plus			✓		*Section 5.8.11*
Filterra			✓		*Section 5.8.11*
FloGard Perk Filter			✓		*Section 5.8.11*
Media Filtration System			✓		*Section 5.8.11*
StormFilter (ZPG Media)			✓		*Section 5.8.11*

CHAPTER 3 – BMP SELECTION & SIZING APPROACH

This chapter describes the steps for selecting appropriate stormwater BMPs. It is organized into three separate sections outlining the process of selecting BMPs to meet the following requirements:

- On-site stormwater management
- Flow control
- Water quality treatment

To determine which of these minimum requirements apply to a project, refer to the 7-step approach in *Volume 1, Chapter 2*. Note that more than one, two, or all of these requirements may apply.

3.1. BMP Selection for On-site Stormwater Management

If the On-site Stormwater Management Requirement is triggered, it can be met by using the On-Site List approach or the On-site Performance Standard approach. The procedures for selecting BMPs under these options are provided below. Selection of BMPs shall build upon site assessment and planning information described in Volume 1, Chapter 7.2 including the requirement to maintain existing trees and native vegetation. Flow control and water quality treatment requirements may also apply (refer to *Sections 3.2 and 3.3*).

3.1.1. On-site List Approach

If the On-site Requirement is triggered (per *Volume 1, Section 4.3.1)* and the On-site List Approach is selected as the method for compliance, follow the steps presented below to select the appropriate GSI BMPs for a given project.

Step 1: Determine if Dispersion and Infiltration are Feasible

Evaluate the general feasibility of dispersion and infiltration BMPs on the project site. Refer to *Appendix C Table C.1, Section 5.3.1 and Section 5.4*. Identify and preserve to the extent feasible areas of the site where dispersion and infiltration are feasible. If infiltration is feasible, determine the design infiltration rate for the native soil (refer to *Section 5.4.1*).

Step 2: Refer to Applicable On-Site List(s)

Identify the On-site List(s) in *Volume 1, Section 5.1* for the project types(s) that apply to the project. The On-site Lists provide GSI BMPs prioritized by category, with Category 1 comprising the highest priority BMPs.

Step 3: Calculate Areas by Surface Type

For each project type, divide the project area into roof areas and all other (i.e., non-roof) impervious surface areas. For surfaces with multiple discharge points (such as roofs with multiple downspouts) divide the surface area into “sub areas” and conduct BMP evaluation for each surface “sub area”.

Step 4: Evaluate BMPs by Category

For each surface area type (i.e., roof or non-roof), evaluate the GSI BMP(s) as described in Steps 5 through 7 below. Consider all GSI BMPs in the first category before moving on to the next category.

Step 5: Evaluate Feasibility of Category 1 BMPs

Determine feasibility of the BMP(s) in Category 1. The BMP is considered infeasible if one of the following applies:

- The BMP is considered infeasible per the “Infeasibility Criteria” provided for the BMP in *Appendix C*, which includes applicable Design Criteria and Site Considerations provided for the BMP in *Chapter 5*.

- Competing needs (e.g., historic preservation laws, health and safety standards) as provided in the *SMC, Section 22.805.070* conflict with the BMP.
- The size of the BMP provided under "On-site List Approach" in *Chapter 5* cannot be met.

Step 6: Select Category 1 BMP(s)

If any of the Category 1 BMPs are feasible for a surface (or surface "sub area"), then a Category 1 BMP must be used to mitigate runoff from the surface (or surface "sub area"). Size the BMPs for the contributing area per the "On-site List Approach" sizing requirements in *Chapter 5*.

Step 7: Document Infeasibility of Category 1 BMPs

If all the Category 1 BMPs are deemed infeasible, infeasibility must be documented. The applicant shall provide a completed On-site List Requirement Infeasibility Criteria Checklist (refer to the tables provided in *Appendix C*) or a narrative description and rationale with substantial evidence sufficient to explain and justify the applicant's conclusion that the GSI BMPs are infeasible.

If there are remaining unmitigated impervious surfaces, proceed to Step 8. If all impervious surface areas are mitigated, go to Step 11.

Step 8: Evaluate/Select Category 2 BMPs

If there are remaining unmitigated impervious surfaces, evaluate the GSI BMPs in Category 2 as explained in Steps 5 through 7.

Step 9: Evaluate/Select Category 3 BMPs

If there are remaining unmitigated impervious surfaces, evaluate the GSI BMPs in Category 3 as explained in Steps 5 through 7.

Step 10: Evaluate/Select Category 4 BMPs (SFR and Parcel-based projects only)

If there are remaining unmitigated impervious surfaces, evaluate the GSI BMPs in Category 4 as explained in Steps 5 through 7.

Step 11: Develop a Soil Amendment Plan

Develop a Soil Amendment Plan to show that soil amendment requirements (*Section 5.1*) will be achieved.

3.1.2. On-site Performance Standard Approach

If the On-site Requirement is triggered and the On-site Performance Standard Approach is selected as the method for compliance, follow the steps presented below to select the appropriate GSI BMPs for a given project.

Step 1: Determine if Infiltration is Feasible

Determine whether infiltration is feasible. If infiltration is feasible, determine the design infiltration rate for the native soil (refer to *Section 5.4.1*).

Step 2: Select BMP(s)

Select a BMP, or multiple BMPs to meet the On-Site Performance Standard. Refer to the General Design Requirements in Chapter 4 for additional requirements that may affect the design and placement of BMPs on the site. Refer to Chapter 5.8.10 of this volume for applicability, site suitability, and design criteria.

Step 3: Use Modeling Approach for BMP design

The Modeling Approach for BMP design must be applied. Refer to *Section 4.1.3* and *Appendix F* for modeling guidelines.

Step 4: Develop a Soil Amendment Plan

Develop a Soil Amendment Plan to show that soil amendment requirements (Section 5.1) will be achieved.

3.2. BMP Selection for Flow Control

If the Flow Control Minimum Requirement is triggered, designers should follow the steps presented below and in Figure 3.1 to select the appropriate flow control BMPs for a given project. On-site stormwater management and water quality treatment requirements may also apply (refer to *Section 3.1 and 3.3*).

Step 1: Determine if Infiltration is Feasible

Determine whether infiltration is feasible. If infiltration is feasible, determine the design infiltration rate for the native soil (refer to *Section 5.4.1*).

Step 2: Determine if Water Quality Treatment requirements also apply

If the Minimum Requirements for Treatment also apply to a project, look for opportunities to use flow control BMPs that can also meet water quality treatment requirements (refer to *Chapter 2* and *Chapter 5* in this volume).

Step 3: Select Flow Control BMP(s)

Select a Flow Control BMP, or multiple BMPs (*refer to Chapter 2*). Refer to the General Design Requirements in *Chapter 4* for additional requirements that may affect the design and placement of BMPs on the site. Refer to *Chapter 5* of this volume for applicability, site suitability, and design criteria.

Step 4: Use Pre-Sized or Modeling Approach for BMP Design

For projects with 10,000 square feet or more new and replaced impervious area, the modeling approach for BMP design must be used (Step 4a). For sites with less than 10,000 square feet new and replaced impervious area, either the pre-sized or modeling approach for BMP design may be used (Steps 4a and 4b).

Step 4a: Use Pre-Sized Approach for BMP design

Apply the Pre-Sized Approach for BMP design (refer to *Section 4.1.2*). The designer may also choose to use the Modeling Approach (refer to Step 3b).

Step 4b: Use Modeling Approach for BMP design

Apply the Modeling Approach for BMP design. Refer to *Section 4.1.3* and *Appendix F* for modeling guidelines.

3.3. BMP Selection for Water Quality Treatment

This section describes the step-by-step process for selecting the type of treatment BMPs that will apply to individual projects, as well as the physical site features that can impact treatment BMP selection. Refer to *Section 3.3.2* for additional detail on BMP selection for the following four performance goals – oil control, phosphorus, enhanced, and basic.

3.3.1. Selection Steps

If one or more Water Quality Minimum Requirements are triggered, designers should follow the steps presented below and in Figure 3.2 to select the appropriate water quality treatment BMPs for a given project. On-site stormwater management and flow control requirements may also apply (refer to *Sections 3.1 and 3.2*).

Step 1: Determine the Associated Pollutants of Concern

- Determine the pollutants of concern through an analysis of the proposed use(s) of the project site. Identify areas of the project site associated with the production of metals, organic compounds, and other toxic wastes that can be entrained in precipitation and runoff (through air pollution or deposition on the ground surface) and ultimately enter receiving waters.

- Determine the potential for high sediment input from runoff containing elevated concentrations of total suspended solids (TSS). Particularly, sites with a large amount of fine-grained particles, such as silt and sand, can clog infiltration and filtration BMPs. High TSS loads can also hinder the function of oil/water separators, especially coalescing plate separator (CPS) systems, if sediment clogs the coalescing plates. Pretreatment to remove TSS is required to extend the maintenance cycle for these systems.

Step 2: Select an Oil Control BMP if Oil Control is Required

If oil control is required (refer to *Volume 1, Section 5.3.2.2*), select an Oil Control BMP using the list in Figure 3.2 and the information in *Section 3.3.2.1*. Refer to the General Design Requirements in *Chapter 4* for additional requirements that may affect the design and placement of BMPs on the site (e.g., flow splitting). Refer to *Section 5.8.10* of this volume for design information.

Step 3: Determine if Infiltration is Feasible

Determine whether infiltration is feasible (refer to *Section 5.4.1*). If infiltration is feasible, determine the design infiltration rate for the native soil, and select and apply pretreatment and infiltration BMPs *(*refer to Figure 3.1*)*.

Step 4: Select a Phosphorus Treatment BMP if Phosphorus Treatment is Required

At the time this manual was developed, there were no established phosphorus-specific treatment requirements for project-scale treatment BMPs in Seattle. However, if phosphorus treatment is required (refer to *Volume 1, Section 5.3.2.3*), select a Phosphorus Treatment BMP using the list in Figure 3.2 and the information in *Section 3.3.2.2*. If a project site is also

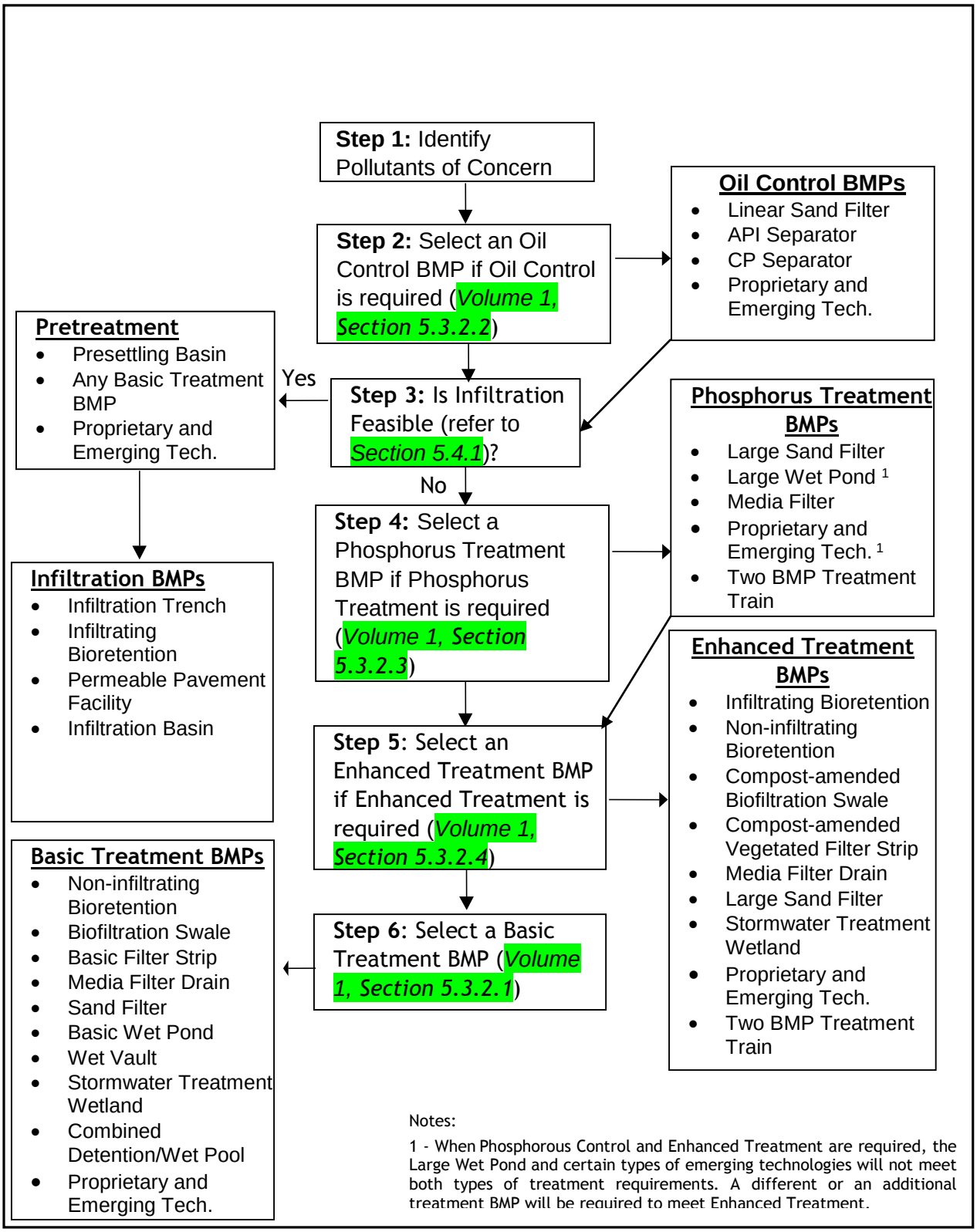


Figure 3.1. Treatment BMP Selection Flow Chart.

subject to the enhanced treatment requirement, select a BMP or treatment train that is listed as providing both Enhanced Treatment and Phosphorus Treatment. Refer to the General Design Requirements in *Chapter 4* for additional requirements that may affect the design and placement of BMPs on the site (e.g., flow splitting). Refer to *Chapter 5* of this volume for applicability, site suitability, and design criteria.

Step 5: Select an Enhanced Treatment BMP if Enhanced Treatment is Required

If enhanced treatment is required (refer to *Volume 1, Section 5.3.2.4*), select an Enhanced Treatment BMP using the list in Figure 3.2 and the information in *Section 3.3.2.3*. If a project site is also subject to the phosphorus treatment requirement, select a BMP or treatment train that is listed as providing both Enhanced Treatment and Phosphorus Treatment. Refer to the General Design Requirements in *Chapter 4* for additional requirements that may affect the design and placement of BMPs on the site. Refer to *Chapter 5* of this volume for applicability, site suitability, and design criteria.

Step 6: Select a Basic Treatment BMP

If the Water Quality Treatment Minimum Requirement is triggered (refer to *Volume 1, Chapters 2* and *5*) and the criteria for Phosphorus Treatment and Enhanced Treatment do not apply (refer to *Volume 1, Section 5.3.2.3* and *5.3.2.4)*, then only basic treatment is required. Select a Basic Treatment BMP using the list in Figure 3.1 and the information in *Section 3.3.2.4*. Refer to the General Design Requirements in *Chapter 4* for additional requirements that may affect the design and placement of BMPs on the site. Refer to *Chapter 5* of this volume for applicability, site suitability, and design criteria.

3.3.2. Treatment Performance Goals and BMP Options

This section identifies choices that meet the treatment BMP categories referred to in *Section 3.3.1*. The treatment BMP categories in this section are discussed in the order of the decision process outlined in Figure 3.1 and include the following:

- Oil Control Treatment, Section 3.3.2.1
- Phosphorus Treatment, Section 3.3.2.2
- Enhanced Treatment, Section 3.3.2.3
- Basic Treatment, Section 3.3.2.4

3.3.2.1. Oil Control Treatment

Performance Goal: Oil Control Treatment BMPs are designed to achieve the following:

- No ongoing or recurring visible sheen
- A 24-hour average Total Petroleum Hydrocarbon (TPH) concentration no greater than 10 mg/l
- A maximum of 15 mg/l for a discrete sample (grab sample)

Note: For the analysis of most petroleum products, use the NWTPH-Dx method in Ecology Publication No. ECY 97-602, Analytical Methods for Petroleum Hydrocarbons. If the concentration of gasoline is of interest, use the NWTPH-Gx method to analyze grab samples.

BMP Options: Any one of the following BMP options may be selected to satisfy the oil control requirement:

- Linear Sand Filter (refer to Section 5.8.5)
- API-Type Oil/Water Separator (refer to Section 5.8.10)
- Coalescing Plate Oil/Water Separator (refer to *Section 5.8.10*)
- Proprietary and Emerging Stormwater Treatment Technologies (refer to *Section 5.8.11*)

Note: The linear sand filter is also used for basic, enhanced, and phosphorus treatment. If used to satisfy one of those treatment requirements, do not use the same BMP to satisfy the oil control requirement unless increased maintenance (quarterly cleaning) is assured. This increase in maintenance is to prevent clogging of the filter by oil so that it will function for suspended solids, metals, and phosphorus removal as well.

3.3.2.2. Phosphorus Treatment

Performance Goal: Phosphorus Treatment BMPs are designed to achieve 50 percent total phosphorus (TP) removal for a range of influent concentrations of 0.1 to 0.5 mg/l. In addition, the Phosphorus Treatment BMPs are designed to achieve Basic Treatment.

BMP Sizing: The BMP should be sized using either the water quality design storm volume or flow rate, whichever is applicable, on an annual average basis (refer to *Appendix F*). The incremental portion of runoff in excess of the water quality design flow rate or volume can be routed around the BMP (offline treatment facilities), or can be passed through the BMP (on-line treatment BMPs) provided a net pollutant reduction is maintained (refer to *Appendix F*). Offline facilities are recommended to prevent resuspension and washout of accumulated phosphorus during large storm events.

BMP Options: Any one of the following options may be chosen to satisfy the Phosphorus Treatment requirement:

- Infiltration with appropriate presettling – refer to *Section 5.4.1*
    - Infiltration treatment:

      If infiltration is through soils that meet the soil suitability criteria for infiltration treatment (refer to *Section 5.4.1*), a presettling basin or a basic treatment BMP can serve for pretreatment.

    - Infiltration preceded by Basic Treatment:

      If infiltration is through soils that do not meet the soil suitability criteria for infiltration treatment (refer to *Section 5.4.1*), treatment must be provided by a

basic treatment BMP unless the soil and site fit the description in the next option below.

- Infiltration preceded by Phosphorus Treatment:

  If the infiltration soils do not meet the soil suitability criteria for infiltration treatment (refer to *Section 5.4.1*) and the infiltration site is within 1/4 mile of a nutrient-critical receiving water, or a tributary to that water, treatment must be provided by one of the other treatment BMP options listed below.

- Media Filter Drain – refer to *Section 5.8.4* or the WSDOT *Highway Runoff Manual* (http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm)
- Large Sand Filter – refer to Section 5.8.5
- Large Wet Pond – refer to Section 5.8.6
- Proprietary and Emerging Stormwater Treatment Technologies targeted for phosphorus removal - refer to *Section 5.8.11*
- Two-BMP Treatment Trains – refer to Table 3.1

Table 3.1. Treatment Trains for Phosphorus Treatment.

First Basic Treatment BMP	Second Treatment BMP
Biofiltration Swale (*Section 5.8.3*)	Basic Sand Filter or Sand Filter Vault (*Section 5.8.5*)
Filter Strip (*Section 5.8.4*)	Linear Sand Filter (*Section 5.8.5*), no presettling needed
Linear Sand Filter (*Section 5.8.5*)	Filter Strip (*Section 5.8.4*)
Basic Wet Pond (*Section 5.8.6*)	Basic Sand Filter or Sand Filter Vault (*Section 5.8.5*)
Wet Vault (*Section 5.8.7*)	Basic Sand Filter or Sand Filter Vault (*Section 5.8.5*)
Stormwater Treatment Wetland (*Section 5.8.8*)	Basic Sand Filter or Sand Filter Vault (*Section 5.8.5*)
Basic Combined Detention and Wet Pool (*Section 5.8.9*)	Basic Sand Filter or Sand Filter Vault (*Section 5.8.5*)

3.3.2.3. Enhanced Treatment

Performance Goal: Enhanced Treatment BMPs are designed to greater than 30 percent dissolved copper removal and greater than 60 percent dissolved zinc removal. The performance goal assumes that the Enhanced Treatment BMP is treating stormwater with dissolved copper typically ranging from 5 to 20 µg/l, and dissolved zinc ranging from 20 to 300 µg/l. In addition, the Enhanced Treatment BMPs are designed to achieve Basic Treatment.

BMP Sizing: The BMP should be sized using either the water quality design storm volume or flow rate, whichever is applicable, on an annual average basis (refer to *Section 4.1*). The incremental portion of runoff in excess of the water quality design flow rate or volume can be routed around the BMP (offline treatment BMPs), or can be passed through the BMP (on-line

treatment BMPs) provided a net pollutant reduction is maintained (refer to *Section 4.2*). Where possible, offline BMPs are recommended to prevent resuspension and washout of accumulated sediment and other particulate-bound pollutants during large storm events.

BMP Options: Any one of the following options may be chosen to satisfy the Enhanced Treatment requirement:

- Infiltration with appropriate presettling – refer to *Section 5.4.1*:
    - Infiltration treatment:

      If infiltration is through soils meeting the minimum criteria for infiltration treatment (refer to *Section 5.4.1*), a presettling basin or a basic treatment BMP can serve for pretreatment.

    - Infiltration preceded by Basic Treatment

      If infiltration is through soils that do not meet the soil suitability criteria for infiltration treatment (refer to *Section 5.4.1*), treatment must be provided by a basic treatment BMP unless the soil and site fit the description in the next option below.

    - Infiltration preceded by Enhanced Treatment

      If the soils do not meet the soil suitability criteria for infiltration treatment (refer to *Section 5.4.1*) and the infiltration site is within 1/4 mile of a fresh water designated for aquatic life use or that has an existing aquatic life use, treatment must be provided by one of the other treatment BMP options listed below.

      Note: Bioretention systems that are constructed using the soil mix specified in *Section 5.4.1* will qualify as Enhanced Treatment, provided that these systems are designed to pass at least 91 percent of the total runoff volume (as determined using an approved continuous runoff model) through the imported soil mix. Catch basins or forebays may be used as pretreatment for bioretention facilities to reduce the potential for clogging of the bioretention soil media.

- Non-infiltrating Bioretention – refer to *Section 5.8.2*
- Compost-amended biofiltration swale – refer to *Section 5.8.4*
- Compost-amended Vegetated Filter Strip (CAVFS) – refer to *Section 5.8.4*
- Media Filter Drain – refer to *Section 5.8.4* or the WSDOT *Highway Runoff Manual* (http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm)
- Large Sand Filter – refer to Section 5.8.5

- Stormwater Treatment Wetland – refer to Section 5.8.8
- Proprietary and Emerging Stormwater Treatment Technologies - refer to *Section 5.8.11*
- Two BMP Treatment Trains – refer to Table 3.2

Table 3.2. Treatment Trains for Enhanced Treatment.

First Basic Treatment BMP	Second Treatment BMP
Biofiltration Swale (*Section 5.8.3*)	Basic Sand Filter, Sand Filter Vault, or Media Filter[a] (*Section 5.8.5*)
Filter Strip (*Section 5.8.4*)	Linear Sand Filter with no presettling cell needed (*Section 5.8.5*)
Linear Sand Filter (*Section 5.8.5*)	Filter Strip (*Section 5.8.4*)
Basic Wet Pond (*Section 5.8.6*)	Basic Sand Filter, Sand Filter Vault, or Media Filter[a] (*Section 5.8.5*)
Wet Vault (*Section 5.8.7*)	Basic Sand Filter, Sand Filter Vault, or Media Filter[a] (*Section 5.8.5*)
Basic Combined Detention/Wet Pool (*Section 5.8.9*)	Basic Sand Filter, Sand Filter Vault, or Media Filter[a] (*Section 5.8.5*)
Basic Sand Filter or Sand Filter Vault with a presettling cell if the filter is not preceded by a detention BMP (*Section 5.8.5*)	Media Filter[a] (*Section 5.8.5*)

[a] The media must be of a type approved for basic or enhanced treatment use by Ecology and accepted by the Director.

3.3.2.4. Basic Treatment

Performance Goal: Basic Treatment BMPs are designed to achieve 80 percent removal of TSS for influent concentrations greater than 100 mg/l, but less than 200 mg/l. For influent concentrations greater than 200 mg/l, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/l, the BMPs are designed to achieve an effluent goal of 20 mg/l TSS.

BMP Sizing: The BMP should be sized using either the water quality design storm volume or flow rate, whichever is applicable (refer to *Section 4.1*). The performance goal applies an average annual basis to the entire annual discharge volume (treated plus bypassed). The incremental portion of runoff in excess of the water quality design flow rate or volume can be routed around the BMP (offline treatment BMPs), or can be passed through the BMP (on-line treatment BMPs) provided a net TSS reduction is maintained (refer to *Section 4.2*).

BMP Options: Any one of the following options may be chosen to satisfy the basic treatment requirement:

- Infiltration Trench – refer to *Section 5.4.2*
- Infiltrating Bioretention – refer to *Section 5.4.4*
- Permeable Pavement Facility – refer to *Section 5.4.6*
- Infiltration Basin – refer to *Section 5.4.8*

- Non-infiltrating Bioretention – refer to *Section 5.8.2*
- Biofiltration Swales – refer to *Section 5.8.3*
- Basic Filter Strip – refer to *Section 5.8.4*
- Compost-amended Vegetated Filter Strip (CAVFS) – refer to *Section 5.8.4*
- Media Filter Drain – refer to *Section 5.8.4* or the WSDOT *Highway Runoff Manual* (http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm)
- Sand Filters – refer to *Section 5.8.5*
- Basic Wet Pond – refer to *Section 5.8.6*
- Wet Vault – refer to *Section 5.8.7*
- Stormwater Treatment Wetland – refer to *Section 5.8.8*
- Combined Detention and Wet Pool – refer to *Section 5.8.9*
- Proprietary and Emerging Stormwater Treatment Technologies – refer to *Section 5.8.11*

CHAPTER 4 – GENERAL DESIGN REQUIREMENTS

This chapter describes general design requirements for the following:

- Sizing approach
- Bypass
- Conveyance
- Pretreatment requirements

4.1. Sizing Approach

This section describes the sizing approach for the following:

- **On-site List Approach**: to meet the On-site Stormwater Management requirement
- **Pre-Sized Approach**: flow control credits, BMP sizing factors, and BMP sizing equations to meet flow control or water quality treatment requirements for small projects
- **Modeling Approach**: continuous modeling approach to meet the on-site performance standard, a specific flow control standard, or a water quality treatment requirement

4.1.1. On-site List Approach

Under the On-site List Approach, the On-site Stormwater Management Requirement may be met by selecting from a prioritized list of GSI BMPs as explained in *Section 3.1.1*. List BMPs must be sized as prescribed under the "On-site List Approach" in *Chapter 5*.

4.1.2. Pre-Sized Approach

The Pre-Sized Approach may be used to select and size flow control and water quality treatment BMPs without performing continuous modeling when the following conditions have been met:

- The new and replaced impervious surface associated with a project does not exceed 10,000 square feet, and
- The project is subject to the Pre-developed Pasture Standard, the Peak Control Standard and/or a treatment standard

4.1.2.1. Pre-Sized Facilities

The BMPs included in the Pre-Sized Approach include the following:

BMP Category and Name	Type of Credit	Applicable Standards
Runoff Reduction BMPs		
Tree Planting and Retention	Flow Control Credit	FC
Downspout Dispersion	Flow Control Credit	FC
Sheet Flow Dispersion	Flow Control Credit	FC
Infiltration BMPs		
Infiltrating Bioretention	BMP Sizing Factor	FC, WQ
Permeable Pavement Facilities	BMP Sizing Factor	FC, WQ
Infiltration Trenches	BMP Sizing Factor	FC, WQ
Dry Wells	BMP Sizing Factor	FC
Alternative Surface BMPs		
Vegetated Roofs	Flow Control Credit	FC
Permeable Pavement Surfaces	Flow Control Credit	FC
Reuse BMPs		
Rainwater Harvesting		FC
Detention BMPs		
Detention Pipe	BMP Sizing Equation	FC
Detention Vault	BMP Sizing Equation	FC
Detention Cistern (aboveground)	BMP Sizing Equation	FC
Non-infiltrating BMPs		
Non-infiltrating Bioretention	BMP Sizing Factor	FC, WQ

Specific design requirements for the pre-sized BMPs (e.g., side slopes, freeboard, aggregate thickness, soil depth) are provided in the "BMP Credit" or "BMP Sizing" sections in *Chapter 5*.

4.1.2.2. Pre-Sized Credits

The benefits of the pre-sized BMPs are provided as either a flow control credit, BMP sizing factor, or BMP sizing equation. These are described below.

- **Flow Control Credits:** Flow control credits are awarded for BMPs that reduce effective impervious surface areas. The credited area may be excluded from drainage calculations used for flow control. Note: This applies to flow control calculations only. If a site is also subject to water quality treatment requirements, calculations for water quality must also be performed.

- **BMP Sizing Factors:** BMPs may be sized using the sizing factors provided in *Chapter 5*. The sizing factors can be used to calculate the BMP size as a function of the contributing area. These sizing factors were developed using a continuous runoff hydrologic model to achieve applicable flow control and water quality treatment standards. For BMPs with variable allowable depths, sizing factors are provided for at

least two typical depths. Designers may linearly interpolate BMP size for intermediate design depths, but may not extrapolate.

- **BMP Sizing Equations:** Detention BMPs may be sized using the sizing equations provided in *Chapter 5*. Sizing equations were developed using a continuous runoff hydrologic model to achieve applicable flow control and water quality treatment standards.

For each BMP, flow control credits or sizing factors were developed for typical design variations (e.g., ponding depths, aggregate thickness, slopes, etc.). To use these BMPs with a different design configuration or BMPs not listed above, the designer must use the Modeling Approach (refer to *Section 4.1.3*).

When using the sizing factors or sizing equations for water quality treatment, stormwater flows from other areas (beyond the area for which the facility is sized) must be bypassed around the facility. When using the sizing factors or sizing equations for flow control, the maximum area that may be routed to a pre-sized BMP must not exceed twice the area for which it is sized. No flow control credit is given for runoff from areas beyond the design area. If additional runoff is routed to a BMP, it must be clearly noted on submitted plans and the overflow infrastructure requires engineering design for the full area (refer *Section 4.3.3*).

BMP sizing factors and equations were developed for the City's Pre-developed Pasture and Peak Control standards. If both standards apply to a project (such as a site in a non-listed creek basin with a capacity constrained drainage system), the larger BMP size or conservative flow control credit must be used. A Pre-Sized Approach was not developed for the Pre-developed Forest Standard because it is not triggered as often as the other flow control standards.

Generalized assumptions were used to design the pre-sized BMPs that may result in conservative sizing or may underestimate flow control or treatment credits for some sites. Refer to "BMP Credit" or "BMP Sizing" sections in *Chapter 5* for modeling assumptions used in the Pre-Sized Approach. Designers have the option to use the pre-sized BMPs provided in this section, or to follow the Modeling Approach (refer to *Section 4.1.3*) and submit an alternative BMP size with supporting engineering calculations for review and consideration.

4.1.2.3. Pre-Sized Calculator

An Excel-based "Pre-Sized Calculator" is provided on DPD stormwater code website. This calculator automates sizing calculations (i.e., the flow control credits, BMP sizing factors and BMP sizing equations described above) and guides the applicant through the process of selecting BMPs. This calculator may be provided as part of a plan submittal to document compliance with flow control and/or treatment standards.

4.1.3. Modeling Approach

Unless otherwise specified, all continuous modeling must be performed using the City of Seattle Design Time Series consisting of a 158-year precipitation and evaporation time series that are representative of the climatic conditions in the City of Seattle. Continuous simulation methods and a list of approved continuous simulation models are provided in *Appendix F*.

4.1.3.1. On-site Performance Standard

As an alternative to the On-site List Approach (*Section 4.1.1*), the On-site Requirement can be met by demonstrating that the On-site Performance Standard (*Volume 1, Section 5.1)* is achieved. Under the Modeling Approach, On-site BMPs are designed to achieve the On-site Performance Standard using a continuous rainfall-runoff model. Specific modeling requirements are presented in the "BMP Credit" or "BMP Sizing" section for each BMP. For compliance with the On-site Performance Standard, it must be demonstrated that the suite of BMPs used on the site results in the standard being met at the point of discharge.

Note: Retained and newly planted trees receive flow control credits to reduce the impervious surface area requiring flow control (refer to *Section 5.2.1*). The impervious area mitigated by these BMPs is subtracted from the drainage area entered into the continuous model.

4.1.3.2. Flow Control

The Modeling Approach may be used for any project to design flow control BMPs, and is required for the following scenarios:

- Projects with new and replaced impervious surface equal to or exceeding 10,000 square feet that trigger a Flow Control Standard
- Projects with new and replaced impervious surface less than 10,000 square feet that are proposing to use different assumptions that those used in the Pre-Sized Approach

Under the Modeling Approach, flow control BMPs are designed to achieve flow control standards using a continuous rainfall-runoff model. Specific modeling requirements are presented in the "BMP Sizing" or "Flow Control Credit" section for each BMP. The BMPs used to meet the On-site List or the On-site Performance Standard may be included in the model and may contribute towards meeting the flow control standard(s), if applicable. When using the Modeling Approach, it must be demonstrated that the suite of BMPs used on the site results in the standard(s) being met at the point of discharge.

Note: Retained and newly planted trees receive flow control credits to reduce the impervious surface area requiring flow control (refer to *Section 5.2.1*). The impervious area mitigated by these BMPs is subtracted from the drainage area entered into the continuous model.

4.1.3.3. Water Quality Treatment

The Modeling Approach may be used for any project to design water quality treatment BMPs, and is required for the following scenarios:

- Projects with new and replaced impervious surface equal to or exceeding 10,000 square feet that trigger a Treatment Standard
- Projects with new and replaced impervious surface less than 10,000 square feet that are proposing to use different assumptions that those used in the Pre-Sized Approach

Under the Modeling Approach, water quality treatment BMPs are designed to treat a specific water quality design storm volume or flow rate (refer to *Volume 1, Section 5.3.1* and *Appendix F)* using a continuous rainfall-runoff model. Specific modeling requirements are

presented in the "BMP Sizing" section for each BMP. The BMPs used to meet the On-site List or the On-site Performance Standard may be included in the model and may contribute towards meeting the treatment standard, if applicable.

4.2. Bypass General Design Requirements

4.2.1. On-line vs. Offline Systems

Most non-infiltrating BMPs can be designed as on-line systems with flows above the water quality design flow or volume simply passing through the BMP with lesser or no pollutant removal efficiency. However, it is sometimes desirable to restrict flows to non-infiltrating BMPs and bypass the remaining higher flows around them. These are called offline systems.

Treatment BMPs located upstream of a detention system can be designed as online or offline BMPs.

- On-line BMPs: Runoff flow rates in excess of the water quality design flow rate can be routed through the BMP provided a net pollutant reduction is maintained, and the applicable annual average performance goal is likely to be met.
- Offline BMPs: For non-infiltrating BMPs not preceded by an equalization or storage basin, flows exceeding the water quality design flow rate may be bypassed around the treatment BMP. However, during bypass events, the facility must continue to receive and treat the water quality design flow rate. Only the higher incremental portion of flow rates are bypassed around a treatment BMP. Design guidelines for flow splitters for use in offline BMPs are provided in *Appendix E*.

Non-infiltrating BMPs preceded by an equalization or storage basin may identify a lower water quality design flow rate provided that at least 91 percent of the total runoff volume predicted by an approved continuous runoff model is treated to the applicable performance goals (e.g., 80 percent TSS removal at the water quality design flow rate and 80 percent TSS removal on an annual average basis).

4.2.2. Bypassing Flows Entering or Leaving a Project Site

The following three flow bypass-related scenarios require that additional considerations be taken into account when designing BMPs (refer to also *Appendix E* for design guidelines for flow splitters):

1. Flow currently enters the project site, but can be bypassed as part of the proposed project improvements.
2. Flow currently enters the project site, but cannot be bypassed as part of the proposed project improvements.
3. Flow that is within the project limits cannot feasibly be routed to the project BMP.

The requirements and guidelines applicable to each scenario are outlined below.

4.2.2.1. Scenario 1 – Managing Flows Entering a Project Site

Flows may bypass flow control and treatment BMPs if all of the following conditions are met:

- Natural drainage courses are maintained.
- Existing flows to wetlands are maintained (refer to *Volume 1, Section 5.2.1*).
- Peak flows are not increased by bypassing.
- The point of discharge does not adversely impact down gradient properties.

4.2.2.2. Scenario 2 – Managing Flows Entering a Project Site

When flows cannot feasibly bypass proposed flow control BMPs, the flow control BMPs must be modeled and sized to handle the combined total flow (i.e., total volume, overflow design). However, the allowable discharge rates must be determined by the Minimum Requirements applicable to runoff from the project site only.

When flows cannot feasibly bypass proposed treatment BMPs, the treatment BMPs must be sized for the combined total flow.

4.2.2.3. Scenario 3 – Uncontrolled Flows Leaving the Project Site

Runoff from a project that cannot feasibly be routed to the proposed flow control or treatment BMPs may be bypassed under one of the following conditions:

- When the proposed flow control and treatment BMPs are designed to manage uncontrolled flow and meet the applicable minimum requirements for the project
- When the bypass area is due to incidental grading to match surrounding roadways or properties, and is less than 1,000 square feet and will not create significant adverse impacts to down gradient properties

4.3. Conveyance General Design Requirements

4.3.1. Conveyance Design and Capacity Analysis

For design or capacity analysis of the public drainage system, early consultation with Seattle Public Utilities is recommended. Client Assistance Memo (CAM) 1180 describes "Design Guidelines for Public Storm Drain Facilities". Requirements and recommendations for Hydrologic Analysis and Design are in *Appendix F*.

4.3.2. Approved Point of Discharge

All projects must convey stormwater flow to an approved point of discharge and include overflows for all stormwater BMPs. The approved point of discharge must, at a minimum, maintain natural drainage patterns to the maximum extent feasible.

The approved point of discharge, in order of preference, includes:

- Surface waters

- Public storm drain pipes
- Ditch and culvert system
- Public combined sewer pipes

The types of conveyance systems to the approved point of discharge, in order of preference, includes:

- Direct pipe connections
- Ditch and culvert system
- Gutter or street flow line
- Surface dispersal

4.3.3. Overflow Requirements

Overflows are critical to minimize flooding and protect the downstream conveyance system, receiving water, and downstream properties. Overflow options include the following:

- Approved point of discharge (refer to *Section 4.3.2*)
- Through interflow to the surface
- To surface discharge
- Combination of these measures

Overflow conveyance options include the following:

- Piped
- Daylighted through a storage reservoir
- Distributed through a flow spreader (refer to *Appendix E*)
- Discharged through overtopping of the BMP

Plans must indicate all flow paths. At a minimum, overflows must be designed to convey peak flows with a 4 percent annual probability (25-year recurrence interval flows). Designers are recommended to consider flooding and nuisance ponding risks associated with larger peak flows. During large storm events, capacity will be limited at the approved point of discharge and backwater calculations may be required.

For dispersion BMPs and for infiltration BMPs designed to fully infiltrate all flows for the 158-year simulation period, a constructed overflow is not required. Plans must indicate surface flow paths in case of failure of the BMP.

4.3.3.1. SFR and Small Project Discharge and Overflow Requirements

The priorities for the approved point of discharge from SFR projects and small projects (less than 5,000 square feet of new and replaced impervious surface) are dependent on the type of infrastructure available.

In sanitary sewer only areas:

1. If a property fronts an open water body or creek, direct discharge is the preferred option.
2. Near-side public storm drain (PSD)/culvert
3. Weep hole (per the Side Sewer Director's Rule)
4. Alley (per the Side Sewer Director's Rule)
5. Far-side PSD/culvert
6. On-site infiltration (refer to SPU procedure 202.8 Small Project Standard for On-Site Infiltration)
7. If in an Environmentally Critical Area (ECA) and infiltration is not feasible due to a geotechnical evaluation, or if full infiltration cannot be achieved (refer to SPU procedure 202.8 Small Project Standard for On-Site Infiltration), then a drainage system extension is required.

Note: The decision to discharge through a curb weep hole (#3 above) or to an alley (#4 above) can be determined by site grade/pumping needs.

In combination combined sewer and drainage system areas without a storm drain or culvert fronting the property:

1. Weep hole (per the Side Sewer Director's Rule)
2. Alley (per the Side Sewer Director's Rule)
3. Overflow tight lined to combined sewer

Note: The decision to discharge through a curb weep hole (#1 above) or to an alley (#2 above) can be determined by site grade/pumping needs.

In combined sewer only areas:

1. Overflow tight lined to combined sewer

4.3.3.2. Overflow Requirements for Sites with No Available Point of Discharge

Specific overflow requirements have been established for small projects (less than 5,000 sf of new plus replaced impervious surface) that have no available point of discharge. On-site infiltration BMPs, whether as the solitary point of discharge, or as the overflow from an GSI

BMP, must be designed to infiltrate the runoff volume from the area of development for the storm event with a 4 percent annual probability (25-year recurrence interval flow).

In sanitary sewer only areas:

1. Overflow to an infiltration BMP if full infiltration can be achieved (refer to SPU procedure 202.8 Small Project Standard for On-Site Infiltration).

2. If in an ECA and infiltration is not feasible due to geotechnical evaluation, or if full infiltration cannot be achieved (refer to SPU procedure 202.8 Small Project Standard for On-Site Infiltration) then a drainage system extension is required.

One option for a small project overflow scenario consists of an infiltration BMP (i.e., infiltration trench or drywell) situated downstream of a bioretention cell or a permeable pavement facility sized to infiltrate storms up to the conveyance standard (25-year recurrence interval flow).

4.4. Pretreatment Requirements

4.4.1. Description

Pretreatment is essential to effective long-term facility performance. Pretreatment facilities generally fall into three categories:

1. Presettling basins: A vault or pond that is located upstream of a flow control or water quality treatment facility and is intended to collect sediment that could otherwise clog or impair the function of the primary facility. For a constructed wetland or other pond or basin facility, the presettling basin will typically consist of a presettling cell.

   Note: Presettling for infiltration BMPs (other than infiltration basins) have specific design requirements that differ from standard presettling basins. These design requirements are discussed in *Section 5.4.1*.

2. Hydrodynamic separators: Flow-through structures with a settling or separation unit to remove sediments and particle-bound pollutants. The facility name refers to the application of the energy of flowing water to facilitate sediment separation and removal. Depending on the type of unit, particle settling may occur by means of swirl action or indirect filtration.

3. Floatables capture: Facilities designed to trap floating oils and debris before it enters a primary treatment facility.

4.4.2. Performance Mechanisms

Where the primary performance mechanism of a treatment facility is biofiltration, infiltration, or settling; excessive sediment can reduce the effectiveness over time by reducing stormwater contact with vegetation or clogging sands and other filtration media. Pretreatment protects facilities from excessive siltation and debris through settling to remove TSS prior to discharging to the primary BMP. The primary performance mechanism for

hydrodynamic separators is to use the energy of flowing water to separate solids from stormwater.

4.4.3. Applicability

Pretreatment must be provided in the following applications:

- For sand filters, media filters, and infiltration basins to protect them from excessive siltation and debris
- Where the basic treatment facility or the receiving water may be adversely affected by non-targeted pollutants (e.g., oil), or may by overwhelmed by a heavy load of targeted pollutants (e.g., suspended solids)

When water quality treatment is required, runoff treated by a pretreatment facility may not be discharged directly to a receiving water; it must be further treated by a basic or enhanced water quality treatment facility.

Refer to Ecology's website for a list of approved stormwater technologies and technologies currently under review for pretreatment (http://www.ecy.wa.gov/programs/WQ/stormwater/newtech/technologies.html).

4.4.4. Site Considerations

Refer to BMP T6.10 – Presettling Basin in Volume V of the Stormwater Management Manual for Western Washington (Ecology 2012) (SWMMWW) for site considerations related to presettling basins. Additional site considerations may apply depending on site conditions and other factors. Refer to manufacturer guidance for site considerations for hydrodynamic separators and floatables capture.

4.4.5. Design Criteria

Refer to BMP T6.10 – Presettling Basin in Volume V of the SWMMWW for presettling basin design criteria. In addition to Ecology's criteria, the City has also developed the following specific design criteria:

- Provide 1 foot minimum sediment storage depth.
- Provide 1 foot minimum freeboard (above the design water surface elevation).
- Line the presettling basin if the runoff will be in direct contact with the soil in accordance with the provisions in *Appendix E*.

Refer to manufacturer guidance for design criteria for hydrodynamic separators and floatables capture.

4.4.6. Operations and Maintenance Requirements

Pretreatment facility operations and maintenance requirements are provided in *Appendix G* for Media Filters, Infiltration Basins, Biofiltration Swales, Filter Strips, Ponds, and Constructed Wetlands.

Refer to Ecology's website and the manufacturer's website for facility-specific maintenance requirements for hydrodynamic separators (http://www.ecy.wa.gov/programs/WQ/stormwater/newtech/technologies.html).

CHAPTER 5 – BMP DESIGN

For each BMP in this chapter, detailed technical information is organized as follows:

- **Description**: provides a description of the BMP and each of the BMP configurations
- **Performance Mechanisms**: defines how pollutants are removed (treatment mechanisms) and/or how stormwater discharge is managed (flow control mechanisms)
- **Applicability**: lists the BMP configurations that can be designed to meet the requirements for on-site stormwater management, flow control, water quality treatment (basic, enhanced, oil control, phosphorus), and/or conveyance
- **Site Considerations**: identifies the limitations associated with siting each BMP. The application of a BMP may be constrained by factors such as approximate footprint, groundwater elevation, soil characteristics, and other site-specific conditions. The intention is to allow the designer to quickly evaluate whether a proposed BMP might be suitable for a particular site or project.
- **Design Criteria**: provides descriptions and specifications for BMP components and materials
- **BMP Sizing**: presents sizing requirements and modeling procedures for each BMP. General modeling guidance is provided in *Appendix F*.
- **Minimum Construction Requirements**: describe critical considerations during construction of the BMP, such as erosion control, landscape stabilization, and timing of BMP installation
- **Operations and Maintenance Requirements**: provide a reference to the operations and maintenance (O&M) requirements included in *Appendix G*

5.1. Soil Amendment BMP

5.1.1. Description

Site soils must meet minimum quality and depth requirement at project completion. Requirements may be achieved by either retaining and protecting undisturbed soil or restoring the soil (e.g., amending with compost) in disturbed areas.

Additional guidance for this BMP can be found in Seattle *Tip 531: Post Construction Soil Management* and *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13* (Stenn et al. 2012), which is available at http://www.buildingsoil.org.

5.1.2. Performance Mechanisms

Naturally occurring (undisturbed) soil, soil organisms, and vegetation provide the following important stormwater management functions:

- Water infiltration
- Nutrient, sediment, and pollutant adsorption
- Sediment and pollutant biofiltration
- Water interflow storage and transmission
- Pollutant decomposition

These functions are largely lost when development strips away native soil and vegetation and replaces it with minimal soil and sod. Not only are these important stormwater management functions lost, but such landscapes themselves can become pollution-generating pervious surfaces due to compaction; increased use of pesticides, fertilizers, and other landscaping and household/industrial chemicals; the concentration of pet wastes; and pollutants that accompany roadside litter.

Soil amendment requirements help to regain greater stormwater functions in the post development landscape, provide increased treatment of pollutants and sediments that result from development and habitation, and minimize the need for some landscaping chemicals; thus, reducing pollution through prevention.

5.1.3. Applicability

The soil amendment BMP can be used to help achieve on-site stormwater management and flow control. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Soil Amendment	✓[a]	✓[a]	✓[b]	✓[b]	✓[b]					

[a] Soil amendment BMP must be used to meet on-site stormwater management standards for pervious areas.

[b] Soil amendment BMP may be used to meet flow control standards for pervious areas, and for impervious areas when integrated into dispersion facility design (refer to *Section 5.3*).

5.1.4. Site Considerations

At project completion, meet soil amendment requirements for all areas subject to clearing, grading, or compaction that have not been covered by impervious surface, incorporated into a drainage facility, or engineered as structural fill or slope. Only the areas where existing vegetation and/or soil are disturbed or compacted must be restored.

5.1.5. Design Criteria

This section describes the implementation options and design requirements for the soil amendment BMP. Typical cross-sections of compost-amended soil in planting bed and turf applications are shown in Figure 5.1.Design criteria are provided in this section for the following elements:

- Implementation options
- Soil retention
- Soil quality
- Soil Amendment Plan

5.1.5.1. Implementation Options

The soil quality design requirements can be met by using one of the four options listed below:

1. Retain and Protect Undisturbed Soil:
    - Leave undisturbed vegetation and soil, and protect from compaction by fencing and keeping materials storage and equipment off these areas during construction.
    - For all areas where soil or vegetation are disturbed, use option 2, 3, or 4.
2. Amend Soil:
    - Amend existing site topsoil or subsoil either at default “pre-approved” rates, or at custom calculated rates to meet the soil quality guidelines based on

engineering tests of the soil and amendment. The default pre-approved rates are:

- In planting beds: place 3 inches of compost and till in to an 8 inch depth.
- In turf areas: place 1.75 inches of compost and till in to an 8 inch depth.
- Scarify (loosen) subsoil 4 inches below amended layer to produce a 12-inch depth of un-compacted soil.
- After planting: apply 2 to 4 inches of arborist wood chip or compost mulch to planting beds. Coarse bark mulch may be used but has lower benefits to plants and soil. Do not use fine bark because it can seal the soil surface.

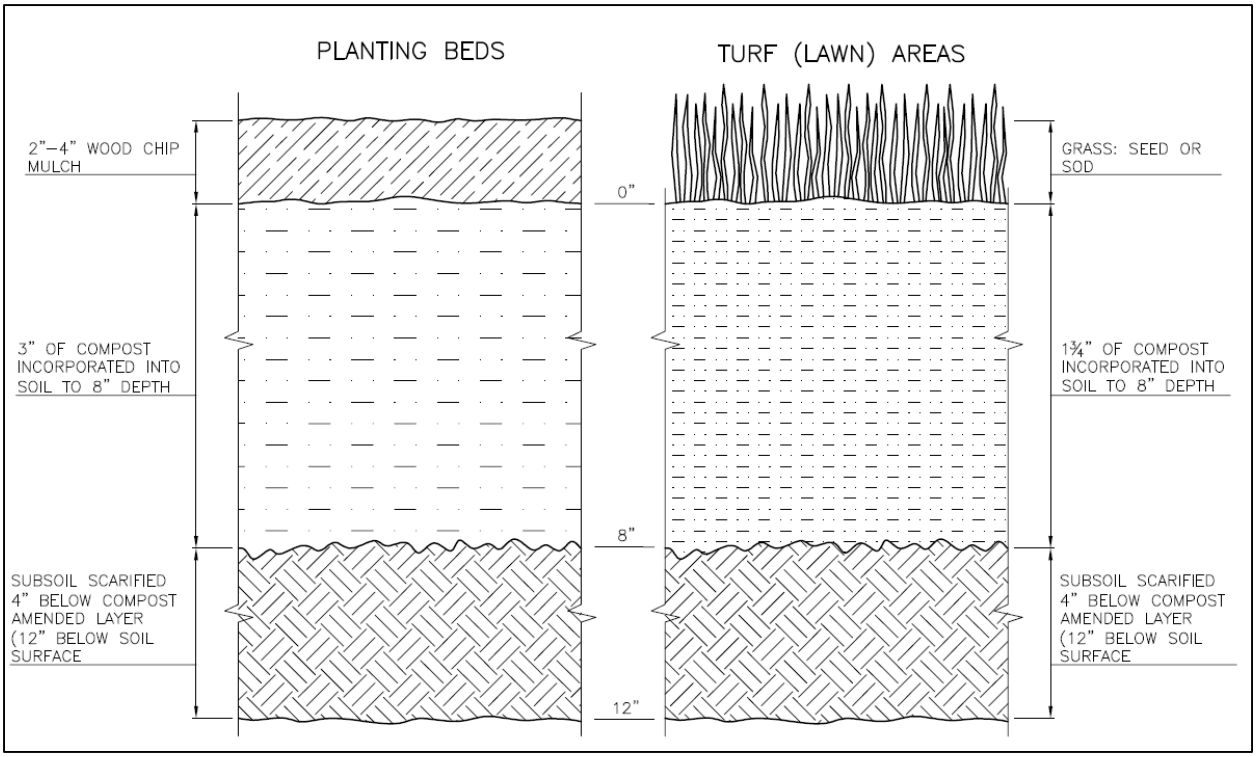


Figure 5.1. Cross-section of Soil Amendment.

3. Stockpile Soil:

   Stockpile existing topsoil during grading and replace it prior to planting. Amend stockpiled topsoil if needed to meet the organic matter or depth requirements either at the default "pre-approved" rate or at a custom calculated rate (refer to the Building Soil manual [Stenn et al. 2012] or website (http://www.buildingsoil.org), for custom calculation method). Scarify subsoil and mulch planting beds, as described in option (2) above.

4. Import Soil:

   - Import topsoil mix of sufficient organic content and depth to meet the requirements. Imported soils should not contain excessive clay or silt fines

(more than 5 percent passing the No. 200 sieve) because that could restrict stormwater infiltration. The default pre-approved rates for imported topsoils are:

- For planting beds: use a mix by volume of 35 percent compost with 65 percent mineral soil to achieve the requirement of a minimum 8 percent (target 10 percent) organic matter by loss-on-ignition test.
- For turf areas: use a mix by volume of 20 percent compost with 80 percent mineral soil to achieve the requirement of a minimum 4 percent (target 5 percent) organic matter by loss-on-ignition test.
- Scarify subsoil and mulch planting beds, as described in option (2) above.

Note: more than one method may be used on different portions of the same site.

5.1.5.2. Soil Retention

Retain the duff layer and native topsoil in an undisturbed state to the maximum extent feasible, and protect from compaction (SMC, Section 22.805.020.D.2). In any areas requiring grading, remove and stockpile the duff layer and topsoil on site in a designated, controlled area, which is not adjacent to public resources and critical areas. Reapply to other portions of the site where feasible.

5.1.5.3. Soil Quality

Soil organic matter is often missing from disturbed soils. Replenish organic matter by amending with compost. It is important that the materials used to meet the Soil Amendment BMP are appropriate and beneficial to the plant cover to be established. Likewise, it is important that imported topsoils improve soil conditions and do not have an excessive percent of clay or silt fines.

Standardized "pre-approved" soil amendment rates have been established for planting beds and turf areas. Alternatively, custom amendment rates may be calculated. Both options are described in further detail in the subsequent section.

All areas subject to clearing and grading that have not been covered by impervious surface, incorporated into a drainage facility, or engineered as structural fill or slope must, at project completion, demonstrate the following:

- A topsoil layer meeting these requirements:
    - An organic matter content, as measured by the loss-on-ignition test, of a minimum 8 percent (target 10 percent) dry weight in planting beds, or a minimum 4 percent (target 5 percent) organic matter content in turf areas[1].

[1] Acceptable test methods for determining loss-on-ignition soil organic matter include the most current version of ASTM D2974 "Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils" and TMECC 05.07A "Loss-On-Ignition Organic Matter Method"

    - A pH from 6.0 to 8.0 or matching the pH of the original undisturbed soil.
    - A minimum depth of 8 inches.

- Root zones where tree roots limit the depth of incorporation of amendments are exempted from this requirement. Fence and protect these root zones from stripping of soil, grading, or compaction to the maximum extent practical.
- Scarify subsoils below the topsoil layer at least 4 inches for a finished minimum depth of 12 inches of uncompacted soil. Incorporate some of the upper material to avoid stratified layers, where feasible.
- After planting: mulch planting beds with 2 to 4 inches of organic material such as arborist wood chips, bark, shredded leaves, compost, etc.
- Use compost and other materials that meet the following organic content requirements:
    - The organic content for "pre-approved" amendment rates can only be met using compost that meets the definition of "composted materials" in WAC 173-350 Section 220. The compost must have an organic matter content of 40 percent to 65 percent, and a carbon to nitrogen ratio below 25:1. The carbon to nitrogen ratio may be as high as 35:1 for plantings composed entirely of plants native to the Puget Sound Lowlands region.
    - Calculated amendment rates may be met through use of composted materials as defined above, or other organic materials amended to meet the carbon to nitrogen ratio requirements, and meeting the contaminant standards compost specified in WAC 173-350 Section 220. Refer to the *Building Soil* manual (Stenn et al. 2012) or website (http://www.buildingsoil.org) for the method of calculating custom amendment rates.

Assure that the resulting soil is conducive to the type of vegetation to be established.

5.1.5.4. Soil Amendment Plan

A Soil Amendment Plan is required and must include the following:

- A site map showing areas to be fenced and left undisturbed during construction, and areas that will be amended at the turf or planting bed rates
- Calculations of the amounts of compost, compost amended topsoil, and mulch to be used on the site

General guidance on these procedures can be found in the *Building Soil* manual (Stenn et al. 2012), available at (http://www.buildingsoil.org).

The City has incorporated the soil amendment plan into the required "Construction Stormwater Control Plan and Post Construction Soil Management Plan", which is available at the DPD website (http://www.seattle.gov/dpd).

5.1.6. BMP Sizing

Lawn and landscaped areas that meet the soil amendment BMP requirements may be modeled, using approved runoff models, as "pasture" rather than "lawn" surface over the underlying soil (till or outwash).

In addition, flow control credit is given in runoff modeling when soil amendment BMP requirements are met and used as part of a dispersion design under the conditions described in:

- Full Dispersion (*Section 5.3.2*)
- Splashblock Downspout Dispersion (*Section 5.3.3*)
- Trench Downspout Dispersion (*Section 5.3.4*)
- Sheet Flow Dispersion (*Section 5.3.5*)
- Concentrated Dispersion (*Section 5.3.6*)

5.1.7. Minimum Construction Requirements

Minimum construction requirements for disturbed areas include the following:

- Install soil to meet Soil Amendment BMP requirements toward the end of construction, and once established, protect from compaction and erosion.
- Plant soil with appropriate vegetation and mulch planting beds installation.

For inspection and verification procedures used for facility approval by City staff, refer to (http://www.seattle.gov/util/greeninfrastructure). These procedures are also summarized in the *Building Soil* manual (Stenn et al. 2012).

5.1.8. Operations and Maintenance Requirements

The most important maintenance issue is to replenish the soil organic matter by leaving leaf litter and grass clippings on-site (or by adding compost and mulch regularly). This BMP is designed to reduce the need for irrigation, fertilizers, herbicides, and pesticides.

5.2. Tree Planting and Retention

5.2.1. Description

New trees can be planted and/or existing trees can be protected and retained on a project site to achieve on-site stormwater management and/or flow control credits.

5.2.2. Performance Mechanisms

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.

5.2.3. Applicability

Retained and newly planted trees receive credits toward meeting on-site stormwater management and flow control requirements. The degree of flow control that can be provided depends on the tree type (i.e., evergreen or deciduous), canopy area, and whether or not the tree canopy overhangs impervious surfaces. This BMP can be applied for meeting the performance standards listed below.

	On-site		Flow Control			Water Quality				
BMP	**List**	**Standard**	**Forest**	**Pasture**	**Peak**	**Basic**	**Enhanced**	**Oil Control**	**Phosphorus**	**Conveyance**
Tree Planting and Retention	✓[a]	✓[a]	✓[a]	✓[a]	✓[a]					

[a] Standard may be partially achieved.

5.2.4. Site Considerations

Trees are a landscape amenity with flow control benefits that can be planted or retained in most settings. On-site stormwater management and/or flow control credit is given for retaining or planting trees within 20 feet of ground level impervious surfaces such as driveways, patios, and parking lots.

Retained or newly planted trees may also count toward Green Factor, landscaping, and/or tree protection requirements.

Site considerations specific to retained and newly planted trees are provided below.

5.2.4.1. Retained Trees

Setbacks of proposed infrastructure from existing trees are critical considerations. Tree protection requirements limit grading and other disturbances in proximity to the tree.

5.2.4.2. Newly Planted Trees

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. Although setbacks will vary by species, some general recommendations are presented below.

- Minimum 5 foot setback from structures
- Minimum 5 foot setback from underground utility lines
- Minimum 2 foot setback from edge of any paved surface.

5.2.5. Design Criteria

This section provides the design requirements for retained trees and newly planted trees.

5.2.5.1. Retained Trees

To achieve on-site stormwater management and/or flow control credits by retaining trees on a project site, the requirements described below must be met. Design criteria are provided in this section for the following elements:

- Tree species and condition
- Tree size
- Tree canopy area (based on dripline delineation)
- Tree location (relative to ground level impervious surfaces)

Tree Species and Condition

Clearly show existing tree species and tree locations on submittal drawings. Trees must be viable for long-term retention (i.e., in good health and compatible with proposed construction).

Tree Size

To receive on-site stormwater management and and/or flow control credit, retained trees must have a minimum 4 inch 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 as presented in *Section 5.2.5.2 Newly Planted Trees*.

Tree Canopy Area

The canopy area of the retained tree is measured 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 (refer to City of Seattle Standard Plan 133). If trees are clustered, overlapping canopies are not double counted.

Tree Location

The credit for retained trees depends upon proximity to ground level impervious surfaces. To receive credit, the existing tree must be located on the development site and within 20 feet of new or replaced ground level impervious surfaces (e.g., driveway, patio, parking lot). For single family residential projects only, credit is also given for trees that are 20 feet or less from existing ground level impervious surfaces in the right-of-way (e.g., sidewalk). Distance from the edge of impervious surfaces is measured from the tree trunk center at ground level.

The City may require an arborist report if impervious surface is proposed within the critical root zone of the existing tree. The critical root zone is defined as the line encircling the base of the tree with half the diameter of the dripline (refer to City of Seattle Standard Plan 133). If the arborist report concludes that the impervious surface should not be placed within 20 feet of the tree and canopy overlap with impervious surface is still anticipated given a longer setback, credit may be approved.

Retained trees planted in planter boxes are not eligible for credit.

During Construction

Fence and protect the existing tree roots, trunk, and canopy during construction activities per Seattle Municipal Code Tree Protection Chapter 25.11, City of Seattle Standard Specification 1-07.16(2), 8-01.3(2)A and City of Seattle Standard Plans 132 and 133.

5.2.5.2. Newly Planted Trees

To achieve on-site stormwater management and/or flow control credits by planting trees on a project site, the requirements described below must be met. Design criteria are provided in this section for the following elements:

- Tree species
- Tree size
- Tree location (with setbacks from ground level impervious surfaces structures and belowground utilities)
- Plant material and planting specifications
- Irrigation

Tree Species

Approved tree species are listed in the City of Seattle Master Tree List available via link from the DPD website (http://www.seattle.gov/trees). Trees in the “small” category are not eligible for credit. Tree species not included on the City of Seattle Tree List may be given credit with prior approval by the Director.

Tree Size

To receive on-site stormwater management and and/or flow control credit, new deciduous trees must be at least 1.5 inches in diameter measured 6 inches above the ground. New evergreen trees must be at least 4 feet tall.

Tree Location

Site trees must according to sun, soil, and moisture requirements. Select planting locations to ensure that sight distances and appropriate setbacks are maintained given mature height, size, and rooting depths.

Retained trees used to receive the newly planted tree credit must meet the tree location requirements listed in *Section 5.2.5.1*, *Retained Trees*.

To help ensure tree survival and canopy coverage, the minimum tree spacing for newly planted trees must accommodate mature tree spread (refer to City of Seattle Master Tree List). On-site stormwater management and/or flow control credit must not be given for new trees with on-center spacing less than 10 feet.

New trees planted in planter boxes are eligible for credit if the planters provide a minimum soil depth of 30 inches and meet the minimum soil volume standards presented in Table 5.1.

Table 5.1. Minimum Soil Volume for New Trees in Planters.

Tree Size Category [a]	Planting Area Soil Volume [b]	Planting Surface Area [c]	Example Dimensions [c]
Small trees	110 cubic feet	44 square feet	5 feet x 9 feet
Small/Medium Trees	225 cubic feet	90 square feet	5 feet x 18 feet
Medium/Large Trees	375 cubic feet	150 square feet	6 feet x 25 feet
Large Trees	525 cubic feet	210 square feet	7 feet x 30 feet

[a] Tree size categories from the City of Seattle Master Tree List.

[b] Note that these are minimum soil volume requirements. Trees will be healthier, bigger and longer-lived if greater soil volume is provided.

[c] Surface area and example dimensions assume a 30 inch soil depth. Smaller surface areas can achieve the same volume if a deeper soil profile is provided, or if adjacent paved surfaces are installed over structural soil or similar technologies.

Plant Material and Planting Specifications

Recommended guidelines for planting materials and methods are provided in City of Seattle Standard Specifications 8-02 and 9-14, and Standard Plans 100a, 100b, and 101.

5.2.6. BMP Credits

5.2.6.1. On-site List Approach

The On-Site List Requirement is met when trees are retained and planted to the maximum extent feasible given site setbacks and tree spacing requirements.

5.2.6.2. Pre-Sized Approach

On-site stormwater management and flow control credits for retained and newly planted trees are provided in Tables 5.2 and 5.3. These credits can be applied to reduce impervious surface area requiring on-site stormwater management or flow control. Credits are the same for on-site stormwater management and all flow control standards and may be applied to project sites of all sizes.

Table 5.2. On-site Stormwater Management and Flow Control Credits for Retained Trees.

Tree Type	Credit
Evergreen	20% of canopy area (minimum of 100 square feet/tree)
Deciduous	10% of canopy area (minimum of 50 square feet/tree)

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

Table 5.3. On-site Stormwater Management and Flow Control Credits for Newly Planted Trees.

Tree Type	Credit
Evergreen	50 square feet/tree
Deciduous	20 square feet/tree

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

To use these credits, the requirements outlined in *Section 5.2.5 Design Criteria must be met*. The total tree credit for retained and newly planted trees must not exceed 25 percent of the new plus replaced impervious surface requiring mitigation. Tree credits are not applicable to trees located in native vegetation areas used for flow dispersion or other flow control or on-site stormwater management credit.

5.2.6.3. Modeling Approach

When using the Modeling Approach to meet flow control standards, flow control credits for retained and newly planted trees can be applied as explained below for the "Pre-Sized Approach". The impervious areas credited by the retained and newly planted trees need not be entered into the contiguous hydrologic model when sizing other on-site stormwater management or flow control BMPs.

5.2.7. Minimum Construction Requirements

Protect retained trees during construction as explained in *Section 5.2.5.1 Retained Trees*. Planting methods for new trees are provided in *Section 5.2.5.2 Newly Planted Trees* section.

5.2.8. Operations and Maintenance Requirements

Retain, maintain and protect trees on the site for the life of the development or until any approved redevelopment occurs. Replace trees that are removed or die with like species during the next appropriate planting season (typically in the fall).

Prune, when necessary for compatibility with other infrastructure and/or to preserve the health and longevity of trees. Meet industry standards for pruning (ANSI A300 standards).

For newly planted trees, provide supplemental irrigation during the first three growing seasons after planting to help ensure tree survival.

Additional O&M requirements for retained and newly planted trees are provided in *Appendix G (BMP No. 26)*.

5.3. Dispersion BMPs

Dispersion BMPs disperse runoff over vegetated pervious areas to provide flow control. The dispersion BMPs in this section include:

- Full dispersion
- Splashblock downspout dispersion
- Trench downspout dispersion
- Sheet flow dispersion
- Concentrated flow dispersion

Key design requirements that are common to all dispersion BMPs are provided in *Section 5.3.1*. Guidance and requirements that are specific to the different types of dispersion are provided in the subsequent sections.

5.3.1. Design Requirements for Dispersion BMPs

5.3.1.1. General Site Considerations

The following are key considerations in determining the feasibility of dispersion BMPs for a particular site:

- *Dispersion flowpath area: D*ispersion BMPs generally require large areas of vegetated ground cover to meet flowpath requirements and are not feasible in most urban settings.
- *Erosion or flooding potential: D*ispersion is not allowed in settings where the dispersed flows might cause erosion or flooding problems, either on site or on adjacent properties.
- *Site topography*: Dispersion flowpaths are prohibited in and near certain sloped areas (refer to flowpath requirements below).

5.3.1.2. General Design Criteria for Dispersion Flowpaths

Flowpath design requirements that are common to all dispersion BMPs are listed below. Additional requirements that are specific to the specific dispersion types are provided in each BMP section.

- The vegetated flowpath must consist of either undisturbed native landscape or well-established lawn, or landscape or groundcover over soil that meets the Soil Amendment BMP requirements outlined in *Section 5.1*. The groundcover must be dense to help disperse and infiltrate flows and prevent erosion.
- The dispersion flowpath is not permitted within Landslide–Prone Critical Areas as defined by the Regulations for Environmentally Critical Areas (SMC, Section 25.09.020).
- The dispersion flowpath is not permitted within a setback above a Steep Slope Critical Area (SMC, Section 25.09.020). The setback is calculated as 10 times the height of the Steep Slope Critical Area (to a 500 foot maximum setback). Dispersion within this setback may be feasible provided a detailed slope stability analysis is completed by a geotechnical engineer. The analysis must determine the effects that dispersion would have on the Steep Slope Critical Area and adjacent properties.
- The dispersion flowpath is not permitted over contaminated sites or abandoned landfills.
- For sites with septic systems, the point of discharge to the dispersion device must be downgradient of the drainfield primary and reserve areas. This requirement may be waived if site topography clearly prohibits flows from intersecting the drainfield.

5.3.2. Full Dispersion

Flow control and water quality treatment standards may be met using "full dispersion" as presented in the SWMMWW. The requirements for full dispersion are difficult to achieve in an urban setting. As an example, residential developments must preserve 65 percent of a site in a forested or native condition and limit the impervious site coverage to 10 percent. Given the large extent of vegetative cover required for full dispersion, these credits will most likely only apply to Seattle Parks projects.

Refer to BMP T5.30 in Volume V of the SWMMWW for full dispersion applicability, site considerations, design criteria, modeling requirements, and minimum construction requirements.

5.3.3. Splashblock Downspout Dispersion

5.3.3.1. Description

Downspout dispersion BMPs disperse roof runoff over vegetated pervious areas to provide flow control. These BMPs are comprised of a dispersion device (i.e., splashblock, dispersion trench) and a minimum vegetated dispersion flow path.

Splashblock downspout dispersion consists of a splashblock or crushed rock pad used to disperse downspout flows to a downslope well-vegetated flowpath of at least 50 feet.

5.3.3.2. Performance Mechanisms

Splashblock downspout dispersion can provide flow control via attenuation, soil storage, and losses to infiltration, evaporation, and transpiration.

5.3.3.3. Applicability

Splashblock downspout dispersion can be designed to provide on-site stormwater management and flow control. This BMP can be applied for meeting the performance standards listed below. If the designer wishes to use a dispersion BMP to meet water quality treatment standards, the facility must meet the additional design requirements for basic filter strips per *Section 5.8.4*.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Splashblock downspout dispersion	✓	✓[a]	✓[a]	✓[a]	✓	✓[b]				

[a] Standard may be partially or completely achieved depending upon underlying soil type.
[b] Must meet additional design requirements for basic filter strips (refer to *Section 5.8.4*).

5.3.3.4. Site Considerations

General site considerations for determining the feasibility of dispersion BMPs for a particular site are provided in *Section 5.3.1.1*.

5.3.3.5. Design Criteria

This section provides a description and requirements for the components of splashblock downspout dispersion. Typical components of splashblock downspout dispersion are shown in Figure 5.2. Design criteria are provided in this section for the following elements:

- Contributing area
- Splashblock or rock pad
- Dispersion flowpath

- Overflow

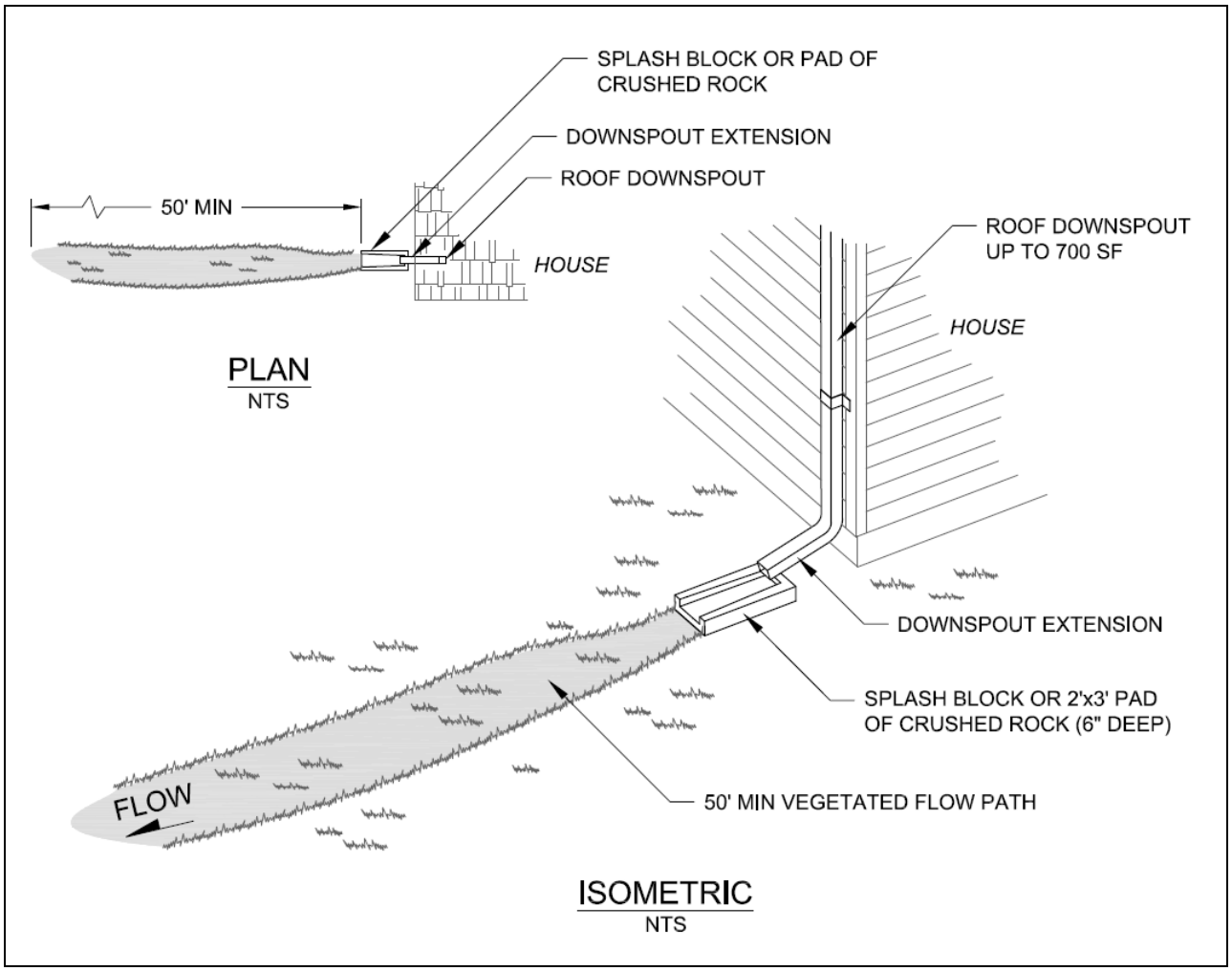


Figure 5.2. Typical Downspout Splashblock Dispersion.

Some of the critical requirements for splashblock downspout dispersion (e.g., flowpaths, setbacks) are shown in Figure 5.3.

Contributing Area

A maximum of 700 square feet of roof area may drain to each splashblock.

Splashblock or Rock Pad

A splashblock or a pad of crushed rock (2 feet wide by 3 feet long by 6 inches deep) must be placed at each downspout point of discharge.

There are two approved methods for splashblock downspout dispersion:

- *Splashblock/Rock Pad*: If the ground is sloped away from the foundation, and there is adequate vegetation and area for effective dispersion, splashblocks/rock pads will typically be adequate to disperse stormwater runoff.

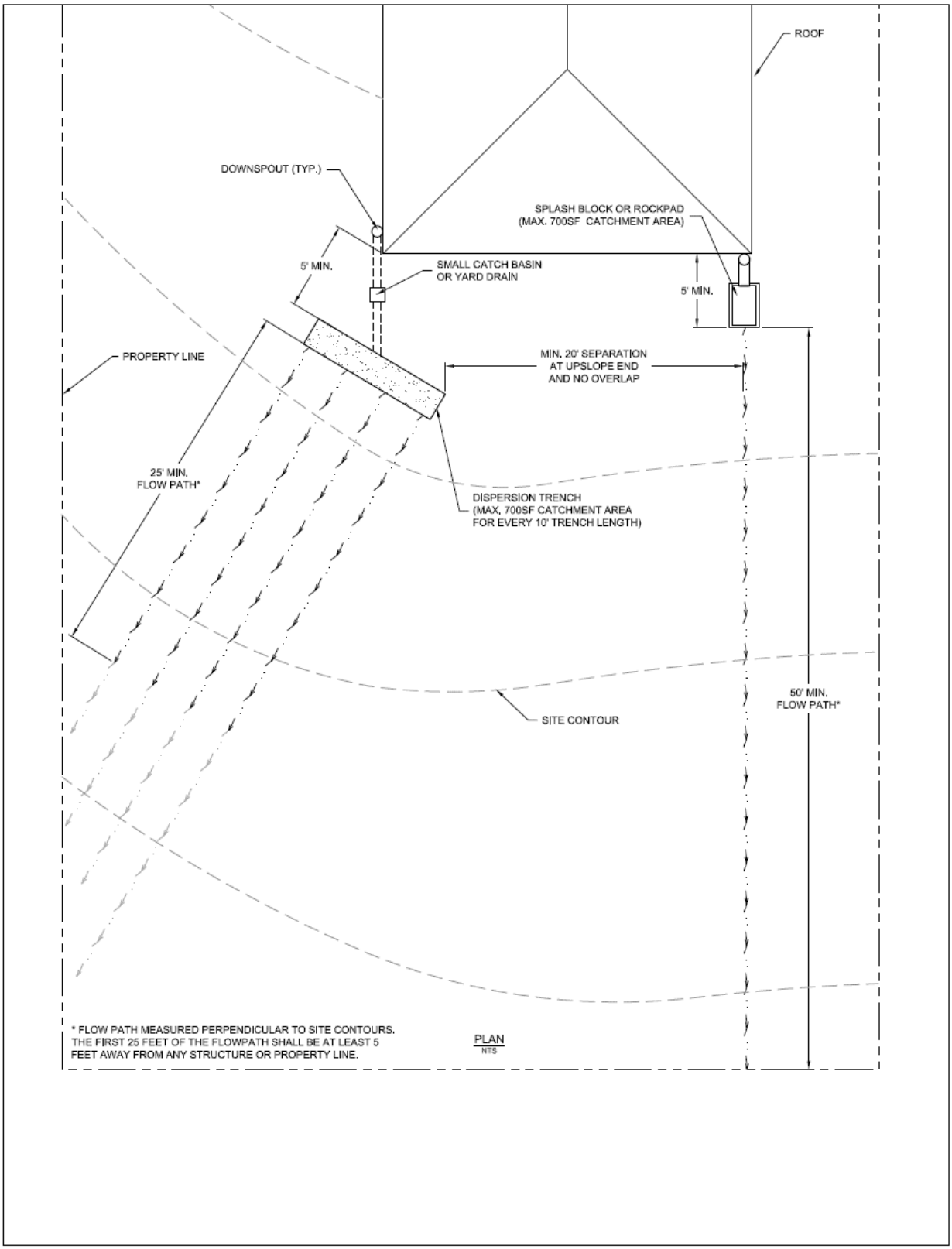


Figure 5.3. Typical Downspout Splashblock and Dispersion Trench Plan.

- *Splashblock/Rock Pad with downspout extension:* If the ground is fairly level, the structure includes a basement, or if foundation drains are proposed, splashblocks with downspout extensions should be used to move the point of discharge away from the foundation. Downspout extensions can include piping to a splashblock/rock pad a considerable distance from the downspout.

Dispersion Flowpath

The general minimum requirements for the dispersion flowpath are provided in *Section 5.3.1.2*. Additional flowpath requirements specific to splashblock downspout dispersion are listed below and shown in Figure 5.3:

- Provide a vegetated flowpath of at least 50 feet between the dispersion device and any property line, structure, slope over 15 percent, stream, wetland, lake, or other impervious surface. Critical area buffers may count toward flowpath lengths. Measure the flowpath length perpendicular to site contours.
- Down gradient of the required 50 foot flowpath, an additional 10 feet must be provided before the flowpath intersects a property line (excluding the property line abutting the right-of-way) or encounters a structure.
- Install the first 25 feet of the dispersion flowpath at least 5 feet from any structure or property line.
- Provide a separate flowpath for each downspout dispersion device. For the purpose of maintaining adequate separation of flows discharged from adjacent dispersion devices, space vegetated flowpaths at least 20 feet apart at the upslope end and do not overlap with other flowpaths at any point along the flowpath lengths.
- For the purpose of measuring setbacks to structures, property lines or other flowpaths, assume the flowpath width to be 3 feet extending from the center line of the splashblock or rock pad. Measure setbacks from the edge of the flowpath.

Overflow

Identify the overland flow path for each downspout dispersion point. Consider surface flows that may extend beyond the design flowpath length. Do not allow flow to cause erosion or flooding onsite or on adjacent properties.

5.3.3.6. BMP Credits

On-site List Approach

The impervious surface area dispersed using splashblock downspout dispersion meets the On-site List Requirement.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), flow control credits may be achieved by using downspout dispersion. Credits are provided in Table 5.4, organized by flow control standard. These credits can be applied to reduce the effective impervious surface area used

in drainage calculations. A 100 percent credit means that the flow control goal is achieved and no further control is required for the area from which runoff is dispersed. If partial credit is received, the standard is not achieved and additional flow control measures may be required. As an example, for a site subject to the Pre-developed Pasture Standard, a dispersed impervious area would receive a 90 percent credit. Therefore, 90 percent of the impervious area dispersed can be excluded from on-site stormwater management and flow control calculations. The effective impervious area (area used to size a downstream flow control facility) would be calculated as 10 percent of the impervious area dispersed.

Table 5.4. Flow Control Credits for Splashblock Downspout Dispersion.

Dispersion Type	Credit (%)	
	Pre-developed Pasture Standard	Peak Control Standard
Splashblock Downspout Dispersion	100%	100%

Impervious Area Mitigated = Impervious Area Dispersed x Credit (%)/100

The flow control credits outlined above are applicable only if downspout dispersion meets the minimum design requirements outlined in this section. Alternatively, dispersion can be evaluated using a continuous hydrologic simulation model as described below.

Modeling Approach

Continuous hydrologic modeling may be used to quantify the on-site stormwater management and flow control performance of splashblock downspout dispersion using the procedures and assumptions listed in Table 5.5.

Table 5.5. Continuous Modeling Assumptions for Downspout Dispersion.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series.
Computational Time Step	5-minutes
Roof area dispersed	Option 1: Roof area dispersed modeled as grass over the underlying soil type (e.g., till). Existing slope condition of dispersion flowpath should be used. Option 2: Represent roof runoff dispersion using the “lateral flow” routine.

5.3.3.7. Minimum Construction Requirements

Protect the dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area according to meet the Soil Amendment BMP requirements in *Section 5.1*, and establish a dense cover of lawn, landscape or groundcover.

5.3.3.8. Operations and Maintenance Requirements

Splashblock downspout dispersion O&M requirements are provided in *Appendix G (BMP No. 24)*.

5.3.4. Trench Downspout Dispersion

5.3.4.1. Description

Trench downspout dispersion consists of a gravel-filled dispersion trench used to disperse downspout flows to a downslope well-vegetated flowpath of at least 25 feet.

5.3.4.2. Performance Mechanisms

Trench downspout dispersion can provide flow control via attenuation, soil storage, and losses to infiltration, evaporation, and transpiration.

5.3.4.3. Applicability

Trench downspout dispersion can be designed to provide on-site stormwater management and flow control. This BMP can be applied for meeting the performance standards listed below. If the designer wishes to use a dispersion BMP to meet water quality treatment standards, the facility must meet the additional design requirements for basic filter strips per *Section 5.8.4*.

	On-site		Flow Control			Water Quality				
BMP	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	Conveyance
Trench downspout dispersion	✓	✓[a]	✓[a]	✓[a]	✓	✓[b]				

[a] Standard may be partially or completely achieved depending upon underlying soil type.
[b] Must meet additional design requirements for basic filter strips (refer to *Section 5.8.4*).

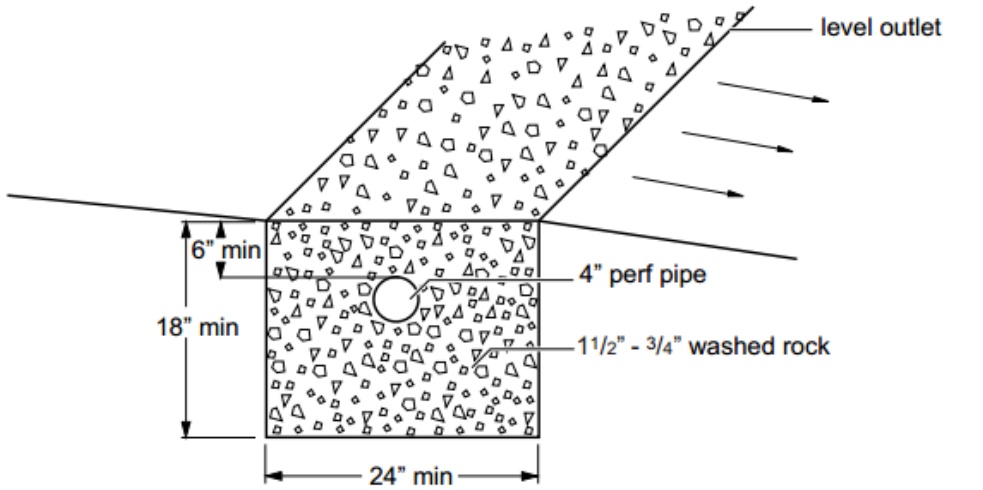
5.3.4.4. Site Considerations

General site considerations for determining the feasibility of dispersion BMPs for a particular site are provided in *Section 5.3.1.1*.

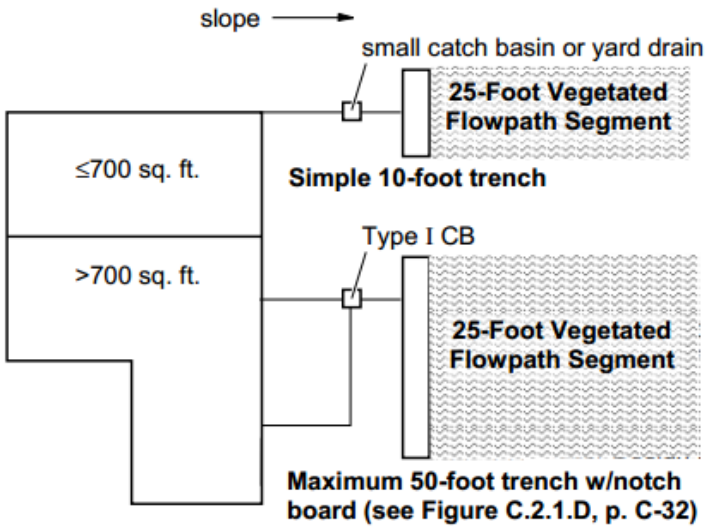
5.3.4.5. Design Criteria

This section provides a description and requirements for the components of trench downspout dispersion. Some of the critical requirements for trench downspout dispersion (e.g., flowpaths, setbacks) are shown in Figure 5.4. Design criteria are provided in this section for the following elements:

- Downspout dispersion trench
- Dispersion flowpath
- Overflow



TRENCH X-SECTION
NTS



PLAN VIEW OF ROOF
NTS

Source: King County

Figure 5.4. Typical Downspout Dispersion Trench.

Downspout Dispersion Trench

The minimum requirements associated with dispersion trench design include the following:

- The trench must be a minimum of 18 inches deep and 2 feet wide.
- The trench must be level and aligned parallel to site elevation contours to disperse the water to the downslope flowpath. The trench must be constructed to prevent point discharge and erosion.
- Water must be conveyed to the trench via a perforated or slotted pipe with a minimum diameter of 4 inches. Pipe cover shall be a minimum of 6 inches.
- Trenches serving up to 700 square feet of roof area must be 10-foot-long. For roof areas larger than 700 square feet, a dispersion trench with a dispersion device, such as a notched grade board, is recommended. Refer to BMP T5.10B in Volume III of the SWMMWW for typical plan and section views of a downspout dispersion trench with notched grade board. The total length of this design must provide at least 10 feet of trench per 700 square feet of roof area and not exceed 50 feet.
- A setback of at least 5 feet must be maintained between any edge of the trench and any property line.
- The setback between any edge of the trench and any structure must be 5 feet for structures without a basement and 10 feet for structures with a basement.

Dispersion Flowpath

The general minimum requirements for the dispersion flowpath are provided in *Section 5.3.1.2*. Additional flowpath requirements specific to trench downspout dispersion are listed below and shown in Figure 5.3:

- A vegetated flowpath must be at least 25 feet between the outlet of the trench and any property line, structure, slope over 15 percent, stream, wetland, lake, or impervious surface. Critical area buffers may count toward flowpath lengths. The flowpath length is measured perpendicular to site contours.
- Down gradient of the required 25 foot flowpath, an additional 10 feet must be provided before the flowpath intersects a property line or encounters a structure.
- The first 25 feet of the dispersion flowpath must be at least 5 feet from any structure or property line.
- Each downspout dispersion device must have a separate flowpath. For the purpose of maintaining adequate separation of flows discharged from adjacent dispersion devices, vegetated flowpaths must be at least 20 feet apart at the upslope end and must not overlap with other flowpaths at any point along the flowpath lengths.
- For the purpose of measuring setbacks to structures, property lines, and other flowpaths, the flowpath width must be assumed to be the length of the dispersion trench. Setbacks must be measured from the edge of the flowpath.

Overflow

Identify the overland flow path for each downspout dispersion point. Consider surface flows that may extend beyond the design flowpath length. Prevent flow from causing erosion or flooding on site or on adjacent properties.

5.3.4.6. BMP Credits

On-site List Approach

The impervious surface area dispersed using trench downspout dispersion meets the On-site List Requirement.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), flow control credits may be achieved by using downspout dispersion. The credits provided in Table 5.6 can be applied to reduce the effective impervious surface area used in on-site stormwater management and flow control calculations as explained for splashblock downspout dispersion (refer to *Section 5.3.3.6*).

Table 5.6. Flow Control Credits for Trench Downspout Dispersion.

Dispersion Type	Credit (%)	
	Pre-developed Pasture Standard	Peak Control Standard
Trench Downspout Dispersion	100%	100%

Impervious Area Mitigated = Impervious Area Dispersed x Credit (%)/100

Modeling Approach

Continuous hydrologic modeling may be used to quantify the on-site stormwater management and flow control performance of trench downspout dispersion using the procedures presented for splashblock downspout dispersion in Table 5.4 (refer to *Section 5.3.3.6*).

5.3.4.7. Minimum Construction Requirements

Protect the dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area to meet the Soil Amendment BMP requirements in *Section 5.1* and establish a dense cover of lawn, landscape or groundcover. During construction confirm the dispersion trench surface is level (e.g., laser testing or flow test).

5.3.4.8. Operations and Maintenance Requirements

Trench downspout dispersion O&M requirements are provided in *Appendix G (BMP No. 24)*.

5.3.5. Sheet Flow Dispersion

5.3.5.1. Description

Sheet flow dispersion is one of the simplest methods of runoff control. This BMP can be used for any impervious or pervious surface that is graded to avoid concentrating flows. Because flows are already dispersed as they leave the surface (i.e., not concentrated), they need only traverse a narrow band of adjacent vegetation for effective flow attenuation and treatment.

5.3.5.2. Performance Mechanisms

Sheet flow dispersion can provide flow control via flow attenuation, soil storage, and losses to infiltration, evaporation, and transpiration.

5.3.5.3. Applicability

Sheet flow dispersion can be designed to provide on-site stormwater management and flow control. This BMP can be applied for meeting the performance standards listed below. If the designer wishes to use a dispersion BMP to meet water quality treatment standards, the facility must meet the additional design requirements for filter strips per *Section 5.8.4*.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Sheet flow dispersion	✓	✓[a]	✓[a]	✓[a]	✓	✓[b]				

[a] Standard may be partially or completely achieved depending upon underlying soil type.
[b] Must meet additional design requirements for basic filter strips (refer to *Section 5.8.4*).

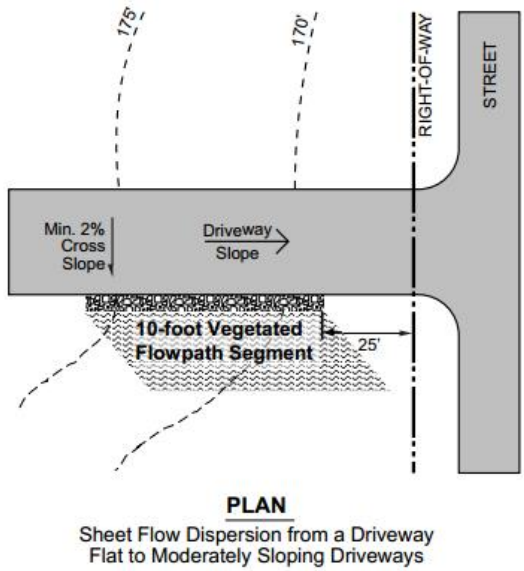
5.3.5.4. Site Considerations

General site considerations for determining the feasibility of dispersion BMPs for a particular site are provided in *Section 5.3.1.1*. Sheet flow dispersion is applicable for impervious surfaces with slopes less than 15 percent, such as sidewalks, driveways, sport courts, patios, roofs without gutters, or other situations where concentration of flows can be avoided.

5.3.5.5. Design Criteria

This section provides a description and requirements for the components of sheet flow dispersion. A typical plan for driveway sheet flow dispersion is shown in Figure 5.5. Design criteria are provided in this section for the following elements:

- Contributing area
- Transition zone
- Dispersion flowpath
- Overflow



Source: King County

Figure 5.5. Typical Sheet Flow Dispersion for Driveways.

Contributing Area

The impervious area contributing sheet flow to the dispersion flowpath must have a slope less than 15 percent. The cross slope towards the transition zone must be a minimum of 2 percent.

Transition Zone

A 2-foot-wide transition zone to discourage channeling must be provided between the edge of the contributing impervious area and the downslope vegetation. This may be an extension of subgrade material (crushed rock), modular pavement, drain rock, or other material approved by the Director.

Dispersion Flowpath

The general minimum requirements associated with the dispersion flowpath are provided in *Section 5.3.1.2*. An additional flowpath requirement specific to sheet flow dispersion is as follows:

- Provide a vegetated flowpath of 10 feet to disperse sheet flow runoff from paved or impervious surface with a contributing area of 20 feet. Provide an additional 10 linear feet of vegetated flowpath for each additional 20 linear feet of contributing area or fraction thereof.
- Down gradient of the required flowpath (per the bullet above), an additional 10 feet must be provided before the flowpath intersects a property line or encounters a structure.

Overflow

Identify the overland flowpath for each downspout dispersion point. Consider surface flows that may extend beyond the design flowpath length. Prevent flow from causing erosion or flooding onsite or on adjacent properties.

5.3.5.6. BMP Credits

On-site List Approach

The impervious surface area dispersed using sheet flow dispersion meets the On-site List Requirement.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), flow control credits may be achieved by using sheet flow dispersion. The credits provided in Table 5.7 can be applied to reduce the effective impervious surface area used in on-site stormwater management and flow control calculations as explained for splashblock downspout dispersion.

Table 5.7. Flow Control Credits for Sheet Flow Dispersion.

Dispersion Type	Credit (%)	
	Pre-developed Pasture Standard	Peak Control Standard
Sheet flow	100%	100%

Impervious Area Mitigated = Impervious Area Dispersed x Credit (%)/100.

Modeling Approach

Continuous hydrologic modeling may be used to quantify the on-site stormwater management and flow control performance of sheet flow dispersion using the procedures and assumptions listed in Table 5.8.

Table 5.8. Continuous Modeling Assumptions for Sheet Flow Dispersion.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series.
Computational Time Step	5-minutes
Impervious area dispersed	Option 1: Impervious area dispersed modeled as grass over the underlying soil type (e.g., till). Existing slope condition of dispersion flowpath should be used. Option 2: Represent impervious runoff dispersion using the “lateral flow” routine.

5.3.5.7. Minimum Construction Requirements

Protect the dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area to meet the Soil Amendment BMP requirements in *Section 5.1* and establish a dense cover of lawn, landscape or groundcover.

5.3.5.8. Operations and Maintenance Requirements

Sheet flow dispersion O&M requirements are provided in *Appendix G (BMP No. 24)*.

5.3.6. Concentrated Flow Dispersion

5.3.6.1. Description

Concentrated flow dispersion BMPs disperse concentrated flows from driveways or other pavement through a vegetated pervious area to provide flow control. In a typical application, sheet flow from a ground-level impervious surface is intercepted by a berm or slot drain and conveyed to a dispersion point (i.e., rock pad or dispersion trench).

5.3.6.2. Performance Mechanisms

Concentrated flow dispersion can provide flow control via attenuation, soil storage, and losses to infiltration, evaporation, and transpiration.

5.3.6.3. Applicability

Concentrated flow dispersion can be designed to provide on-site stormwater management and flow control. This BMP can be applied for meeting the performance standards listed below. If the designer wishes to use a dispersion BMP to meet water quality treatment standards, the facility must meet the additional design requirements for filter strips per *Section 5.8.4*.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Concentrated Flow Dispersion	✓	✓[a]	✓[a]	✓[a]	✓	✓[b]				

[a] Standard may be partially or completely achieved depending upon underlying soil type.
[b] Must meet additional design requirements for basic filter strips (refer to *Section 5.8.4*).

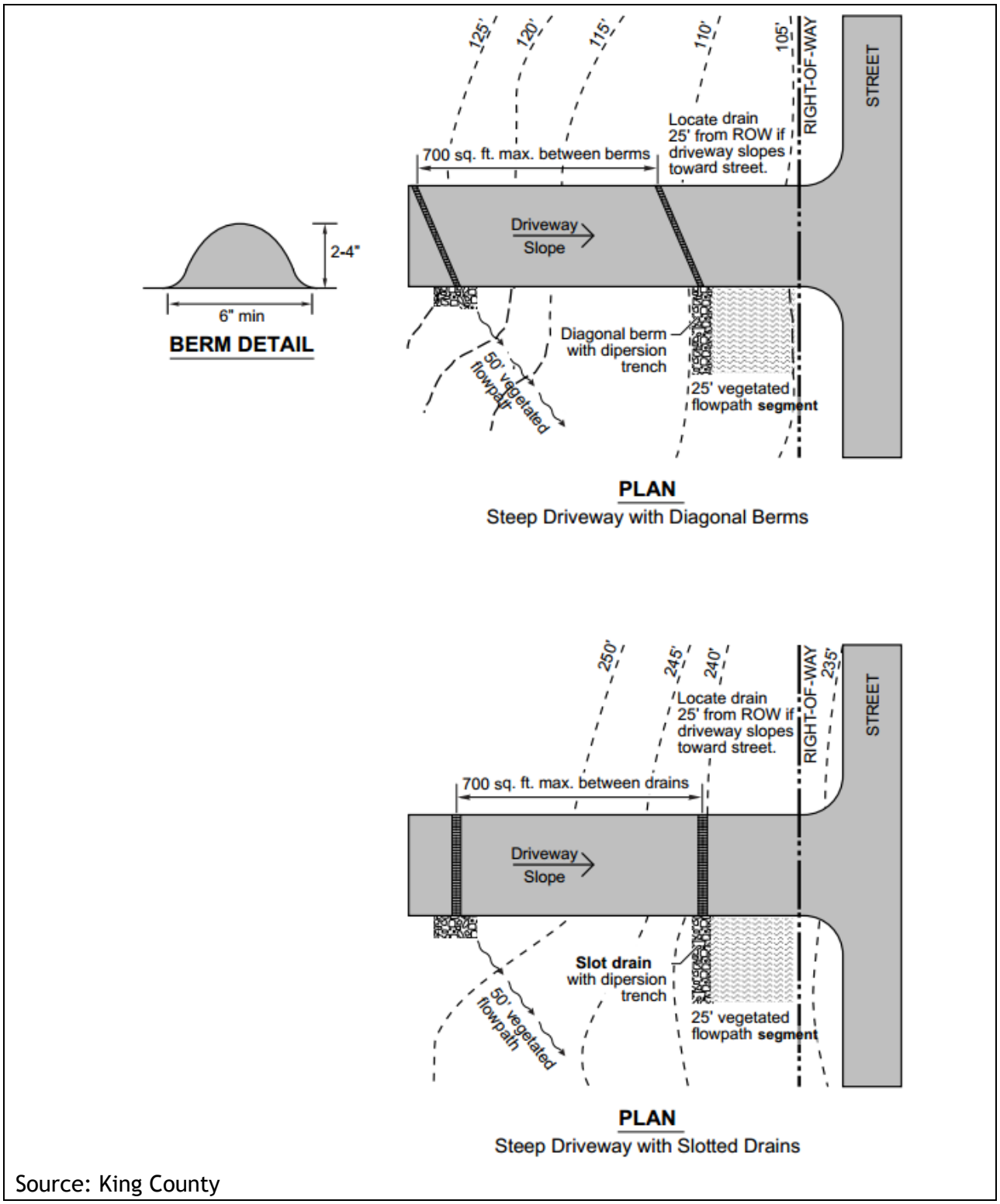
5.3.6.4. Site Considerations

General site considerations for determining the feasibility of dispersion BMPs for a particular site are provided in *Section 5.3.1.1*.

5.3.6.5. Design Criteria

This section provides a description and requirements for the components of concentrated flow dispersion. A typical plan for concentrated flow dispersion for steep driveways is shown in Figure 5.6. Design criteria are provided in this section for the following elements:

- Contributing area
- Berm or slotted drain
- Rock pad(dispersion device option 1)
- Downspout dispersion trench (dispersion device option 2)
- Dispersion flowpath
- Overflow



Source: King County

Figure 5.6. Typical Concentrated Flow Dispersion for Steep Driveways.

Contributing Area

A maximum of 700 square feet of impervious area may drain to each concentrated flow dispersion device (i.e., rock pad or dispersion trench).

Berm or Slotted Drain

A slotted drain, diagonal berm, or similar measure must be provided to direct flow to the rock pad or dispersion trench.

Rock Pad (if applicable)

A pad of crushed rock (2 feet wide by 3 feet long by 6 inches deep) must be placed at each point of discharge.

Dispersion Trench (if applicable)

The minimum requirements associated with dispersion trench design include the following:

- The trench must be a minimum of 18 inches deep and 2 feet wide.
- The trench must be level and aligned parallel to site elevation contours to disperse the water to the downslope flowpath. The trench must be constructed to prevent point discharge and erosion.
- Trenches serving up to 700 square feet of roof area must be 10-foot-long.
- A setback of at least 5 feet must be maintained between any edge of the trench and any structure or property line.

Dispersion Flowpath

The minimum requirements for the dispersion flowpath are listed below:

- For rock pads, a vegetated flowpath of at least 50 feet must be provided between the dispersion device and any property line, structure, slope over 15 percent, stream, wetland, lake, or other impervious surface. Critical area buffers may count toward flowpath lengths. The flowpath length is measured perpendicular to site contours.
- For dispersion trenches, a vegetated flowpath of at least 25 feet must be provided between the outlet of the trench and any property line, structure, slope over 15 percent, stream, wetland, lake, or impervious surface. Critical area buffers may count toward flowpath lengths. The flowpath length is measured perpendicular to site contours.
- Down gradient of the required flowpath (per the bullets above), an additional 10 feet must be provided before the flowpath intersects a property line or encounters a structure.
- The first 25 feet of the dispersion flowpath must be at least 5 feet from any structure or property line.
- Each downspout dispersion device must have a separate flowpath. For the purpose of maintaining adequate separation of flows discharged from adjacent dispersion devices, vegetated flowpaths must be at least 20 feet apart at the upslope end and must not overlap with other flowpaths at any point along the flowpath lengths.
- For the purpose of measuring setbacks to structures, property lines, and other flowpaths, the following must be assumed:

- The rock pad flowpath width must be assumed to be 3 feet extending from the center line of the rock pad
- The dispersion trench flowpath width must be assumed to be the length of the dispersion trench.
- Setbacks must be measured from the edge of the flowpath.

Overflow

Identify the overland flow path for each dispersion point. Consider surface flows that may extend beyond the design flowpath length. Prevent flow from causing erosion or flooding onsite or on adjacent properties.

5.3.6.6. BMP Credits

On-site List Approach

The impervious surface area dispersed using sheet concentrated dispersion meets the On-site List Requirement.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), flow control credits may be achieved by using concentrated flow dispersion. The credits provided in Table 5.9 can be applied to reduce the effective impervious surface area used in on-site stormwater management and flow control calculations as explained for splashblock downspout dispersion.

Table 5.9. Flow Control Credits for Concentrated Flow Dispersion.

Dispersion Type	Credit (%)	
	Pre-developed Pasture Standard	Peak Control Standard
Concentrated Flow Dispersion	100%	100%

Impervious Area Mitigated = Impervious Area Dispersed x Credit (%)/100

Modeling Approach

Continuous hydrologic modeling may be used to quantify the on-site stormwater management and flow control performance of concentrated flow dispersion using the procedures and assumptions listed in Table 5.10.

Table 5.10. Continuous Modeling Assumptions for Concentrated Flow Dispersion.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series.
Computational Time Step	5-minutes
Impervious area dispersed	Option 1: Impervious area dispersed modeled as grass over the underlying soil type (e.g., till). Existing slope condition of dispersion flowpath should be used. Option 2: Represent impervious runoff dispersion using the “lateral flow” routine.

5.3.6.7. Minimum Construction Requirements

Protect the concentrated flow dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area to meet the Soil Amendment BMP requirements in *Section 5.1* and establish a dense cover of lawn, landscape or groundcover. If a dispersion trench is used, confirm the trench surface is level (e.g., laser testing or flow test).

5.3.6.8. Operations and Maintenance Requirements

Concentrated flow dispersion O&M requirements are provided in *Appendix G (BMP No. 24)*.

5.4. Infiltration BMPs

Infiltration BMPs are designed to facilitate percolation of stormwater into the ground. The infiltration BMPs in this section include:

- Infiltration trenches (*Section 5.4.2*)
- Drywells (*Section 5.4.3*)
- Infiltrating bioretention (*Section 5.4.4*)
- Rain gardens (*Section 5.4.5*)
- Permeable pavement facilities (*Section 5.4.6*)
- Perforated stub-out connections (*Section 5.4.7*)
- Infiltration basins (*Section 5.4.8*)

5.4.1. Design Requirements for Infiltration BMPs

Infiltration, where appropriate, is the City's preferred method for stormwater management because it attempts to restore the predevelopment flow regime. Due to the geologic and topographic conditions in Seattle, not all sites are suitable for stormwater infiltration. The City may limit the use of infiltration practices in some areas due to topography and potential landslide hazards. In addition, many locations in Seattle have soils that are underlain by hydraulically-restrictive materials. These relatively impervious layers may limit or preclude infiltration causing perched groundwater conditions during the wet season.

5.4.1.1. Roles and Responsibilities of Licensed Professionals

This section provides the minimum requirements for siting, designing, and constructing infiltration facilities. This information does not preclude the use of professional judgment to evaluate and manage risk associated with design, construction, and operation of infiltration facilities. Recommendations contained in a stamped and signed letter from a licensed professional engineer, engineering geologist, geologist, or hydrogeologist, herein referred to as "licensed professional," who has experience in infiltration and groundwater testing and infiltration facility design, must provide rationale and specific data supporting their professional judgment. The licensed professional may recommend additional exploration and testing, more stringent requirements for design, and evaluation of the post-construction performance of the facilities. However, all infiltration facilities are required to meet the minimum requirements set forth in this Stormwater Manual and Volume III of the SWMMWW and must be in accordance with all rules and laws of the State of Washington, including protection of human health and the environment.

5.4.1.2. General Considerations

When siting, designing and constructing infiltration facilities, there are multiple factors that must be considered to ensure effective performance. This section provides the general requirements that are common to all of the infiltration facilities included in this manual.

Additional requirements specific to the different types of infiltration BMPs are provided in *Section 5.4.2* through *5.4.8*.

Note that permeable pavement surfaces (*Section 5.6.2*) are not considered infiltration facilities for the purpose of this manual because they do not receive runoff from other areas and mitigate only the rain falling on the pavement surface. Although stormwater will infiltrate into the underlying soil, the volume infiltrated is similar to that infiltrated on vegetated permeable surfaces and do not necessitate the restrictions set forth in this section. Similarly, dispersion BMPs (*Section 5.3*) are not considered infiltration facilities for the purposes of this manual. Although stormwater will infiltrate into the underlying soil, the stormwater is dispersed across a large area (subject to setbacks) making many of the restrictions set forth in this section unnecessary. The specific restrictions and setbacks that are applicable to permeable pavement surfaces and dispersion BMPs are provided in their respective sections.

In addition to the shallow infiltration facilities listed above, this section covers provisions for Underground Injection Control wells (UICs). For the purposes of this section, UICs up to 15 feet deep are categorized as "shallow" UICs and "deep" UICs are greater than 15 feet deep. Note that drywells are often considered shallow UICs.

UIC wells are regulated by Ecology and the UIC Program (WAC 173-218). If UIC wells are being considered, refer to Ecology for requirements, including Ecology's *Guidance for UIC Wells that Manage Stormwater* (Ecology UIC Guidance Manual, 2006). Refer to the Department of Ecology website for updates and revisions.

According to Washington Administrative Code (WAC 173-218-030), a UIC well is defined as "a well that is used to discharge fluids into the subsurface. A UIC well is one of the following: (1) A bored, drilled or driven shaft, or dug hole whose depth is greater than the largest surface dimension; (2) an improved sinkhole; or (3) a subsurface fluid distribution system." UIC systems meeting the above criteria may include drywells, pipe or french drains, drain fields, and other similar devices that are used to discharge stormwater directly into the ground. Infiltration trenches with perforated or slotted pipe used to disperse and inject flows are also considered to be UIC wells.

The person responsible for the infiltration facility (i.e., the property owner for private systems) must determine whether the facility is a regulated well and what requirements apply. The City does not advise on the application of Ecology's UIC program or its requirements.

5.4.1.3. Infiltration Feasibility

This section provides step-by-step procedures that must be followed to evaluate the feasibility of infiltration facilities for a project site and to determine design infiltration rates for facility design. Each of the following steps is outlined in more detail in the subsequent sections.

- **Step 1** – Conduct general site characterization including review of existing subsurface information and land use constraints in the vicinity of the proposed facility

- **Step 2** – Evaluate setback and site restrictions for infiltration facilities to determine whether infiltration is feasible for the site
- **Step 3** – Conduct subsurface characterization, infiltration testing, and groundwater monitoring, as applicable
- **Step 4** – Conduct mounding analysis, if applicable

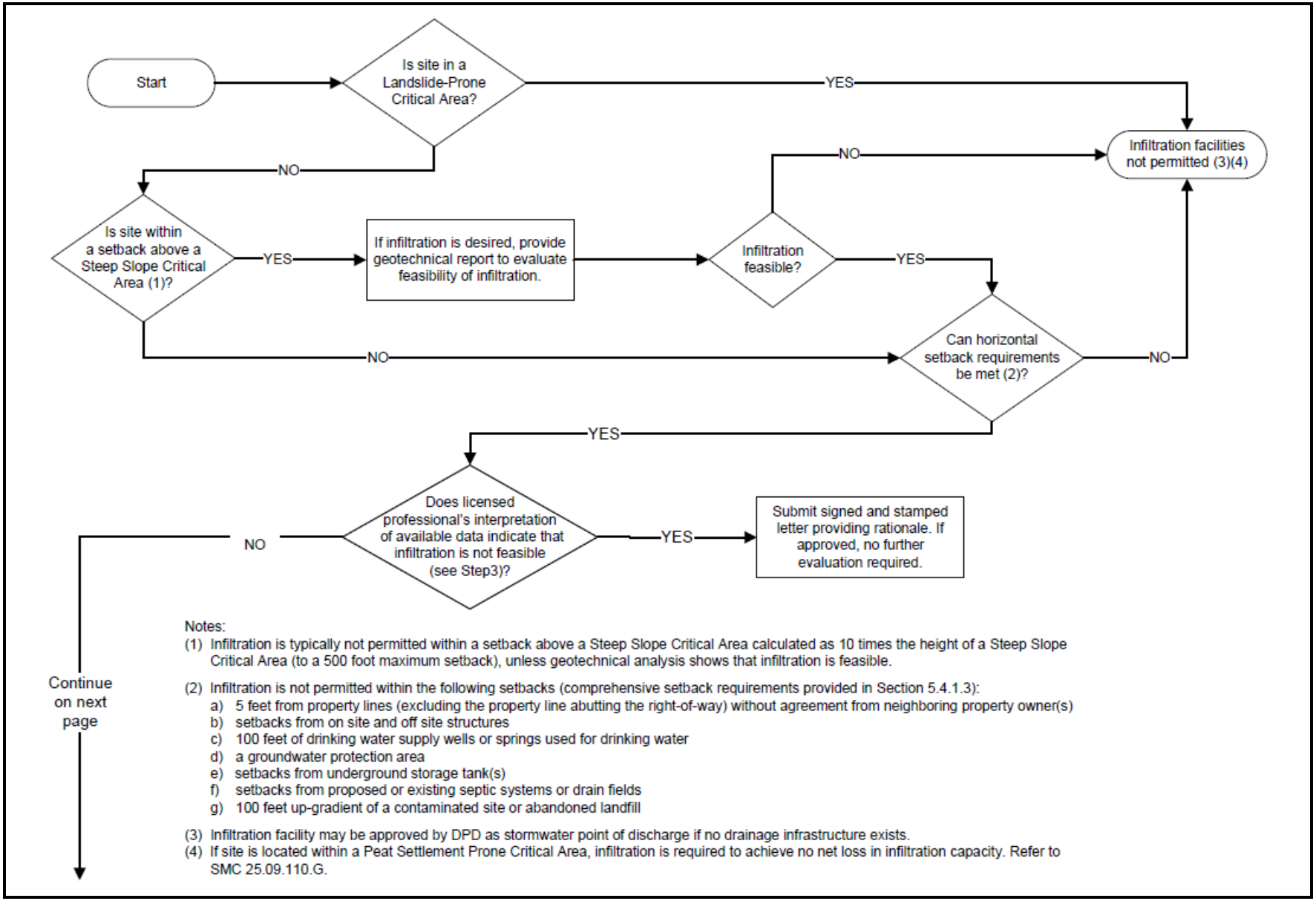
  The minimum requirements for projects where UIC wells will be installed are provided below. The subsurface characterization and testing warranted for a particular site should be determined based on the professional judgment of a licensed professional with relevant expertise.

An infiltration feasibility flow chart is presented as Figure 5.7.

5.4.1.4. Step 1: Conduct General Site Characterization

The first step in designing an infiltration facility is to select a location(s) and assess the site suitability. For projects proposing to use shallow infiltration or shallow UICs, review the following information as part of this initial site characterization:

Information	Project Type	
	SFR, Trail, or Sidewalk	Parcel or Roadway
Site Geology – A description of local site geology, including soil or rock units likely to be encountered, the groundwater regime, and geologic history of the site	No	Yes
Topography –Topography within 500 feet of the proposed facility (GIS topographic data may be used)	Yes	Yes
Water Supply Wells - Location of water supply wells within 500 feet of proposed facility	No	Yes
Contaminated Sites and Landfills - Location of contaminated sites and abandoned landfills within 500 feet of the site	No	Yes
Groundwater Protection Areas - Location of groundwater protection areas and/or 1-, 5-, and 10-year time of travel zones for municipal well protection areas	No	Yes
Steep Slopes or Landslide Hazard Areas - Location of steep slope areas or landslide hazard areas within 500 feet of the site	Yes	Yes
Septic Systems and Drain Fields - Location of septic systems and drain fields in the vicinity of the proposed facility	Yes	Yes
Anticipated Site Use - Anticipated site use (street/highway, residential, commercial, high-use site that may affect the water quality of stormwater runoff)	No	Yes



Notes:

(1) Infiltration is typically not permitted within a setback above a Steep Slope Critical Area calculated as 10 times the height of a Steep Slope Critical Area (to a 500 foot maximum setback), unless geotechnical analysis shows that infiltration is feasible.

(2) Infiltration is not permitted within the following setbacks (comprehensive setback requirements provided in Section 5.4.1.3):
- a) 5 feet from property lines (excluding the property line abutting the right-of-way) without agreement from neighboring property owner(s)
- b) setbacks from on site and off site structures
- c) 100 feet of drinking water supply wells or springs used for drinking water
- d) a groundwater protection area
- e) setbacks from underground storage tank(s)
- f) setbacks from proposed or existing septic systems or drain fields
- g) 100 feet up-gradient of a contaminated site or abandoned landfill

(3) Infiltration facility may be approved by DPD as stormwater point of discharge if no drainage infrastructure exists.

(4) If site is located within a Peat Settlement Prone Critical Area, infiltration is required to achieve no net loss in infiltration capacity. Refer to SMC 25.09.110.G.

Figure 5.7. Infiltration Feasibility Flow Chart.

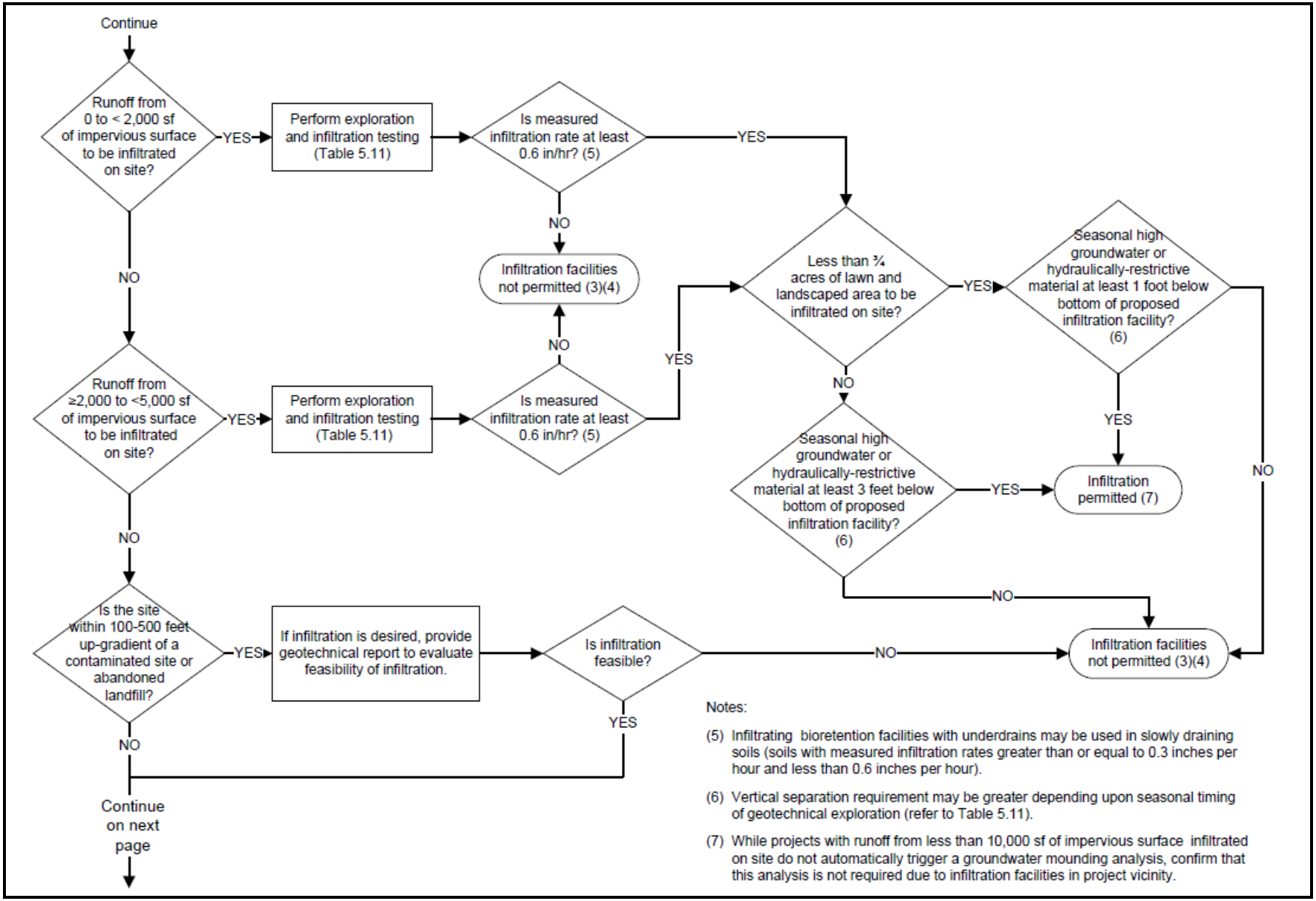


Figure 5.7 (continued). Infiltration Feasibility Flow Chart.

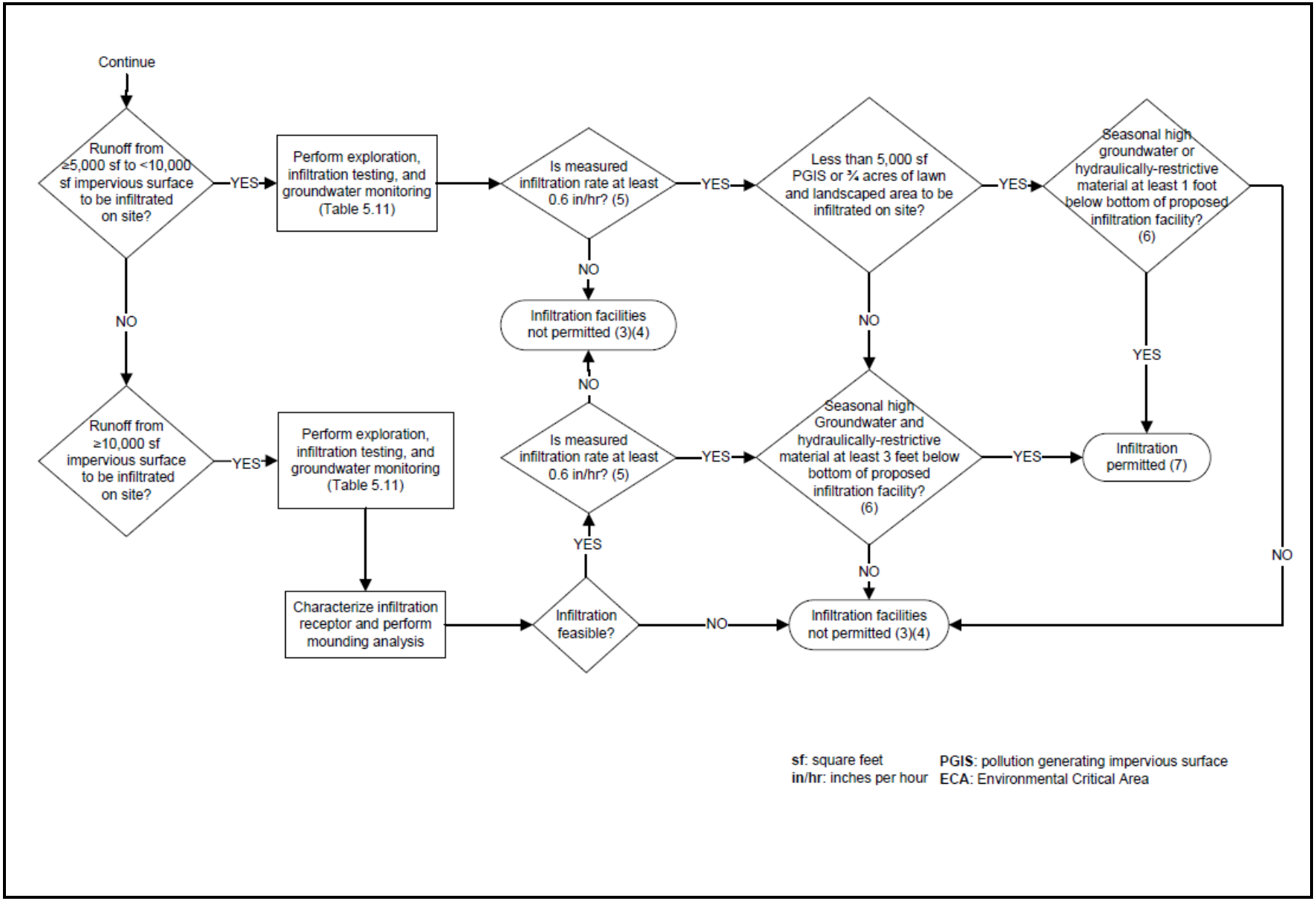


Figure 5.7 (continued). Infiltration Feasibility Flow Chart.

Sources of data to evaluate site suitability include, but are not limited to, City of Seattle Department of Planning and Development Critical Area maps, Washington Department of Natural Resources Subsurface GIS, Flood Hazard maps, and other mapping information available from the City of Seattle (including SPU and SDOT), King County, and consultant reports for other public agencies. Any of the above information identified as part of the review shall be shown on a map relative to the proposed infiltration location(s).

For projects proposing to use deep UICs, the following information shall be reviewed and mapped, in addition to the information listed above for shallow infiltration:

- Regional geologic mapping
- Publicly available geotechnical exploration data
- Steep slopes and landslide hazard critical areas within a quarter mile (1,320 feet) of proposed UIC location

5.4.1.5. Step 2: Evaluate Setbacks and Site Restrictions

Using the site characterization information identified under Step 1, evaluate the site for infiltration suitability based on the prohibitions, restrictions, and setbacks provided below. Based on this evaluation, identify all portions of the site where infiltration may be feasible. Additionally, for UICs, setback and site restrictions shall be in accordance with the UIC Guidance Manual (Ecology 2006).

Prohibitions

The following list identifies conditions that limit or prohibit infiltration facilities:

- In locations where the measured infiltration rate is less than 0.6 inches per hour, determined by procedures in *Appendix D*, infiltration facilities are not approved as a means to meet on-site stormwater management, flow control, or water quality treatment requirements. As an exception, infiltrating bioretention facilities with underdrains may be used in slowly draining soils (soils with measured infiltration rates greater than or equal to 0.3 inches per hour and less than 0.6 inches per hour.
- Infiltration is typically not permitted within Landslide–Prone Critical Areas as defined by the Regulations for ECAs (SMC, Section 25.09.020).
- Infiltration is typically not permitted within a setback above a Steep Slope Critical Area (SMC, Section 25.09.020). For slopes higher than 10 feet, the setback is calculated as 10 times the height of the Steep Slope Critical Area (to a 500 foot maximum setback). Infiltration within this setback may be feasible provided a detailed slope stability analysis is completed by a licensed professional engineer or engineering geologist. The analysis shall determine the effects that infiltration would have on the Steep Slope Critical Area and adjacent properties.
- Other ECAs may have infiltration restrictions. Infiltration within an ECA must be evaluated by DPD as part of an ECA application submittal (SMC, Chapter 25.09).

Note: If development site is located within a Peat Settlement Prone Critical Area, infiltration is required to achieve no net loss in infiltration capacity. Refer to SMC, Section 25.09.110.G.

Setbacks

The following sections provide the horizontal and vertical setbacks for infiltration facilities. Deviations from these setbacks must be approved by the Director and require a report stamped and signed by a licensed professional stating that the siting of an infiltration facility within a setback will not cause an adverse impact to the public or the environment.

Horizontal Setbacks

For most infiltration BMPs, setbacks are measured from the vertical extent of maximum ponding before overflow. For bioretention and rain gardens, setback distances are as measured from the bottom edge of the bioretention or rain garden soil mix (i.e., bioretention cell bottom at the toe of the side slope).

- Infiltration is not permitted within 5 feet from property lines (excluding the property line abutting the right-of-way) without agreement from neighboring property owners.
- Infiltration is not permitted within the following setbacks from onsite and offsite structures:
    - When runoff from <5,000 square feet of new/replaced impervious area is infiltrated on site, the facility shall not be within 5 feet from structure without basement and 10 feet from structure with basement.
    - When runoff from ≥5,000 square feet of new/replaced impervious area is infiltrated on site, a building structure shall not intersect with a 1H:1V slope from the bottom edge of an infiltration facility. The resulting setback shall be no less than 5 feet from a structure without basement and 10 feet from a structure with basement. For setbacks from structures on adjacent lots, potential structures should be considered for future build-out conditions.
- Infiltration is not permitted within 100 feet of drinking water supply wells or springs used for drinking water.
- Infiltration is not permitted within a groundwater protection area unless approved by the King County Department of Health and the Director. If approved, water quality treatment may be required.
- Infiltration is not permitted within 10 feet an underground storage tank or connecting underground pipes when the capacity of the tank and pipe system is 1100 gallons or less. (Applicable to tanks used to store petroleum products, chemicals, or liquid hazardous wastes.)
- Infiltration is not permitted within 100 feet of an underground storage tank or connecting underground pipes when the capacity of the tank and pipe system is greater than 1,100 gallons.
- Rain gardens, bioretention, permeable pavement facilities, infiltration trenches and drywells are not permitted within 10 feet of proposed or existing septic systems or

drain fields. Other infiltration BMPs are not permitted within 100 feet up-gradient of proposed or existing septic systems or drain fields.

- Infiltration is not permitted within 100 feet up-gradient of a contaminated site or abandoned landfill.

Vertical Setbacks

Infiltration facilities require a minimum vertical separation from the bottom of the facility to the underlying groundwater table or hydraulically-restrictive material as determined by the licensed professional.

The separation requirements depend upon the facility's tributary area and the seasonal timing of the geotechnical exploration conducted to evaluate clearance. Following are the separation requirements that apply when explorations are conducted in the wet season (November through March):

- A minimum of 3 feet of clearance (is necessary between the lowest elevation of the facility and the seasonal high groundwater elevation or hydraulically-restrictive material if the area tributary to the facility meets or exceeds any of the following limitations:
    - 5,000 square feet of pollution-generating impervious surface
    - 10,000 square feet of impervious area
    - 3/4 acres (32,670 square feet) of lawn and landscaped area
- If the tributary area to an individual facility does not exceed the area thresholds above, a minimum of 1 foot of clearance is adequate between the lowest elevation of the facility and the seasonal high groundwater elevation or hydraulically-restrictive material. This clearance also applies to permeable pavement facilities regardless of size.
- If explorations are conducted outside of the wet season (April through October), the clearance requirements to groundwater only increase from 3 feet to 8 feet for larger contributing areas and from 1 foot to 3 feet for smaller contributing areas.

Restrictions Specific to Contaminated Soil or Groundwater

Infiltration has the potential to mobilize contaminants present in soil and groundwater. Therefore, stormwater infiltration systems may not be constructed on sites where soil and/or groundwater contamination problems have been identified. In addition, infiltration is not permitted within 100 feet up-gradient of a contaminated site or landfill (active or closed). For projects where runoff from 5,000 square feet or more of impervious area will be infiltrated on site, infiltration within 500 feet up-gradient of a contaminated site or landfill (active or closed)requires analysis and approval by a licensed hydrogeologist.

Setbacks and exclusion areas shall be measured from the site of the proposed infiltration facility to the nearest extent of contamination, or if not known, the edge of the parcel where contamination has been found.

Contaminated sites are regulated by the U.S. Environmental Protection Agency (EPA) and Ecology. Refer to the following websites for information on potentially contaminated sites:

- EPA Superfund Program site list (http://www.epa.gov/superfund/sites/index.htm)
- EPA Resource Conservation and Recovery Act (RCRA) Program site list (http://www.epa.gov/epawaste/hazard/correctiveaction/facility/index.htm)
- EPA mapping tool that plots the locations of Superfund and RCRA-regulated sites (http://www.epa.gov/environ/emef/)
- Ecology regulated contaminated sites (http://www.ecy.wa.gov/fs/)
- Ecology Toxics Cleanup Program website (http://www.ecy.wa.gov/cleanup.html)

5.4.1.6. Step 3: Conduct Subsurface Characterization and Testing

The level of subsurface exploration and testing required for the siting and design of infiltration facilities depends on the total impervious area contributing runoff to infiltration facilities on the project site. The minimum exploration and testing requirements are provided in Table 5.11. Additional information about these requirements is provided below.

In some cases, available data and the licensed professional's interpretation of subsurface material characteristics can be used to demonstrate that infiltration is infeasible on a site and precludes the need for all of the subsurface characterization or testing prescribed in Table 5.11. Examples of these instances include, but are not limited to:

- Groundwater monitoring data at the proposed facility site showing groundwater elevations not meeting the vertical setback criterion.
- Identification by the licensed professional of hydraulically-restrictive materials beneath the proposed facility and within the vertical setback criterion. Examples of materials that may be interpreted as hydraulically-restrictive include:
    - Glacially consolidated soils that have greater than 50 percent fines
    - Glacially unconsolidated soils that have greater than 70 percent fines
    - Bedrock

To support these instances, the licensed professional must submit a stamped and signed letter that provides rationale and specific data supporting their professional judgment.

Geotechnical Explorations

Geotechnical explorations are required to identify subsurface and groundwater conditions that may affect performance of the infiltration facility. Explorations should be performed at the location of the proposed facility or as close as possible, but no more than 50 feet away. The seasonal timing, number and depth of geotechnical explorations required are provided in Table 5.11 and exploration procedures are provide in Appendix D.

Table 5.11. Minimum Exploration and Testing Requirements for Infiltration Facility Design.

Impervious Area Infiltrated On-site [a]	Geotechnical Explorations		Infiltration Tests		Groundwater Monitoring [c]		Characterization of Infiltration Receptor	Groundwater Mounding Analysis	Verification Testing
	Minimum Number and Location of Explorations	Minimum Exploration Depth [b]	Minimum Number and Location of Tests	Types of Tests	Minimum Number of Wells	Duration			
Shallow Infiltration Facilities (non-UIC)									
<2,000 ft^2	1 per facility[d] AND 1 per 75 feet of facility length Preferably, the exploration is conducted at the location of the proposed facility, but it must be within 50 feet of the facility location.	Minimum exploration in accordance with Simple Test procedures in *Appendix D*	1 per 75 feet of facility length Preferably, the test is conducted at the location of the proposed facility, but it must be within 50 feet of the facility location.	Simple Test	No	NA	No	No	No
≥2,000 to <5,000 ft^2		• Explorations conducted between November and March shall extend 2 feet below the bottom of proposed facility, and if groundwater or a hydraulically-restrictive material is encountered within 1 foot of the bottom of the facility, no further investigation is required • Explorations conducted between April and October shall extend 4 feet below the bottom of proposed facility, and if a hydraulically-restrictive material is encountered within 1 foot or groundwater is encountered within 3 feet of the bottom of the facility, no further investigation is required		Simple Test (If all of the on-site infiltration will occur within a single facility, the Small PIT method is recommended.)	No	NA			No
≥5,000 to <10,000 ft^2		• Explorations conducted between November and March that will not serve as groundwater monitoring wells shall extend 4 feet below the bottom of proposed facility, and if groundwater or a hydraulically-restrictive material is encountered within 3 feet of the bottom of the facility, no further investigation is required • Explorations conducted between April and October that will not serve as groundwater monitoring wells shall extend 10 feet below the bottom of proposed facility and if a hydraulically-restrictive material is encountered within 3 feet or groundwater is encountered within 8 feet of the bottom of the facility, no further investigation is required • if the bottom of the facility is not known, the minimum exploration depth shall be 16 feet below grade; • Explorations that will also serve as groundwater monitoring wells shall not be less than 20 feet below the bottom of proposed facility and the criteria for vertical separation to groundwater or hydraulically-restrictive materials listed above shall apply	1 per 75 feet of facility length If licensed professional determines continuity of subsurface materials based on site explorations, fewer PITs may be used. Additional PITs are required if the subsurface materials are discontinuous. Preferably, the test is conducted at the location of the proposed facility, but it must be within 50 feet of the facility location.	Small PIT	Minimum of 1 point	Through at least one wet season (November through March); if within 200 feet of Lake Union, Lake Washington, or the Ship Canal, monitoring through an entire year is required			No
≥10,000 ft^2 to <1 acre				Small PIT	Minimum of 3 points	Through at least 1 year	Yes	Yes	Yes
≥1 acre				Small or Large PIT					

Table 5.11 (continued). Minimum Exploration and Testing Requirements for Infiltration Facility Design.

Impervious Area Infiltrated On-site [a]	Geotechnical Explorations		Infiltration Tests		Groundwater Monitoring [c]		Characterization of Infiltration Receptor	Groundwater Mounding Analysis	Verification Testing
	Minimum Number and Location of Explorations	Minimum Exploration Depth [b]	Minimum Number and Location of Tests	Types of Tests	Minimum Number of Wells	Duration			
Shallow UIC Infiltration Facilities (≤15 ft deep)									
Drywells up to 6 feet deep	Apply requirements for shallow infiltration facilities								
≥5,000 to <10,000 ft^2	1 at every UIC location AND 1 per 75 feet of facility length Preferably, the exploration is conducted at the location of the proposed facility, but it must be within 50 feet of the facility location.	• Explorations conducted between November and March that will not serve as groundwater monitoring wells shall extend 4 feet below the bottom of proposed facility, and if groundwater or a hydraulically-restrictive material is encountered within 3 feet of the bottom of the facility, no further investigation is required • Explorations conducted between April and October that will not serve as groundwater monitoring wells shall extend 10 feet below the bottom of proposed facility and if a hydraulically-restrictive material is encountered within 3 feet or groundwater is encountered within 8 feet of the bottom of the facility, no further investigation is required • Explorations that will also serve as groundwater monitoring wells shall not be less than 20 feet below the bottom of proposed facility and the criteria for vertical separation to groundwater or hydraulically-restrictive materials listed above shall apply	One at every UIC location	Small PIT	Minimum of 1 point	Through at least one wet season (November through March); if within 200 feet of Lake Union, Lake Washington, or the Ship Canal, monitoring through an entire year is required	No	No	Yes
≥10,000 ft^2				Large PIT	Minimum of 3 points	Through at least 1 year	Yes	Yes	Yes
Deep UIC Infiltration Facilities (>15 ft deep)									
<10,000 ft^2	One at every UIC location	At least 10 feet below regional groundwater table or into aquitard underlying target soil	One at every UIC location	Deep UIC Infiltration Test	Minimum of 3 points	Through at least one wet season (November through March); if within 200 feet of Lake Union, Lake Washington, or the Ship Canal, monitoring through an entire year is required	No	No	Yes
≥10,000 ft^2						Through at least 1 year	Yes	Yes	Yes

[a] On-site is defined for SFR and Parcel projects as the project area; for Trail, Sidewalk or Roadway projects, it is defined by one intersection to the other and blocks may vary in length.

[b] Exploration depth below the bottom of the proposed infiltration facility. The bottom of the facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into native soil. For Small and Large PITs, sampling of distinct materials below the bottom of the facility and within the vertical setback is required. Beyond this depth, samples should be taken every 2.5 feet.

[c] Groundwater monitoring is not required if available piezometer data within 50 feet of the proposed facility shows the highest groundwater level to be at least 20 feet below the bottom of the proposed facility

[d] For bioretention or raingardens, a facility refers to either a single cell, or a series of cells connected in series, with the overflows of upstream cells directed to downstream cells to provide additional flow control and/or treatment and conveyance

Infiltration Tests

This manual includes four methods of field infiltration testing:

- Small-scale infiltration test (Simple Test)
- Small Pilot Infiltration Test (PIT)
- Large PIT
- Deep UIC infiltration test

The type of infiltration test required for a project is provided in Table 5.11 and varies by the impervious area routed to infiltration facilities on a development site. Infiltration testing procedures methods are provided in *Appendix D*. The small PIT and large PIT test reports shall be prepared by a Washington State licensed professional experienced in infiltration testing.

Groundwater Monitoring

Groundwater monitoring is required when runoff from more than 5,000 square feet of impervious surface is infiltrated on site (refer to Table 5.11). For projects infiltrating runoff from more than 5,000 and less than 10,000 square feet of impervious area, one monitoring well is required to establish groundwater elevations near the facility. For projects infiltrating runoff from 10,000 square feet or more of impervious area, a minimum of three groundwater monitoring wells are required per site to establish groundwater flow direction and gradient.

Characterization of the Infiltration Receptor

For projects proposing to infiltrate runoff from more than 10,000 square feet of impervious surface, the infiltration receptor (unsaturated and saturated soil receiving the stormwater) shall be characterized (refer to Table 5.11). Characterization of the infiltration receptor shall include assessment and documentation of the following elements:

- Depth to groundwater and to hydraulically-restrictive material
- Seasonal variation of groundwater table based on well water levels and observed mottling of soils
- Existing groundwater flow direction and gradient
- Approximation of the lateral extent of infiltration receptor
- Volumetric water holding capacity of the infiltration receptor soils. The volumetric water holding capacity is the storage volume in the soil layer directly below the infiltration facility and above the seasonal high groundwater mark, or hydraulically-restrictive material.
- Horizontal hydraulic conductivity of the saturated zone to assess the aquifer's ability to laterally transport the infiltrated water

As part of the infiltration receptor characterization for deep UICs, the treatment capacity in the vadose zone (the unsaturated sediments between the bottom of the well and the top of

an unconfined aquifer) should be evaluated in accordance with the UIC Guidance Manual (Ecology 2006) to determine pretreatment requirements.

5.4.1.7. Step 4: Groundwater Mounding

Infiltration of large volumes of water may result in a rise in the water table or development of a shallow water table on hydraulically-restrictive materials that slow the downward percolation of water. If this mounding of water is excessive, the infiltration facility may become less effective and/or adjacent structures or facilities may be impacted by the rising water table. In addition, if the infiltration facility is adjacent to a slope, slope stability may be decreased. To address this, a mounding analysis shall be required for projects that will be infiltrating on site greater than or equal to 10,000 sf of impervious area and where the depth to the seasonal high groundwater elevation or hydraulically-restrictive material is less than 15 feet below the bottom of the proposed facility to evaluate the impact of the infiltration facility on local groundwater flow direction and water table elevations.

The groundwater mounding analysis procedures are provided in *Appendix D*.

Determining Design Infiltration Rate

Infiltration rates are measured using the procedures presented in *Appendix D*. The measured infiltration rate must be reduced using correction factors to account for site variability and number of tests conducted, uncertainty of the test method, and potential for long-term clogging due to siltation and bio-buildup. The corrected infiltration rate is considered the "long-term" or "design" infiltration rate and is used for all BMP sizing calculations.

Correction factors are provided in *Appendix D*. A minimum total correction factor (CF_T) of 0.5 shall be applied to all measured infiltration rates. In addition, the design infiltration rate (after applying the correction factor) shall not exceed 10 inches per hour.

Verification Testing for Infiltration Facilities

Verification testing is required for infiltration facilities and UICs receiving runoff from greater than 5,000 square feet of impervious area. It may be required for smaller facilities if the City determines there may be a risk of infiltration system failure. Site conditions that may justify infiltration facility verification testing include, but are not limited to,

- Soil and groundwater conditions observed during construction that are different than those observed at the test locations
- Presence of hydraulically-restrictive subsurface materials
- History of infiltration failure in the project area
- High groundwater levels
- Risk of flooding in the event of system failure
- Indications of sediment loads to the facility during construction
- Indications of soil compaction during construction

- New information gained during construction with regards to infiltration facility design and performance (e.g., better subsurface characterization, groundwater data, etc.).

Specific verification testing procedures for shallow infiltration facilities are not provided and shall be developed by the licensed professional responsible for design of the infiltration facility. At a minimum, the verification testing shall demonstrate that the infiltration facility performs at the design infiltration rates, and groundwater mounding does not reduce the performance of the facility or impact nearby structures

Verification testing of shallow and deep UIC shall consist of the infiltration testing procedures described in *Appendix D*.

Infiltration Facility Sizing

The Pre-Sized Approach for sizing infiltration facilities may be used when the new and replaced impervious surface associated with a project does not exceed 10,000 square feet. Sizing factors for selected infiltration facilities are provided in the BMP Sizing sections of *Chapter 5*.

For larger sites, or to use BMPs or design configurations not included in the Pre-Sized Approach, infiltration facilities must be sized to meet on-site stormwater management, flow control and/or water quality treatment requirements using an approved continuous simulation hydrologic model (refer to *Appendix F*). Below are the procedures for sizing an infiltration facility to (A) infiltrate 100 percent of runoff; (B) meet the water quality treatment requirements, and (C) meet flow peak and/or duration control standard.

(A) For 100 percent infiltration (e.g., for project sites without a point of discharge):

- Input dimensions of your infiltration facility
- Input design infiltration rate (measured infiltration rate with CF_T applied)
- Input a riser height and diameter to represent the facility overflow conditions (any flow through the riser indicates that you have less than 100 percent infiltration and must increase your infiltration facility dimensions)
- Run the model and review the model-reported percentage of runoff infiltrated. If less than 100 percent infiltrated, increase facility dimension until you achieve 100 percent infiltration. There is no need to check duration when infiltrating 100 percent of the full continuous record runoff file.

(B) For 91 percent infiltration (water quality treatment requirement):

The procedure is the same as above, except that your target is to infiltrate 91 percent of the influent runoff volume. In addition, to prevent the onset of anaerobic conditions, an infiltration facility designed for water quality treatment purposes must be designed to drain the water quality design treatment volume within 48 hours. The water quality design treatment volume is reported by the approved models.

The drawdown time can be calculated by using a horizontal projection of the infiltration basin mid-depth dimension and the estimated design infiltration rate. See also the infiltration soil requirements for treatment outlined in *Section 5.4.1.7*.

Infiltration facilities for treatment can be located upstream or downstream of detention and can be off-line or on-line (refer to *Section 4.2.1*). Refer to *Appendix E* for flow splitter design details.

(C) To meet flow peak and/or duration standard with infiltration:

This design allows less than 100 percent infiltration as long as any facility overflows meet the numerical peak and/or duration standards outlined in *Volume 1, Chapter 2*. Set up the model as explained for 100 percent infiltration. Run the model and review the flow duration and flow frequency results to determine if the standard is achieved.

Soil Requirements for Infiltration Treatment

The soil requirements for infiltration treatment vary depending on the type of facility. Many infiltration facilities (e.g., infiltration basins and trenches) rely on the properties of the native soils (i.e., existing underneath the facility) to meet treatment requirements. Bioretention systems utilize imported soils meeting specific criteria to meet treatment requirements. The following sections summarize the applicable soil requirements for each facility.

Native Soil Requirements for Infiltration Treatment Facilities

Infiltration basins, infiltration trenches, and permeable pavement facilities meet the requirements for basic, phosphorus, and enhanced treatment provided that the following Soil Suitability Criteria (SSC) are met:

- **SSC#1**: For infiltration facilities used for treatment purposes, the measured (initial) soil infiltration rate shall be 9 inches/hour, or less. Design (long-term) infiltration rates up to 3.0 inches/hour can also be considered, if the infiltration receptor is not a sole-source aquifer, and in the judgment of the experienced licensed professional, the treatment soil has characteristics comparable to those specified in SSC#2 to adequately control the target pollutants.
- **SSC#2**: The underlying soil to a depth of at least 18 inches must meet the following conditions:
    - Cation exchange capacity (CEC), as determined by U.S. EPA Method 9081, of the soil must be greater than or equal to 5 milliequivalents per 100 milligrams of dry soil. Lower CEC content may be considered if it is based on a soil loading capacity determination for the target pollutants that is approved by the Director.
    - Organic content of the treatment soil (ASTM D 2974): Organic matter can increase the sorptive capacity of the soil for some pollutants. Soil organic content should be at least 1 percent; however, the licensed professional

designing the facility should evaluate whether the organic matter content is sufficient for control of the target pollutant(s).

- **SSC#3**: Waste materials shall not be used as infiltration media.

Imported Soil Requirements for Bioretention Systems

Bioretention facilities (*Section 5.4.4* and *Section 5.8.2*) meet the requirements for basic and enhanced treatment, but are not subject to the same native soil infiltration treatment requirements for basins and trenches discussed above (i.e., SSC#1 through #3) because they utilize the City-specific standards for imported bioretention soil mix. Soil requirements for bioretention facilities designed to meet water quality treatment requirements are summarized below:

1. The bioretention soil mix shall meet the City of Seattle Bioretention Soil Standard Specification 7-21.

2. The minimum depth of treatment soil must be 18 inches.

5.4.1.8. Presettling and Pretreatment Requirements for Infiltration Facilities

Infiltration facilities may require presettling or pretreatment as described below.

Presettling

Infiltration practices are susceptible to clogging by suspended solids in stormwater runoff. A presettling technique may be required at the flow entrance of a facility to capture debris and sediment load from contributing areas. Do not include the area designated for presettling in the footprint sizing for water quality treatment and flow control. Refer to individual BMPs in *Chapter 5* for presettling requirements.

Pretreatment

When water quality treatment requirements are triggered, treat runoff from pollution generating surfaces with a basic treatment BMP prior to infiltration or design the infiltration facility to meet treatment requirements. Many infiltration facilities meet basic and enhanced water quality treatment requirements (refer to *Section 3.3*) when it is shown that at least 91 percent of the total runoff volume for the simulation period is infiltrated through a media which meets the treatment soil requirements outlined in *Section 5.4.1.7*. Applicable drawdown requirements must also be met (see *Section 4.1.3.3*). Infiltration practices in areas that contribute uncontrolled concentrations of oil, grease, floatable organic or floatable inorganic material require analysis to ensure adequate pretreatment.

5.4.1.9. Minimum Construction Requirements for Infiltration Facilities

During construction, it is critical that the subgrade soils be protected from clogging and compaction to maintain the soil properties identified during infiltration testing (e.g., infiltration capacity) and ensure facility performance. The minimum construction requirements common to infiltration facilities are provided below.

- **General**: The approved plan sheets provide construction sequencing that protect the infiltration facility during construction.

- **Sediment Control**: Protect the infiltration facility from sedimentation that can clog the facility and reduce infiltration capacity.
    - Minimize site disturbance at the location of the infiltration facility and in up-gradient areas.
    - Do not use infiltration facilities as sediment control facilities.
    - Direct all drainage away from the facility location after initial rough grading. Flow can be directed away from the facility with temporary diversion swales or other approved protection.
    - Do not construct infiltration facilities until all contributing drainage areas are stabilized with appropriate erosion and sediment control BMPs and to the satisfaction of the engineer.
    - Inspect and maintain erosion and sediment control practices on a regular basis. If deposition of sediment occurs in the infiltration area, remove material and scarify the surface to a minimum depth of 3 inches.
- **Compaction Prevention**: Soil compaction can lead to a reduction of infiltration rates and facility failure; accordingly, minimizing compaction of the base and sidewalls of the infiltration area is critical. Before the development site is graded, rope/fence the area of the infiltration facility to restrict access and flagged to prevent soil compaction by heavy equipment. Perform excavation with machinery operating adjacent to the infiltration facility and do not allow heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires on the bottom of the infiltration facility footprint. Do not excavate during wet or saturated conditions.
- **Scarification**: The soil surface can become smeared and sealed by excavation equipment. Scarify or rake the sidewalls and bottom of an infiltration facility excavation to a minimum depth of 3 inches after excavation to restore infiltration rates.

5.4.2. Infiltration Trenches

5.4.2.1. Description

Infiltration trenches are backfilled with a coarse aggregate, allowing for temporary storage of stormwater runoff in the voids of the aggregate material. Stored runoff gradually infiltrates into the surrounding soil. Stormwater runoff can enter the trench as overland surface flow through a grate or exposed aggregate surface, or as concentrated flow delivered to the aggregate-filled trench using a perforated or slotted distribution pipe.

5.4.2.2. Performance Mechanisms

Flow control occurs through temporary storage of stormwater runoff in the spatial voids of the aggregate material and subsequent infiltration of stormwater into the underlying soils. Pollutant removal mechanisms include infiltration, filtration, sedimentation, biological decomposition, and soil adsorption.

5.4.2.3. Applicability

An infiltration trench can be designed to provide on-site stormwater management, flow control and/or water quality treatment. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Infiltration Trenches	✓[a]	✓	✓	✓	✓	✓[b]	✓[b]			

[a] Infiltration trenches must be considered for compliance with the On-site List requirement when the site measured infiltration rate is at least 0.5 inches per hour.

[b] Soil suitability criteria (SSC) for subgrade soils (*Section 5.4.1*) and applicable drawdown requirements (*Section 5.4.1*) must be met.

5.4.2.4. Site Considerations

Site considerations for the applicability of infiltration trenches include:

- **Setbacks and Separation**: Infiltration trenches must meet the requirements for infiltration facilities presented in *Section 5.4.1*. Requirements include horizontal setbacks and a minimum vertical separation from the bottom of the facility to the underlying water table, bedrock, or other impermeable layer.

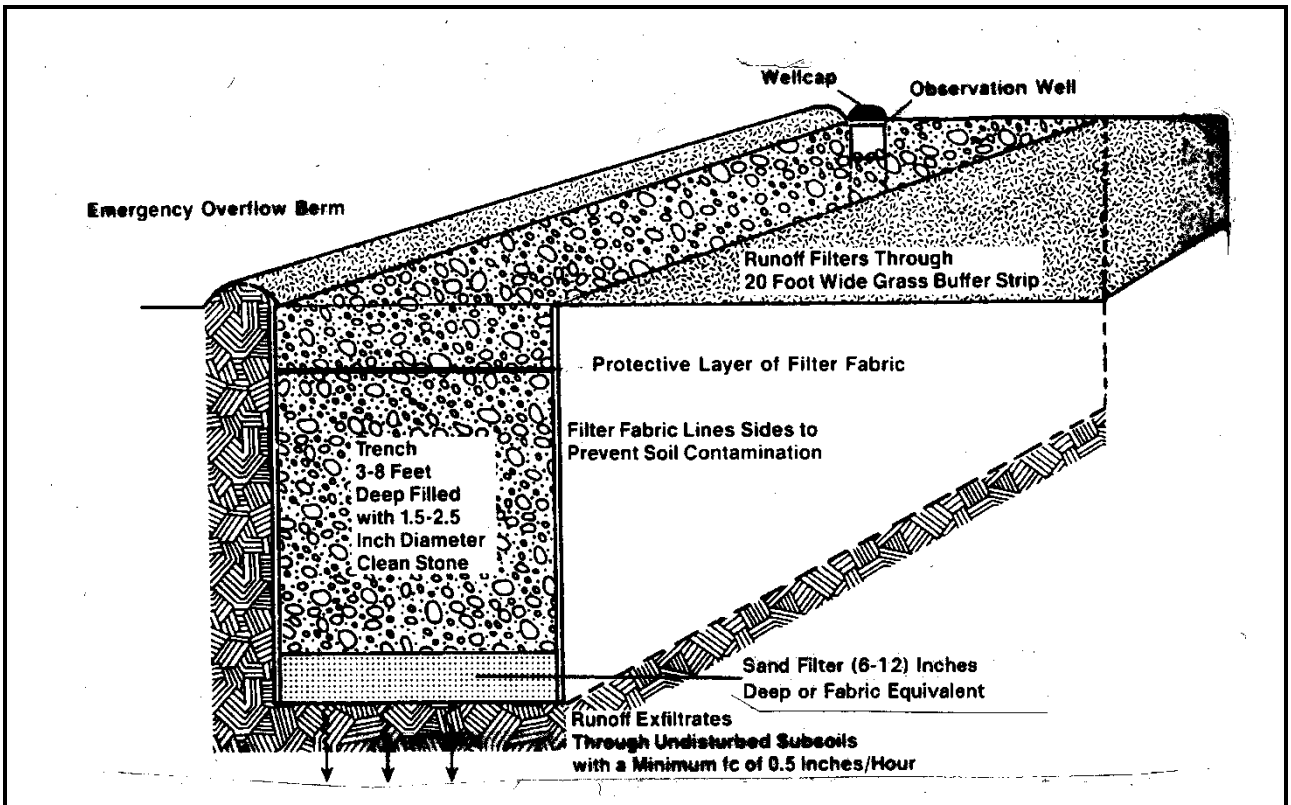
- **Subgrade Soil Infiltration Rate**: The existing underlying and surrounding subgrade soils are a principal factor for determining infiltration capacity and facility sizing. Lower infiltration rates will necessitate a larger trench to achieve performance standards. Infiltration testing methods are provided in *Appendix D*.

- **Underground Injection Control (UIC)**: Infiltration trenches may be considered UIC systems and subject to Department of Ecology requirements (refer to *Section 5.4.1*).

5.4.2.5. Design Criteria

This section provides a description and requirements for the components of infiltration trenches. See Figure 5.8 for schematic of a typical infiltration trench. Design criteria are provided in this section for the following elements:

- Trench dimensions and layout
- Aggregate material
- Geotextile
- Flow entrance and presettling
- Observation well
- Overflow



Source: Department of Ecology

Figure 5.8. Typical Infiltration Trench.

Trench Dimensions and Layout

The minimum requirements associated with the trench dimensions and layout include the following:

- The minimum depth of an infiltration trench must be 18 inches.
- The minimum width of an infiltration trench must be 24 inches. Sides of adjacent trenches must be a minimum of 5 feet apart.
- The bottom of the trench must be level.

To maximize the storage depth in the trench, the trench should be oriented parallel to site contour lines. The trench can be placed under a pervious or impervious surface cover to conserve space.

Aggregate Material

Trenches must be filled with uniformly-graded, washed gravel with a nominal size from 3/4- to 1-1/2-inch diameter. The minimum void volume must be 30 percent. These requirements can be met with City of Seattle Mineral Aggregate Type 4.

Geotextile

Non-woven geotextile fabric, according to the specifications presented in *Appendix E*, must completely surround the aggregate material. A 6-inch minimum layer of sand may be used as a filter media at the bottom of the trench instead of geotextile.

Flow Entrance and Presettling

For trenches designed to receive sheet flow, the site must be graded so that runoff is directed as sheet flow across a minimum 10-foot grass buffer strip to remove larger sediment particles prior to runoff entering the trench. One foot of gravel must be placed over the geotextile covering the trench aggregate to allow flows to enter the trench.

Trenches designed to receive concentrated stormwater flows must include a catch basin with trap and sump upstream of the trench to capture sediment and reduce the potential for clogging. Concentrated flows must be distributed into the aggregate material using a perforated or slotted subsurface pipe with a minimum diameter of 4 inches.

Observation Well

Infiltration trenches that are designed to meet flow control and/or treatment requirements and receive runoff from contributing areas of 2,000 square feet or more must be equipped with an observation well to measure the drawdown time following a storm and to monitor sedimentation to determine maintenance needs. Observation wells must consist of a 4-inch minimum diameter perforated or slotted pipe that extends to the bottom of the trench (i.e., to the subgrade) and is equipped with a secure well cap, located at a point approximately halfway along the trench length.

Overflow

Trenches must have an overflow designed to convey excess flow to an approved point of discharge per Section 4.3.2.

To prevent damage to overlying pavement, trenches located beneath pavement must be constructed with a trench pipe overflow connected to a small yard drain or catch basin with a

grate cover. Design must be such that, if the trench infiltration capacity is exceeded, the trench pipe overflow would occur out of the catch basin to an approved point of discharge. The vertical elevation difference between the pavement surface and the trench pipe overflow invert shall be 1 foot minimum.

5.4.2.6. BMP Credits

On-site List Approach

The impervious surface area mitigated with an infiltration trench sized according to Table 5.12 meets the On-site List Requirement. Aggregate-filled trench shall be a minimum of 24 inches wide and 18 inches deep. Trenches can be made wider and shorter if the total trench area is equivalent to the minimum required per Table 5.12 and the trench bottom is level. Note that infiltration trenches are considered infeasible for measured infiltration rates less than 0.5 inches per hour.

Table 5.12. On-site List Sizing for Infiltration Trenches.

Subgrade Short-term (measured) Infiltration Rate (inch/hour)	Trench Length (L) (ft) per 1,000 square feet of Impervious Area
20	20
8	30
2	75
1	125
0.5	190

Trench Length (ft) = (Contributing Impervious Area (sf)/1,000) x L

5.4.2.7. Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized infiltration trenches may be used to achieve Pre-developed Pasture, Peak Control and Treatment Standards. Sizing factors for infiltration trenches receiving runoff from an impervious surface are provided in Table 5.13. Factors are organized by flow control standard, trench depth, and subgrade soil design infiltration rate. A 1.5-foot or 3-foot aggregate storage reservoir depth may be selected. The “aggregate storage reservoir” is the subsurface aggregate layer below the overflow invert elevation that stores water for infiltration into the underlying subgrade soils (refer to Figure 5.8). The design rate for the subgrade soils must be rounded down to the nearest infiltration rate in the pre-sized table (i.e., 0.25, 0.5, or 1.0 inch per hour).

To use these sizing factors to meet flow control standards, the facility must meet the general requirements for infiltration trenches outlined in this section, plus the following specific requirements:

- The trench area must be sized using the applicable sizing factor.
- The average aggregate storage reservoir depth across the trench must be set at the designated height (1.5 or 3 feet). For intermediate ponding depths (between 1.5 and 3.0 feet), the sizing factor may be linearly interpolated.

- To use these pre-sized infiltration trenches to meet the water quality treatment standard, the underlying soil must meet treatment soil requirements specified in *Section 5.4.1*.
- The aggregate storage reservoir must be composed of Mineral Aggregate Type 4 or approved equal.
- Invert of overflow must be set at top of the storage reservoir to provide the required aggregate storage reservoir depth (e.g., pipe invert set at 1.5 or 3 feet if the bottom of the trench is flat).

Table 5.13. Sizing Factors for Infiltration Trenches.

Trench Depth	Subgrade Soil Design Infiltration Rate	Sizing Factor for Infiltration Trench Area		
		Pre-developed Pasture Standard	Peak Control Standard	Water Quality Treatment Standard
1.5 feet	0.25 inch/hour	27.3%	55.1%	12.7%
	0.5 inch/hour	16.8%	30.0%	8.3%
	1.0 inch/hour	10.7%	17.4%	5.3%
3.0 feet	0.25 inch/hour	17.0%	31.9%	8.6%
	0.5 inch/hour	12.0%	20.1%	5.9%
	1.0 inch/hour	7.8%	13.1%	4.0%

Infiltration Trench Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Trench Area ÷ Factor (%)/100

The infiltration trench facility area is calculated as a function of the area contributing runoff to the trench. As an example, to meet the Pre-developed Pasture Standard, the trench area would be equal to 27.3 percent of the contributing area when the subgrade infiltration rate is between 0.25 and 0.5 inches per hour and the trench depth is 1.5 feet.

Alternatively, infiltration trench facilities can be sized using a continuous hydrologic simulation model as described in the subsequent section.

Modeling Approach

When using continuous hydrologic modeling to size infiltration trenches, the assumptions listed in Table 5.14 must be applied. It is recommended that infiltration trenches be modeled as a gravel-filled trench with infiltration to underlying soil and an overflow. The tributary areas, trench area, and depth should be iteratively sized until the Minimum Requirements for On-site Stormwater Management and/or Flow Control are met (refer to *Volume 1 - Project Minimum Requirements*). General sizing procedures for infiltration facilities are presented in *Section 5.4.1*.

Table 5.14. Continuous Modeling Assumptions for Infiltration Trench Facilities.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series.
Computational Time Step	5-minutes.
Inflows to Facility	Surface flow and interflow from drainage area routed to facility.
Precipitation and Evaporation Applied to Facility	Yes, if sited under pervious surface. If model does not apply precipitation and evaporation to facility, include the facility area in the basin area.
Aggregate Storage Reservoir Depth	Average depth of aggregate below overflow invert.
Aggregate Storage Reservoir Porosity	Assume maximum 30 percent unless test showing higher porosity is provided.
Subgrade Soil Design Infiltration Rate	Measured infiltration rate with correction factor applied (*Section 5.4.1*, *Appendix D*.
Infiltration Across Wetted Surface Area	No (bottom area only).
Outlet Structure	Overflow elevation set at average maximum subsurface ponding depth. May be modeled as weir flow over riser edge or notch. Note that freeboard must be sufficient to allow water surface elevation to rise above the overflow elevation to provide head for discharge.

5.4.2.8. Minimum Construction Requirements

During construction, it is critical to prevent clogging and over-compaction of the subgrade. Construction requirements for infiltration facilities are provided in *Section 5.4.1*. Additional minimum requirements associated with infiltration trench construction include the following:

- **Aggregate Placement and Compaction** – Place the stone aggregate in lifts and compact using plate compactors. As a rule of thumb, a maximum loose lift thickness of 12 inches is recommended. The compaction process aids in adhering the geotextile to the excavation sides, thereby, reducing soil piping, geotextile clogging, and settlement problems.

- **Potential Contamination** – Prevent natural or fill soils from intermixing with the aggregate. Remove all contaminated aggregate and replace with uncontaminated aggregate.

- **Overlap** - Following the stone aggregate placement, fold the geotextile over the stone aggregate to form a 12-inch minimum longitudinal overlap. When geotextile overlaps are required between rolls, overlap the upstream roll a minimum of 2 feet over the downstream roll in order to provide a shingled effect.

For inspection and verification procedures used for facility approval by City staff, refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

5.4.2.9. Operations and Maintenance Requirements

General O&M requirements for infiltration facilities apply to infiltration trenches. Infiltration trench O&M requirements are provided in *Appendix G (BMP No. 2)*.

5.4.3. Drywells

5.4.3.1. Description

Drywells are similar to infiltration trenches but are typically deeper and require less surface area. Stormwater is delivered to the drywell by pipe.

5.4.3.2. Performance Mechanisms

Flow control occurs through temporary storage of stormwater runoff in the spatial voids of the aggregate material, and subsequent infiltration of stormwater into the underlying soils.

5.4.3.3. Applicability

A drywell can be designed to provide on-site stormwater management and/or flow control. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Drywell	✓[a]	✓	✓	✓	✓					

[a] Drywells must be considered for compliance with the On-site List requirement when the site measured infiltration rate is at least 5 inches per hour.

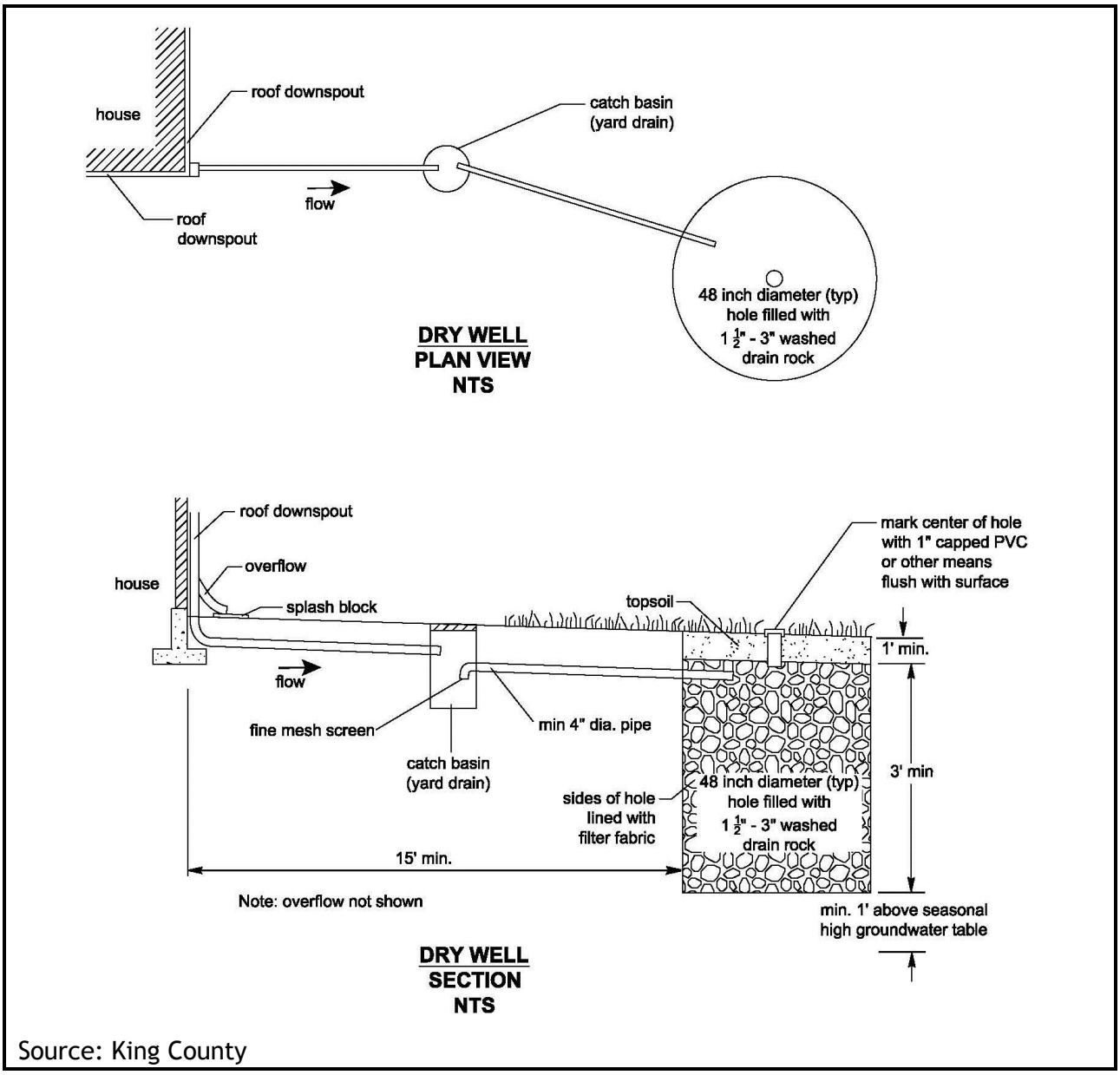
5.4.3.4. Site Considerations

Site considerations are the same as presented for infiltration trenches (refer to *Section 5.4.2.4*). Drywells are more likely to be considered underground injection control (UIC) systems because they are often deeper than the largest surface dimension (refer to *Section 5.4.1*).

5.4.3.5. Design Criteria

This section following provides a description and requirements for the components of drywells. Figure 5.9 shows a typical drywell system. Design criteria are provided in this section for the following elements:

- Drywell dimensions and layout
- Aggregate material
- Geotextile
- Flow entrance and presettling
- Observation well
- Overflow



Source: King County

Figure 5.9. Typical Infiltration Drywell.Drywell Dimensions and Layout

Minimum requirements associated with the drywell dimensions and layout include the following:

- The minimum depth of a drywell must be 3 feet.
- Spacing between drywells must be a minimum of 10 feet.

The drywell can be placed under a pervious or impervious surface cover to conserve space.

Aggregate Material

Drywells must be filled with uniformly graded, washed gravel with a nominal size from 3/4- to 1-1/2-inch diameter. The minimum void volume must be 30 percent. These requirements can be met with City of Seattle Mineral Aggregate Type 4.

Geotextile

Non-woven geotextile fabric, according to the specifications presented in *Appendix E*, must be placed around the walls, bottom and top of the drywell aggregate. A 6-inch minimum layer of sand may be used as a filter media at the bottom of the well instead of geotextile.

Flow Entrance and Presettling

Stormwater inflows must be routed through a catch basin with trap and sump upstream of the drywell to capture sediment and reduce the potential for clogging. Flows must be delivered to the drywell aggregate using a perforated or slotted subsurface pipe with a 4-inch minimum diameter.

Observation Well

Drywells that are designed to meet flow control requirements and receive runoff from contributing areas of 5,000 square feet or more must be equipped with an observation well to measure the drawdown time following a storm and to monitor sedimentation to determine maintenance needs. Observation wells must consist of a 4-inch minimum diameter perforated or slotted pipe that extends to the bottom of the trench (i.e., to the subgrade) and is equipped with a secure well cap.

Overflow

Drywells must have an overflow designed to convey excess flow to an approved point of discharge per *Section 4.3.2*.

To prevent damage to overlying pavement, trenches located beneath pavement must be constructed with a trench pipe overflow connected to a small yard drain or catch basin with a grate cover. Design must be such that, if the trench infiltration capacity is exceeded, the trench pipe overflow would occur out of the catch basin to an approved point of discharge. The vertical elevation difference between the pavement surface and the trench pipe overflow invert shall be one foot minimum.

5.4.3.6. BMP Sizing

On-site List Approach

The impervious surface area mitigated with a drywell sized according to Table 5.15 meets the On-site List Requirement. Note that drywells are considered infeasible for measured infiltration rates less than 5 inches per hour.

Table 5.15. On-site List Sizing for Drywells.

Short-term (measured) Infiltration Rate (inch/hour)	Aggregate Volume (V) (cf) per 1,000 Square Feet of Impervious Area
20	60
8	90

Drywell Aggregate Volume (sf) = (Contributing Impervious Area (sf)/1,000) x V
Drywell shall be a minimum of 48 inches in diameter.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized drywells may be used to achieve Pre-developed Pasture and Peak Control Standards. Sizing factors for drywells receiving runoff from an impervious surface are provided in Table 5.16. Factors are organized by flow control standard, drywell depth, and subgrade soil design infiltration rate. A 4-foot or 6-foot aggregate storage reservoir depth may be selected. The "aggregate storage reservoir" is the subsurface aggregate layer below the overflow invert elevation that stores water for infiltration into the underlying subgrade soils. The design rate for the subgrade soils must be rounded down to the nearest infiltration rate in the pre-sized table (i.e., 0.25, 0.5, or 1.0 inch per hour). To use these sizing factors to meet flow control standards, the facility must meet the general requirements for drywells outlined in this section plus the following specific requirements:

- The drywell area must be sized using the applicable sizing factor.
- The average aggregate storage reservoir depth in the drywell must be set at the designated height (4 or 6 feet). For intermediate ponding depths (between 4 and 6 feet), the sizing factor may be linearly interpolated.
- The aggregate storage reservoir must be composed of Mineral Aggregate Type 4 or approved equal.
- The invert of the overflow must be set at top of the storage reservoir to provide the required aggregate storage reservoir depth (e.g., pipe invert set at 4 or 6 feet if the bottom of the well is flat).

Table 5.16. Sizing Factors for Drywells.

Drywell Depth	Subgrade Soil Design Infiltration Rate	Sizing Factor for Drywell Area	
		Pre-developed Pasture Standard	Peak Control Standard
4.0 feet	0.25 inch/hour	13.6%	24.9%
	0.5 inch/hour	10.1%	17.6%
	1.0 inch/hour	6.7%	11.1%
6.0 feet	0.25 inch/hour	9.7%	17.5%
	0.5 inch/hour	7.9%	13.2%
	1.0 inch/hour	5.7%	8.9%

Drywell Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Drywell Area ÷ Factor (%)/100

The drywell facility area is calculated as a function of the area contributing runoff to the drywell. As an example, to meet the Pre-developed Pasture Standard, the well area would be equal to 7.9 percent of the contributing area when the subgrade infiltration rate is between 0.5 and 1.0 inches per hour and the well depth is 6.0 feet.

Alternatively, drywell facilities can be sized using a continuous hydrologic simulation model as described in the subsequent section.

Modeling Approach

Continuous hydrologic modeling may be used to size drywells using the general infiltration facility sizing procedures presented in *Section 5.4.1* and the procedures presented for infiltration trenches in *Section 5.4.2.6*.

5.4.3.7. Minimum Construction Requirements

During construction, it is critical to prevent clogging and over-compaction of the subgrade. Construction requirements for infiltration facilities are provided in *Section 5.4.1*. For inspection and verification procedures used for facility approval by City staff, refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

5.4.3.8. Operations and Maintenance Requirements

General O&M requirements for infiltration facilities apply to drywells. Drywell O&M requirements are provided in *Appendix G (BMP No. 2)*.

5.4.4. Infiltrating Bioretention

5.4.4.1. Description

Infiltrating bioretention facilities are shallow earthen depressions or containers (e.g., concrete planter) with a designed soil mix and plants adapted to the local climate and soil moisture conditions. Stormwater is stored as surface ponding before it filters through the underlying bioretention soil. Stormwater that exceeds the surface storage capacity overflows to an adjacent drainage system. Treated water is either infiltrated into the underlying soil or collected by an underdrain and discharged to the drainage system.

Two variations of infiltrating bioretention facilities are included in this section:

- **Infiltrating bioretention facility**: Bioretention facilities can have either sloped sides (e.g., an earthen depression) or vertical sides (e.g., vertical walled container with an open bottom). Infiltrating bioretention cells are not lined, and may or may not have an underdrain or outlet control structure (e.g., orifice).
- **Infiltrating bioretention facility series**: Bioretention facilities with sloped or vertical sides may be connected in series, with the overflows of upstream cells directed to downstream cells to provide additional flow control and/or treatment and conveyance.

Infiltration facilities must meet the requirements in *Section 5.4.1*.

Rain gardens are similar to infiltrating bioretention facilities, but are subject to fewer technical requirements (refer to *Section 5.4.5*). Bioretention facilities are considered "non-infiltrating" if they include a liner or other impermeable barrier to prevent infiltration to the underlying soil (refer to *Section 5.8.2*).

5.4.4.2. Performance Mechanisms

Infiltrating bioretention provides flow control via detention, attenuation, and losses due to infiltration, interception, evaporation, and transpiration. Water quality treatment is accomplished through sedimentation, filtration, uptake, or biodegradation and transformation of pollutants by soil organisms, soil media, and plants.

5.4.4.3. Applicability

Infiltrating bioretention facilities can be designed to provide on-site stormwater management, flow control and/or water quality treatment. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Infiltrating bioretention without underdrain	✓	✓	✓	✓	✓	✓	✓			✓[a]
Infiltrating bioretention with underdrain	✓	TBD			✓	✓	✓			✓[a]

[a] Infiltrating bioretention facilities may be connected in series, with the overflows from upstream cells directed to downstream cells to provide conveyance.

5.4.4.4. Site Considerations

Due to the geologic and topographic conditions in Seattle, not all sites are suitable for stormwater infiltration. General requirements and limitations related to infiltrating facilities are provided in *Section 5.4.1*. The following are key considerations for determining the feasibility of bioretention facilities for a particular site:

- **Setbacks and Separation**: Bioretention facilities with infiltration to underlying soils must meet the requirements for infiltration facilities presented in *Section 5.4.1*. Requirements include horizontal setbacks and a minimum vertical separation from the bottom of the facility to the underlying water table, bedrock, or other impermeable layer.

- **Subgrade soil infiltration rate***:* The existing underlying and surrounding subgrade soils are a principal factor for determining infiltration capacity, facility sizing, and facility type. Lower infiltration rates will necessitate a larger facility to achieve performance standards and may require an underdrain. Infiltration testing methods are provided in *Appendix D*.

- **Site topography**: On sloped sites, bioretention facilities with side slopes require a larger facility footprint area. In addition, infiltration is prohibited in and near certain sloped areas (refer to *Section 5.4.1*).

- **Phosphorous considerations***:* Infiltrating bioretention is not permitted within 1/4 mile of nutrient-critical receiving waters if the underlying native soil does not meet the treatment soil requirements outlined in *Section 5.4.1*. Bioretention with an underdrain is not permitted if the underdrained water would be routed to a nutrient-critical receiving water.

5.4.4.5. Design Criteria

This section provides a description, recommendations, and requirements for the components of bioretention facilities. Typical components of bioretention facilities without underdrains and with underdrains are shown in Figures 5.10 and 5.11, respectively.

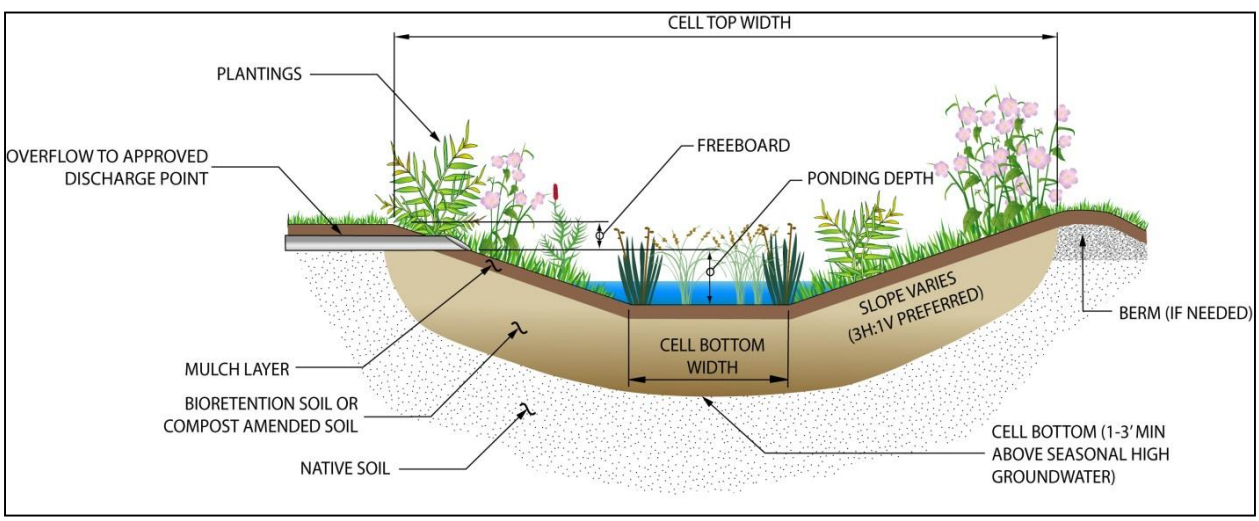


Figure 5.10. Infiltrating Bioretention Facility with no Underdrain.

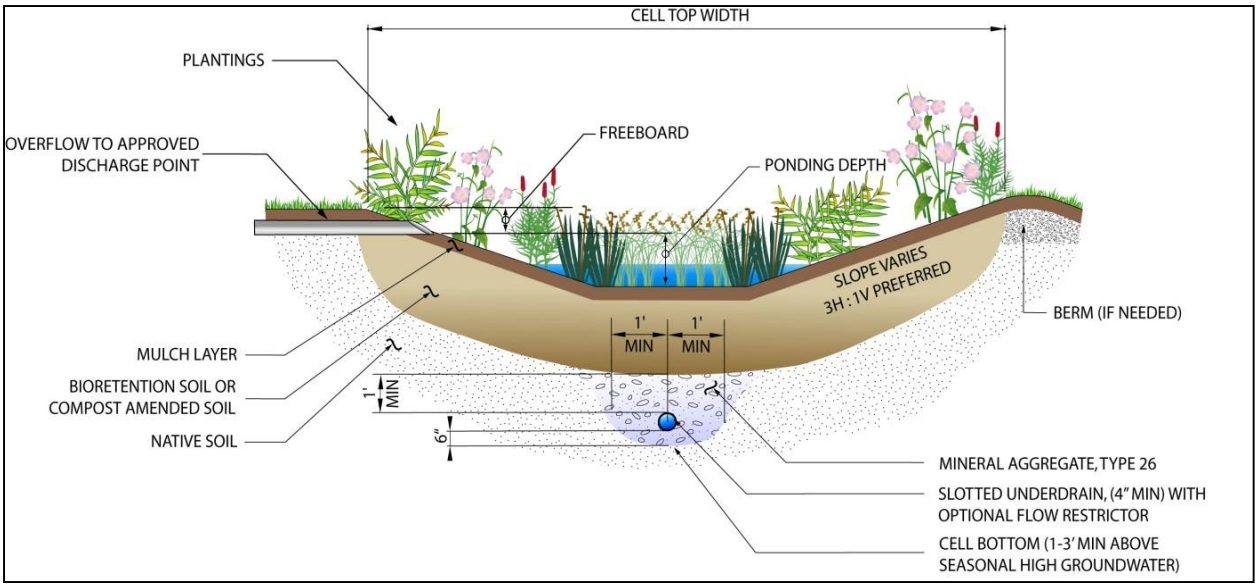


Figure 5.11. Infiltrating Bioretention Facility with Underdrain.

Design criteria are provided in this section for the following elements:

- Contributing area
- Flow entrance
- Pre-settling
- Ponding area
- Bioretention soil
- Underdrain
- Flow restrictor
- Overflow
- Hydraulic restriction layers
- Plant material
- Mulch layer
- Observation port

The Low Impact Development Technical Guidance Manual for Puget Sound (Puget Sound LID Manual) provides additional guidance on bioretention design. The Seattle Right-of-Way Improvements Manual provides additional guidance for bioretention facilities in the public right-of-way.

Contributing Area

The contributing area to a bioretention facility is limited as follows:

- No single facility must receive runoff from more than 5,000 square feet[2] of impervious area, except as noted below for a series of bioretention cells.
- Runoff from more than 5,000 square feet of impervious area may be directed to an upstream cell in a bioretention series (interconnected series of cells).

The bioretention facility should be sized to meet the performance standard for the contributing area routed to the facility. It is recommended that facilities not be oversized because the vegetation in oversized facilities may not receive sufficient stormwater runoff for irrigation, increasing maintenance requirements. Bioretention facilities sited in the right-of-way must not be oversized.

Stormwater flows from other areas (beyond the area for which the facility is sized) must be bypassed around the facility in order to reduce sediment loading to the cell and the potential for bioretention soil clogging and increased maintenance. For water quality treatment facilities, if bypass is not feasible, facilities must be sized to treat runoff from the entire area draining to the facility. While it is also preferred that flow control facilities be sized to manage only the area draining to the facility, excess flows may be routed through a bioretention facility sized to meet flow control standards with the following limitations:

- The maximum impervious drainage area that may be routed to a bioretention facility cannot exceed twice the impervious area for which it is sized. Additional runoff contributions from pervious areas are acceptable. No flow control credit is given for runoff from areas beyond the design area.
- Additional runoff routed to a facility must be clearly noted on submitted plans.
- The plans must show how overflows will be conveyed to the downstream point of discharge.
- The overflow conveyance infrastructure requires engineering design to safely convey runoff from the total catchment area (refer to *Section 4.3*).
- Pre-settling measures must be designed for the total catchment area.
- Calculations must demonstrate that the water velocities in the vegetated areas of the facility do not exceed 2 feet per second during the 25-year recurrence interval flow (calculated through the narrowest vegetated cross section of the facility).

Flow Entrance

Flow entrances must be sized to capture flow from the catchment area and designed to both reduce the potential for clogging at the inlet and prevent inflow from causing erosion in the facility. Four primary types of flow entrances can be used for bioretention facilities: dispersed flow (e.g., vegetated buffer strips), sheet flow, curb cuts, and concentrated flow

[2] Area limitation is to ensure that bioretention facilities are small-scale and distributed.

(e.g., piped flow). Vegetated buffer strips are the preferred entrance type because they slow incoming flows and provide initial settling of particulates.

The minimum requirements associated with the flow entrance design include the following:

- For sheet flow into a facility, a minimum 1-inch drop from the edge of a contributing impervious surface to the vegetated flow entrance is required. This drop is intended to allow for less frequent maintenance by allowing some sediment/debris buildup at the edge before sheet flow into the facility is impeded.
- For curb cut flow entrances, the curb cut width must be sized based on the catchment area, longitudinal slope along the curb, and the cross slope at the inlet. The minimum curb cut width must be 8 inches for non-right-of-way applications (e.g., parking lots) and 10 inches in the right-of-way (refer to the Seattle Right-of-Way Improvements Manual).
- Curb cut flow entrances must have either a minimum of 5 percent slope from the outer curb face extending to a minimum of 12 inches beyond the back of curb, or provide a minimum of a 2-inch vertical drop from the back of curb to the vegetated surface of the facility.
- If concentrated flows are entering the facility, flow energy dissipation (e.g., rock/cobble pad or flow dispersion weir) must be incorporated to reduce the potential for erosion at the inlet.

Pre-settling

Pre-settling may be required at the flow entrance of a bioretention facility to capture debris and sediment load from contributing catchment areas. By having a designated "pre-settling zone" maintenance can be targeted in this area to remove sediment build-up.

The area designated as the "pre-settling zone" must not be included in the footprint size required to meet on-site stormwater management, flow control and/or water quality treatment standards. However, the "pre-settling zone" must be included in the total landscaped area for evaluation against the 500 square foot threshold for O&M infeasibility applicable to facilities in the right-of-way (*Appendix C*).

The minimum requirements associated with the pre-settling design include the following:

- The minimum pre-settling requirements for bioretention facilities sited in non-Roadway Projects are provided in Table 5.15.
- The minimum pre-settling requirements for bioretention facilities sited in Roadway Projects are provided in the Table 5.16.

Note that individual cells may not receive runoff from more than 5,000 square feet of impervious surface; therefore, pre-settling will only be triggered for bioretention facility series that receive runoff from larger areas.

Table 5.17. Pre-settling Requirements for Bioretention Facilities in Non-Roadway Projects.

Impervious Area (square feet) Contributing Runoff to a Single Flow Entrance	Pre-settling Requirements
<5,000	No pre-settling is required.
≥5,000 and <10,000	The bottom of the first 2 to 3 feet of the upstream bioretention cell (at the flow entrance) must be designated the "Pre-settling Zone." This bottom area of the cell must be constructed of cobbles, concrete open celled paving grids, plastic lattices filled with gravel or groundcover vegetation, a pre-cast concrete pad, or similar material for collection of sediment for maintenance. Alternatively, a catch basin (such as COS Type 241 or 240) with a minimum 2-foot sump may be used as the pre-settling zone. Where the pipe (from the catch basin) daylights into the bioretention cell, energy dissipation from the catch basin into the bioretention cell must be provided.
≥10,000	Pre-settling requirements are project specific, to be determined by designer and approved by the Director.

Ponding Area

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the bioretention facility. The minimum requirements for ponding area design for facilities with both side slopes and vertical sides include:

- The bottom area of an individual cell must be no larger than 800 square feet (limitation is to ensure that bioretention facilities are small-scale and distributed).
- The ponding depth must be a maximum of 12 inches. In high density right-of-way applications, the ponding depth must be no greater than 6 inches (refer to the Seattle Right-of-Way Improvements Manual).
- The surface pool drawdown time must be a maximum of 24 hours (drain time is calculated as a function of ponding depth and subgrade soil design infiltration rate).
- Freeboard must be provided to ensure that any overflows are safely conveyed to an approved point of discharge. The minimum freeboard measured from the invert of the overflow point (e.g., standpipe, earthen channel, curb cut) to the overtopping elevation of the facility must be 2 inches for drainage areas less than 1,000 square feet, and 6 inches for drainage areas 1,000 square feet or greater. Less freeboard is allowable if calculations show 3 inches of freeboard are provided during the 25-year recurrence interval flow.
- The site must be graded such that any flows exceeding the capacity of the facility are safely conveyed to an approved point of discharge.

Table 5.18. Pre-settling Requirements for Bioretention Facilities in Roadway Projects.

Longitudinal Length of Street (L) or Impervious Area (A) Contributing Runoff to a Single Flow Entrance	Pre-settling Requirements
Residential Streets	
L ≤ 360 linear feet of gutter OR A ≤ 6,700 square feet of ROW Impervious Area (Road, Sidewalk)	No pre-settling is required.
360 < L ≤ 660 linear feet of gutter OR 6,700 < A ≤ 12,300 square feet of ROW Impervious Area (Road & Sidewalk)	The bottom of the first 2-3 feet of the upstream bioretention cell (at the flow entrance) must be designated the "Pre-settling Zone." This bottom area must be constructed of a pre-cast concrete pad surrounded by cobbles per detail in the Seattle Right-of-Way Improvements Manual.
L > 660 linear feet of gutter OR A > 12,300 square feet of ROW Impervious Area (Road & Sidewalk)	Pre-settling requirements are project specific, to be determined by designer and approved by the Director.
Arterial Streets	
L ≤ 360 linear feet of gutter OR A ≤ 9,000 square feet of ROW Impervious Area (Road, Sidewalk).	No pre-settling is required.
360 < L ≤ 660 linear feet of gutter OR 9000 < A ≤ 16,500 square feet of ROW Impervious Area (Road & Sidewalk5).	The bottom of the first 2-3 feet of the upstream bioretention cell (at the flow entrance) must be designated the "Pre-settling Zone." This bottom area must be constructed of a pre-cast concrete pad surrounded by cobbles per detail in the Seattle Right-of-Way Improvements Manual.
L > 600 linear feet of gutter OR A > 16,500 square feet of ROW Impervious Area (Road & Sidewalk)	Pre-settling requirements are project specific, to be determined by designer and approved by the Director.

Additional minimum requirements for ponding area design specific to bioretention facilities with side slopes include the following:

- The maximum planted side slope must be 2.5H:1V. If total facility depth exceeds 3 feet, the maximum planted side slope is 3H:1V. If steeper sides are necessary, rockery, concrete walls, or steeper soil wraps may be used.
- If berming is used to achieve the minimum top facility elevation needed to meet ponding depth and freeboard needs, maximum slope on berm must be 2.5H:1V, and minimum top width of design berm must be 1 foot. Soil used for berming must be

imported bioretention soil or amended subgrade soil and compacted to a minimum of 90 percent dry density.

- The bottom width of a flat-bottomed facility varies when sited on a sloped grade. The average bottom width for the facility must be no less than 18 inches.

Additional minimum requirements for ponding area design specific to bioretention facilities with vertical sides include the following:

- The facility width (planted area between walls) must be no less than 2 feet.

Bioretention Soil

Proper soil specification, preparation, installation, and maintenance are critical factors for bioretention performance. The minimum requirements associated with bioretention soil design include:

- The bioretention soil must meet City of Seattle Standard Specification 7-21 (http://www.seattle.gov/util/greeninfrastructure). The specification may be met in two ways:
    - Imported bioretention soil that meets the standard specification may be used.
    - If the subgrade soil meets the aggregate specification in the City of Seattle Standard Specification 7-21, it may be amended with compost per the specification, rather than importing materials.
- For facilities without underdrains, imported or amended soil depth must be a minimum depth of 12 inches for on-site stormwater management and flow control credit, and 18 inches for water quality treatment credit.
- For facilities with underdrains, the imported or amended soil must have a minimum depth of 18 inches.

Filter fabrics should not be used between the bioretention soil layer and the underlying subgrade unless specified by a geotechnical engineer. Filter fabrics are often not required because the gradation between the bioretention soil and the subgrade soil is typically not large enough to result in significant migration of fines from the subgrade into the bioretention soil. Additionally, filter fabrics may clog with downward migration of fines from the bioretention soil material.

Underdrain (Optional)

Underdrain systems (refer to Figure 5.11) should be installed only if the bioretention area is located where infiltration is not permitted and a liner is used, or where subgrade soils have infiltration rates that do not meet the maximum pool drawdown time. In these cases underdrain systems can be installed and the facility can be used to filter pollutants and detain flows. However, designs utilizing underdrains provide less infiltration and flow control benefits.

The underdrain pipe diameter will depend on hydraulic capacity required. The underdrain can be connected to a downstream BMP, such as another bioretention cell as part of a connected system, or to an approved point of discharge.

Elevating the underdrain above the bottom of the facility to create a temporary saturated zone beneath the drain promotes denitrification (conversion of nitrate to nitrogen gas), prolongs moist soil conditions for plant survival during dry periods, and promotes infiltration and volume reduction for unlined systems.

The minimum requirements associated with the underdrain design include:

- Slotted, thick-walled plastic pipe must be used. For specification refer to SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).
- Pipe must have a minimum diameter of 4 inches.
- Underdrain pipe slope must be no less than 0.5 percent.
- Pipe must be placed in filter material and have a minimum cover depth of 4 inches.
- Filter material must meet the specifications of City of Seattle Mineral Aggregate Type 26 (gravel backfill for drains, City of Seattle Standard Specifications).
- A 6-inch non-perforated cleanout must be connected to the underdrain every 300 feet minimum.

Flow Restrictor (Optional)

A flow restrictor assembly may be installed at the outlet of an underdrain system to further detain outflow. The orifice diameter may be sized to achieve the desired performance goal. The minimum requirements associated with the flow restrictor design include:

- An inspection chamber (catch basin or maintenance hole with clearances per City of Seattle Standard Plans 270 and 272A) must be installed at the flow control assembly to allow for access and maintenance.
- The minimum orifice diameter must be 0.25 inches. Note that a smaller orifice size is allowed for this subsurface application because the bioretention soil serves as a filter, making clogging of the orifice less likely.

Overflow

A bioretention facility overflow controls overtopping, with a pipe, an earthen channel or a curb cut installed at the designed maximum ponding elevation and connected to a downstream BMP or an approved point of discharge.

The minimum requirements associated with the overflow design include the following:

- Overflows must convey excess flow to approved point of discharge per *Section 4.3.2*.
- The drain pipe, if used, must have a minimum diameter of 4 inches.

Hydraulic Restriction Layers (Optional)

Infiltrating bioretention facilities infiltrate stormwater into the underlying soil. However, adjacent roads, foundations, slopes, utilities, or other infrastructure may require that some infiltration pathways are restricted to prevent excessive hydrologic loading. Two types of hydraulic restricting layers can be incorporated into bioretention facility designs:

- Clay (bentonite) liners as low permeability liners
- Geomembrane liners which completely block flow

The hydraulic restriction layer must not be used across the entire facility bottom. Only the infiltrating bottom area (i.e., unlined) must be used in sizing calculations or hydrologic modeling.

Plant Material

In general, the predominant plant material used in bioretention facilities are species adapted to stresses associated with wet and dry conditions. Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, wetland plants may be planted in the lower areas and drought-tolerant species planted on the perimeter of the facility or on mounded areas.

The minimum requirements associated with the vegetation design include the following:

- The design plans must specify that vegetation coverage of selected plants will achieve 90 percent coverage within 2 years or additional plantings will be provided until this coverage requirement is met.
- For facilities receiving runoff from 5,000 square feet or more impervious surface, plant spacing and plant size must be designed to achieve specified coverage by a certified landscape architect.
- The plants must be sited according to sun, soil, wind, and moisture requirements.
- At a minimum, provisions must be made for supplemental irrigation during the first two growing seasons following installation.

Refer to the Puget Sound LID Manual for guidance on plant selection and recommendations for increasing survival rates. Recommended planting lists can be found in the Puget Sound LID Manual, the Seattle Right-of-Way Improvements Manual, and the Seattle Green Factor plant list (http://www.seattle.gov/util/greeninfrastructure). Plants for bioretention facilities sited in the right-of-way must be selected from the Green Factor plant list.

Mulch Layer

Properly selected organic mulch material reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to the soil. Compost and arborist wood chip mulch are recommended for different applications within the bioretention cell. Compost mulch is an excellent slow-release source of plant nutrients and does not float, but compost does not suppress weed growth as well as bulkier, higher carbon mulches like wood chips.

Arborist wood chips are superior to bark mulch in promoting plant growth, feeding beneficial soil organisms, reducing plant water stress, and maintaining surface soil porosity.

Organic mulch must consist of the following:

- Compost (per City of Seattle Standard Specification 9-14.4(9)) in the bottom of the facility and up to the ponding elevation
- Arborist wood chip mulch (per City of Seattle Standard Specification 9-14.4(5)) on cell slopes above the ponding elevation and the around the rim area
- A minimum of 2 inches and a maximum of 3 inches for both types of organic mulch

Organic mulch must not include:

- Weed seeds
- Soil
- Roots and other material that are not from the aboveground components of a tree
- Mineral aggregate
- Pure bark (Bark is essentially sterile and inhibits plant establishment.)
- Grass clippings (Decomposing grass clippings are a source of nitrogen and phosphorus and are not recommended for mulch in bioretention areas.)

In bioretention areas where higher flow velocities are anticipated, an aggregate mulch may be used to dissipate flow energy and protect underlying bioretention soil. Aggregate mulch varies in size and type, but 1- to 1-1/2-inch gravel (rounded) decorative rock is typical. The area covered with aggregate mulch must not exceed one third of the facility bottom area.

As an alternative to mulch, a dense groundcover may be used. Mulch is required in conjunction with the groundcover until groundcover is established. Mulch is not required for turf-vegetated cells.

Observation Port

Bioretention cells that are designed to meet flow control and/or treatment requirements and receive runoff from contributing areas of 2,000 square feet or more must be equipped with an observation port to allow monitoring of the drawdown time through the subsurface layers (e.g., bioretention soil) following a storm. The observation port must consist of a 4-inch minimum diameter pipe that extends to the bottom of the cell (i.e., to the subgrade) and is hydraulically disconnected from the ponding section and hydraulically connected to the bioretention soil layer and any underlying aggregate storage reservoir. The pipe must be equipped with a secure well cap. The observation port may be located either within the ponded area or offset outside of the cell for access adjacent to the facility. For cells with underdrains, the observation port may be combined with the underdrain cleanout system.

5.4.4.6. BMP Sizing

On-site List Approach

Infiltrating bioretention applied to meet the On-site List Approach shall be sized according to the sizing factors provided in Table 5.19. Factors are organized by ponding depth and subgrade soil design infiltration rate. A 2- or 6- inch facility ponding depth may be selected. The design rate for the subgrade soils must be rounded down to the nearest infiltration rate in the sizing table (i.e., 0.25, 0.5, or 1.0 inch per hour). The facility must meet the general requirements for infiltrating bioretention outlined in this section plus the following specific requirements:

- The bottom area shall be sized using the applicable sizing factor.
- The bottom area shall be flat (0 percent slope).
- Side slopes within ponded area shall be no steeper than 3H:1V.
- The bioretention soil depth shall be a minimum of 12 inches.
- The minimum ponding depth shall be set at the designated height (2 or 6 inches). For intermediate ponding depths (between 2 and 6 inches), the sizing factor may be linearly interpolated.
- No underdrain or impermeable liner shall be used.

Table 5.19. On-site List Sizing for Infiltrating Bioretention.

Ponding Depth	Subgrade Soil Design Infiltration Rate	Sizing Factor for Bioretention Bottom Area On-Site Performance Standard
2-inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	
	1.25 inches/hour	
6-inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	
	1.25 inches/hour	

– sizing factors not provided; NA- not applicable
Bioretention Bottom Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Bioretention Bottom Area ÷ Factor (%)/100

The *bottom* area for the cell is calculated as a function of the impervious area routed to it. As an example, the bottom area of the bioretention cell would be equal to X percent of the impervious area routed to it when the subgrade infiltration rate is equal to or greater than 1.0 inch per hour and the ponding depth is 6 inches. The total bioretention footprint area (top

area) can be calculated as a function of the cell bottom area, the side slopes and the total facility depth (i.e., ponding and freeboard depth).

The bioretention bottom area required as presented in Table 5.19 may be reduced as much as 50 percent if it is demonstrated that a larger area cannot be achieved given site constraints.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), simple equations are used to calculate the size of "pre-designed" bioretention facilities subject to specific design requirements (e.g., side slope). In this section, the Pre-Sized Approach for infiltrating bioretention without underdrains is provided. For infiltrating bioretention facilities with underdrains, the sizing factors provided for non-infiltrating bioretention may be used (refer to *Section 5.8.2.6*).

Pre-sized infiltrating bioretention facilities without underdrains may be used to achieve the Pre-developed Pasture, Peak Flow Control and Treatment Standards. Sizing factors for infiltrating bioretention facilities without underdrains are provided in Table 5.20. Factors are organized by configuration (i.e., sloped sides or vertical sides), performance standard, facility ponding depth, and subgrade soil design infiltration rate. A 2-, 6-, or 12-inch facility ponding depth may be selected. The design infiltration rate for the subgrade soils must be rounded down to the nearest infiltration rate in the pre-sized table (i.e., 0.25, 0.5, or 1.0 inch per hour). To use these pre-sized facilities, the bioretention facility must meet the general requirements outlined in this section plus the following specific requirements:

- The bottom area must be sized using the applicable sizing factor.
- The bottom area must be flat (0 percent slope).
- For facilities with sloped sides, the side slopes within the ponded area must be no steeper than 3H:1V.
- For facilities without underdrains, the bioretention soil depth must be a minimum of 12 inches for flow control and 18 inches for water quality treatment.
- For facilities with underdrains, the amended soil must have a minimum depth of 18 inches.
- The minimum ponding depth must be set at the designated height (2, 6, or 12 inches). For intermediate ponding depths (between 2 and 12 inches), the sizing factor may be linearly interpolated.

The bottom area for the bioretention facility area is calculated as a function of the impervious area routed to it. As an example, to meet the Pre-developed Pasture Standard, the bottom area of the bioretention facility without an underdrain would be equal to 6.4 percent of the impervious area routed to it when the subgrade infiltration rate is equal to or greater than 1.0 inch per hour and the ponding depth is 6 inches. For facilities with sloped sides, the total facility footprint area (top area) is calculated as a function of the bottom area, the side slopes and the total facility depth (i.e., ponding and freeboard depth).

Table 5.20. Sizing Factors for Infiltrating Bioretention.

Bioretention Configuration	Ponding Depth	Subgrade Soil Design Infiltration Rate	Sizing Factor for Facility Bottom Area		
			Pre-developed Pasture Standard	Peak Control Standard	Water Quality Treatment Standard
Sloped sides	2-inches	0.25 inch/hour	23.0%	–	–
		0.5 inch/hour	15.8%	–	–
		1.0 inch/hour	9.3%	–	–
	6-inches	0.25 inch/hour	14.6%	33.1%	5.0%
		0.5 inch/hour	9.9%	20.5%	2.9%
		1.0 inch/hour	6.4%	10.6%	1.6%
	12-inches	0.25 inch/hour	NA	NA	N/A
		0.5 inch/hour	6.5%	13.4%	1.7%
		1.0 inch/hour	4.1%	6.7%	0.9%
Vertical sides	6-inches	0.25 inch/hour			
		0.5 inch/hour			
		1.0 inch/hour			
	12-inches	0.25 inch/hour			
		0.5 inch/hour			
		1.0 inch/hour			

– sizing factors not provided; NA- not applicable

Bioretention Facility Bottom Area = Contributing Impervious Area x Factor (%)/100

Impervious Area Mitigated = Bioretention Facility Bottom Area ÷ Factor (%)/100

Bioretention facilities with 12 inches of ponding must have a design subgrade soil infiltration rate of at least 0.5 inches per hour to achieve drawdown requirements.

Alternatively, infiltrating bioretention facilities can be sized using a continuous simulation hydrologic model as described in the subsequent section.

Modeling Approach

When using continuous simulation hydrologic modeling to size bioretention cells, the assumptions listed in Table 5.21 must be applied. It is recommended that bioretention cells be modeled as a layer of soil (with specified infiltration rate and porosity) with ponding, infiltration to underlying soil and overflow. The contributing area, cell bottom area, and ponding depth should be iteratively sized until the Minimum Requirements for On-site Stormwater Management, Flow Control and/or Treatment are met (*Volume 1, Chapter 3*). General sizing procedures for infiltration facilities are presented in *Section 5.4.1*.

Table 5.21. Continuous Modeling Assumptions for Bioretention Cells.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Inflows to Facility	Surface flow and interflow from drainage area routed to facility.
Precipitation and Evaporation Applied to Facility	Yes. If model does not apply precipitation and evaporation to facility, include the facility area in the basin area (note that this will underestimate the evaporation of ponded water).
Bioretention Soil Infiltration Rate	The design infiltration rate must be 6 inches per hour.
Bioretention Soil Porosity	A 30 percent porosity must be assumed for facility sizing.
Bioretention Soil Depth	For facilities without underdrains, the soil must have a minimum of 12 inches for flow control and minimum of 18 inches for water quality treatment. For facilities with underdrains, the soil must have a minimum depth of 18 inches.
Subgrade Soil Design Infiltration Rate	Measured infiltration rate with correction factor applied (*Section 5.4.1*, *Appendix D*)
Infiltration Across Wetted Surface Area	Yes (unless hydraulic restriction layers are used to prevent infiltration on the side slopes).
Underdrain (optional)	If an underdrain is placed at bottom extent of the bioretention soil layer, all water that filters through the bioretention soil must be routed through the underdrain (i.e., no losses to infiltration). If there is no liner or impermeable layer and the underdrain is elevated above the bottom extent of the bioretention soil or aggregate layer, water stored in the bioretention soil or aggregate below the underdrain invert may be allowed to infiltrate.
Overflow Structure	The overflow elevation must be set at the maximum ponding elevation (excluding freeboard). It may be modeled as weir flow over a riser edge or notch. Note that the total facility depth (including freeboard) must be sufficient to allow water surface elevation to rise above the overflow elevation to provide head for discharge.

5.4.4.7. Minimum Construction Requirements

During construction, it is critical to prevent clogging and over-compaction of the subgrade and bioretention soils. General construction requirements for infiltration facilities are provided in *Section 5.4.1*. Additional minimum requirements associated with bioretention facility construction include the following:

- Place bioretention soil must per the requirements of City of Seattle Standard Specifications and amend subgrade soil per *Section 5.1*.
- Do not excavate or place soil or soil amendment during wet or saturated conditions.

For inspection and verification procedures used for facility approval by City staff, refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

5.4.4.8. Operations and Maintenance Requirements

Bioretention O&M requirements are provided in *Appendix G (BMP No. 22)*.

5.4.5. Rain Gardens

5.4.5.1. Description

Rain gardens are shallow, landscaped depressions with compost amended soil or imported bioretention soil and plants adapted to the local climate and soil moisture conditions. Stormwater is stored as surface ponding before it filters through the underlying amended soil. Stormwater that exceeds the surface storage capacity overflows to an adjacent drainage system. Treated water is infiltrated into the underlying soil.

Rain gardens are infiltration facilities and must meet the requirements in *Section 5.4.1*.

Rain gardens are similar to infiltrating bioretention facilities (refer to *Section 5.4.4*) with the following exceptions:

- Rain gardens may only be used to meet on-site stormwater management requirements and must not be used on projects that trigger water quality treatment or flow control requirements.
- Rain gardens may not have a liner or underdrain.
- The maximum ponding depth is 6 inches.
- Rain gardens may have compost amended soil rather than imported bioretention soil.
- There are no presettling requirements.
- A small-scale infiltration test may be used instead of a pilot infiltration test (PIT).
- A certified landscape architect is not required for vegetation design.
- Rain gardens must not receive runoff from a public roadway.
- Observation ports are not required.

5.4.5.2. Performance Mechanisms

Like infiltrating bioretention, rain gardens provide flow control via detention, attenuation, and losses due to infiltration, interception, evaporation, and transpiration. Water quality treatment is accomplished through sedimentation, filtration, adsorption, phytoremediation, and biodegradation of pollutants by soil organisms.

5.4.5.3. Applicability

As shown in the table below, rain gardens can only be designed to provide on-site stormwater management. To meet flow control and/or water quality treatment standards, an infiltrating bioretention facility may be used (refer to *Section 5.4.4*).

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Rain garden	✓									

5.4.5.4. Site Considerations

Due to the geologic and topographic conditions in Seattle, not all sites are suitable for stormwater infiltration. General requirements and limitations related to infiltrating facilities are provided in *Section 5.4.1*. The following are key considerations that influence whether rain gardens are feasible for a particular site:

- **Setbacks and Separation**: Rain gardens must meet the requirements for infiltration facilities presented in *Section 5.4.1*. Requirements include horizontal setbacks and a minimum vertical separation from the bottom of the facility to the underlying water table, bedrock, or other impermeable layer.
- **Subgrade soil infiltration rate***:* The existing underlying and surrounding subgrade soils are a principal factor for determining infiltration capacity and facility sizing. Lower infiltration rates will necessitate a larger facility to achieve the on-site stormwater management standard. Infiltration testing methods are provided in *Appendix D*.
- **Site topography**: On sloped sites, rain gardens require a larger facility footprint area. In addition, infiltration is prohibited in and near certain sloped areas (refer to *Section 5.4.1*).

5.4.5.5. Design Criteria

This section provides a description, recommendations, and requirements for the components of rain gardens. Typical components of a rain garden are shown in Figure 5.12. Design criteria are provided in this section for the following elements:

- Contributing area
- Flow entrance
- Ponding area
- Rain garden soil
- Overflow
- Plant material
- Mulch layer

For additional guidance on rain garden design and construction, refer to the Rain Garden Handbook for Western Washington Homeowners (WSU 2013, or as revised).

(Under development)

Figure 5.12. Typical Rain Garden.

Contributing Area

A rain garden must not receive runoff from more than 5,000 square feet of impervious area. This area limitation is to ensure that rain gardens are small-scale and distributed.

The rain garden cell area must be sized to meet the performance standard for the contributing area routed to the cell. It is recommended that cells not be oversized because the vegetation in oversized cells may not receive sufficient storm water runoff for irrigation, increasing O&M requirements. Rain gardens sited in the right-of-way must not be oversized.

Stormwater flows from other areas (beyond the area for which the rain garden is sized) should be bypassed around the cell in order to reduce sediment loading to the cell and the potential for clogging. While it is preferred that rain gardens be sized to manage only the area draining to the cell, excess flows may be routed through a rain garden cell designed for the on-site stormwater management standard with the following limitations:

- The maximum impervious drainage area that may be routed to a rain garden must not exceed twice the area for which it is sized to a maximum of 5,000 square feet. Additional runoff contributions from pervious areas are acceptable. No on-site stormwater management credit is given for runoff from areas beyond the design area.
- Additional runoff routed to a rain garden must be clearly noted on submitted plans.
- The plans must show how overflows will be conveyed to the downstream point of discharge.
- The overflow conveyance infrastructure must safely convey runoff from the total catchment area (refer to *Section 4.3.3*).

Flow Entrance

Flow entrances should be sized to capture flow from the catchment area and designed to both reduce the potential for clogging at the inlet and prevent inflow from causing erosion in the rain garden cell. Four primary types of flow entrances can be used for rain gardens:

- Dispersed flow (e.g., vegetated buffer strips)
- Sheet flow
- Curb cuts
- Concentrated flow (e.g., piped flow)

Vegetated buffer strips are the preferred entrance type because they slow incoming flows and provide initial settling of particulates. Refer to the Puget Sound LID Manual for guidance on flow entrances.

The minimum requirements associated with the flow entrance design include the following:

- For sheet flow into a rain garden, a minimum 1-inch drop from the edge of a contributing impervious surface to the vegetated flow entrance is required. This drop is intended to allow for less frequent maintenance by allowing some sediment/debris buildup at the edge before sheet flow into the facility is impeded.
- For curb cut flow entrances, the curb cut width must be sized based on the catchment area, longitudinal slope along the curb, and the cross slope at the inlet. The minimum curb cut width must be 8 inches for non-right-of-way applications (e.g., parking lots) and 10 inches in the right-of-way (Refer to the Seattle Right-of-Way Improvements Manual).
- Curb cut flow entrances must have either a minimum of 5 percent slope from the outer curb face extending to a minimum of 12 inches beyond the back of curb, or provide a minimum of 2-inch vertical drop from the back of curb to the vegetated surface of the cell.
- If concentrated flows are entering the cell, flow energy dissipation (e.g., rock/cobble pad or flow dispersion weir) must be incorporated to reduce the potential for erosion at the inlet.

Ponding Area

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the cell. The minimum requirements associated with the cell ponding area design include the following:

- The bottom area of an individual rain garden must be no larger than 800 square feet[3].

[3] Area limitation is to ensure that rain gardens are small-scale and distributed.

- The ponding depth must be a maximum of 6 inches.
- The surface pool drawdown time must be a maximum of 24 hours[4].
- The maximum planted side slope must be 2.5H:1V. If total cell depth exceeds 3 feet, the maximum planted side slope is 3H:1V. If steeper sides are necessary, rockery, concrete walls or steeper soil wraps may be used.
- If berming is used to achieve the minimum top cell elevation needed to meet ponding depth and freeboard needs, maximum slope on berm must be 2.5H:1V, and minimum top width of design berm must be 1 foot. Soil used for berming must be imported bioretention soil or amended subgrade soil and compacted to a minimum of 90 percent dry density.
- The bottom width of a flat-bottomed facility varies when sited on a sloped grade. The average bottom width for the facility must be no less than 18 inches.
- Freeboard must be provided to ensure that overflows are safely conveyed to an approved point of discharge. The minimum freeboard measured from the invert of the overflow point (e.g., standpipe, earthen channel, curb cut) to the cell overtopping elevation must be 2 inches for drainage areas less than 1,000 square feet and 6 inches for drainage areas 1,000 square feet or greater.

  Less freeboard is allowable if calculations show 3 inches of freeboard are provided during the 25-year recurrence interval flow. The facility must meet overflow conveyance requirements (*Section 4.3.3*). For facilities in the right-of-way with ponding depths of 3-inches or less (e.g., Sidewalk Projects), it is acceptable to allow overflow over the curb to the roadway conveyance system.
- The site must be graded such that any flows exceeding the capacity of the cell are safely conveyed to an approved point of discharge.

Rain Garden Soil

Proper soil specification, preparation, installation, and maintenance are critical factors for rain garden performance. To meet rain garden soil requirements, the subgrade soil may be amended with compost according to the requirements in *Section 5.1* or the subgrade soil may be over excavated and replaced with imported bioretention soil.

To determine if the subgrade soil is suitable for amending with compost, a simple soil texture test can be performed. When digging the test hole for the subgrade soil infiltration test do the following:

- Squeeze moist soil into a ball. If the soil falls apart or can be broken up easily and is gritty feeling, this suggests a sandier, well-draining soil. This type of soil is suitable for amending and use in the rain garden.

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[4] Drain time should be calculated as a function of ponding depth and subgrade soil design infiltration rate.

- If the soil is sticky, smooth, and forms a ball that can be worked like modeling clay, this suggests poor-draining soil with high clay content. If the soil is smooth, pliable but not sticky then it is likely a silty soil and moderate to poor draining. These soils are less suitable for amending and should be replaced with imported bioretention soil (refer to *Section 5.4.4.5*).

If the soil is dry, add water a few drops at a time, break down the chunks to work the water into soil, and then perform the soil texture test.

If subgrade soil is not suitable for amendment, imported bioretention soil per the City of Seattle Standard Specification 7-21 must be used (refer to Section 5.4.4.5).

Overflow

A rain garden must have an overflow unless it is designed to provide full infiltration into underlying soil (*Section 5.4.1*). The rain garden overflow can be provided by a drain pipe, earthen channel or curb cut installed at the designed maximum ponding elevation and connected to a downstream BMP or an approved point of discharge.

The minimum requirements associated with the overflow design include the following:

- Overflows must be designed to convey excess flow to the approved point of discharge per *Section 4.3.2*.
- The drain pipe, if used, must have a minimum diameter of 4 inches.

Plant Materials

In general, the predominant plant material used in rain gardens are species adapted to stresses associated with wet and dry conditions. Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, wetland plants may be planted in the lower areas and drought-tolerant species planted on the perimeter of the facility or on mounded areas.

The minimum requirements associated with the vegetation design include the following:

- The design plans must specify that vegetation coverage of selected plants will achieve 90 percent coverage within 2 years or additional plantings will be provided until this coverage requirement is met.
- The plants must be sited according to sun, soil, wind and moisture requirements.
- At a minimum, provisions must be made for supplemental irrigation during the first two growing seasons following installation.

Refer to the Puget Sound LID Manual for guidance on plant selection and recommendations for increasing survival rates. Recommended planting lists can be found in the Puget Sound LID Manual, the Seattle Right-of-Way Improvements Manual, and the Seattle Green Factor plant list (http://www.seattle.gov/util/greeninfrastructure). Plants for rain gardens sited in the right-of-way must be selected from the Green Factor plant list.

Mulch Layer

Properly selected organic mulch material reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to the soil. Compost and arborist wood chip mulch are recommended for different applications within the rain garden cell. Compost mulch is an excellent slow-release source of plant nutrients and does not float, but compost does not suppress weed growth as well as bulkier, higher carbon mulches like wood chips. Arborist wood chips are superior to bark mulch in promoting plant growth, feeding beneficial soil organisms, reducing plant water stress, and maintaining surface soil porosity.

Organic mulch must consist of the following:

- Compost (per City of Seattle Standard Specification 9-14.4(9)) in the bottom of the facility and up to the ponding elevation
- Arborist wood chip mulch (per City of Seattle Standard Specification 9-14.4(9)) on cell slopes above the ponding elevation and the around the rim area
- A minimum of 2 inches and a maximum of 3 inches for both types of organic mulch

Organic mulch must not include:

- Weed seeds
- Soil
- Roots and other material that is not from the aboveground components of a tree
- Mineral aggregate
- Pure bark (bark is essentially sterile and inhibits plant establishment)
- Grass clippings (decomposing grass clippings are a source of nitrogen and are not recommended for mulch in rain garden areas)

In rain garden areas where higher flow velocities are anticipated, an aggregate mulch may be used to dissipate flow energy and protect underlying rain garden soil. Aggregate mulch varies in size and type, but 1- to 1-1/2-inch gravel (rounded) decorative rock is typical. The area covered with aggregate mulch must not exceed one third of the rain garden bottom area.

As an alternative to mulch, a dense groundcover may be used. Mulch is required in conjunction with the groundcover until groundcover is established. Mulch is not required for turf-vegetated cells.

5.4.5.6. BMP Sizing

On-site List Approach

Rain gardens applied to meet the On-site List Approach must be sized according to the sizing factors provided in Table 5.22. Factors are organized by ponding depth and subgrade soil design infiltration rate. A 2- or 6- inch facility ponding depth may be selected. The design

rate for the subgrade soils must be rounded down to the nearest infiltration rate in the sizing table (i.e., 0.25, 0.5, or 1.0 inch per hour). The rain garden must meet the general requirements for rain gardens outlined in this section plus the following specific requirements:

- The bottom area must be sized using the applicable sizing factor.
- The bottom area must be flat (0 percent slope).
- Side slopes within ponded area must be no steeper than 3H:1V.
- The rain garden soil depth must be a minimum of 12 inches.
- The minimum ponding depth must be set at the designated height (2 or 6 inches). For intermediate ponding depths (between 2 and 6 inches), the sizing factor may be linearly interpolated.
- No underdrain or impermeable liner must be used.

Table 5.22. On-site List Sizing for Rain Gardens.

Ponding Depth	Subgrade Soil Design Infiltration Rate	Sizing Factor for Rain Garden Bottom Area
		On-Site Performance Standard
2-inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	
6-inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	

– sizing factors not provided; NA- not applicable
Rain Garden Bottom Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Rain Garden Bottom Area ÷ Factor (%)/100

The bottom area for the rain garden is calculated as a function of the impervious area routed to it. As an example, the bottom area of the rain garden would be equal to X percent of the impervious area routed to it when the subgrade infiltration rate is equal to or greater than 1.0 inch per hour and the ponding depth is 6 inches. The total rain garden footprint area (top area) can be calculated as a function of the cell bottom area, the side slopes, and the total facility depth (i.e., ponding and freeboard depth).

The rain garden bottom area required as presented in Table 5.22 may be reduced as much as 50 percent if it is demonstrated that a larger area cannot be achieved given site constraints.

Modeling Approach

Rain gardens must be sized using the On-site List approach (above). If the applicant wishes to use continuous modeling, infiltrating bioretention must be used.

5.4.5.7. Minimum Construction Requirements

During construction, it is critical to prevent clogging and over-compaction of the subgrade, bioretention soils or amended soils. General construction requirements for infiltration facilities are provided in *Section 5.4.1*. Additionally, excavation, soil placement, or soil amendment must not be allowed during wet or saturated conditions.

5.4.5.8. Operations and Maintenance Requirements

Rain garden O&M requirements are provided in *Appendix G (BMP No. 28)*.

5.4.6. Permeable Pavement Facilities

5.4.6.1. Description

Permeable pavement is a paving system which allows rainfall to percolate into an underlying aggregate storage reservoir, where stormwater is stored and infiltrated to the underlying subgrade or removed by an overflow drainage system. Two categories of permeable pavement BMPs are included in this manual: permeable pavement "facilities" (provided in this section) and permeable pavement "surfaces" (provided in *Section 5.6.2*). A comparison of these BMPs is provided in Table 5.23.

Table 5.23. Comparison of Permeable Pavement Facilities and Surfaces.

Characteristic		Permeable Pavement Facility	Permeable Pavement Surface
Infiltration Facility	Subject to restrictions for infiltration facilities (e.g., setbacks, separation from groundwater)	Yes	No
Performance	Can typically be designed to meet all performance standards	Yes	Low-slope installations only
Run-On	Can be designed to receive stormwater runoff from other contributing areas	Yes	No
Lateral Impermeable Barriers	Installation on sloped subgrade requires lateral impermeable barriers (e.g., check dams) to achieve the design storage depth across the facility	Yes	High slope installations only

A permeable pavement "facility" consists of a pervious wearing course (e.g., porous asphalt, pervious concrete) and a storage reservoir installed over subgrade soil. The storage reservoir is designed to support expected loads and store stormwater to allow time for the water to infiltrate into the underlying soil. The depth of temporary ponding within the storage reservoir is sized to meet performance standards. The storage reservoir aggregate must be laid partially or completely below surrounding grade. Installation on sloped subgrade requires lateral impermeable barriers (e.g., check dams) to achieve the design storage depth across the facility. When designed with the appropriate subsurface ponding storage, permeable pavement facilities can meet on-site stormwater management and flow control standards.

Facilities can also achieve treatment standards when underlying soil meets the treatment soil requirements outlined in *Section 5.4.1* or an aggregate treatment course is included.

Permeable pavement facilities may be designed to receive runoff from other contributing areas ("run-on").

Permeable pavement facilities are infiltration facilities and must meet the requirements in *Section 5.4.1*.

While similar to facilities, permeable pavement "surfaces" are designed to function as a permeable land surface and not intended to receive runoff from other surfaces. Therefore,

they are not considered infiltration facilities and have less onerous design requirements (refer to *Section 5.6.2*).

5.4.6.2. Performance Mechanisms

Flow control occurs through temporary storage of stormwater runoff in the voids of the aggregate material and subsequent infiltration of stormwater into the underlying soils. Pollutant removal mechanisms include infiltration, filtration and sedimentation, biological decomposition, and soil adsorption.

5.4.6.3. Applicability

The flow control performance of a permeable pavement facility is a function of the infiltration rate of the underlying subgrade soil and the depth of the aggregate storage reservoir that stores stormwater until it is infiltrated.

Permeable pavement facilities can meet water quality treatment requirements when the underlying soil meets the treatment soil requirements outlined in *Section 5.4.1* or a water quality treatment course is included.

This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Permeable pavement facility	✓	✓	✓	✓	✓	✓[a]	✓[a]			

[a] Underlying soil must meet the treatment soil requirements outlined in *Section 5.4.1* or a water quality treatment course must be included.

5.4.6.4. Site Considerations

Unlike many flow control facilities that require dedicated space on a site, permeable pavement facilities are part of the usable lot area and can be used to replace conventional pavements, including:

- Sidewalks and pedestrian plazas
- Pedestrian and bike trails
- Driveways
- Most parking lots
- Low volume roads, alleys, and access drives

For information on use within the street right-of-way, refer to the City of Seattle Right-of-Way Improvement Manual. A link to this document is available on the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

Site considerations for the applicability of permeable pavement facilities include:

- **Setbacks and Separation**: Permeable pavement facilities must meet the requirements for infiltration facilities presented in *Section 5.4.1*. Requirements include horizontal setbacks and a minimum vertical separation from the bottom of the facility to the underlying water table, bedrock, or other impermeable layer. Infiltration testing methods are provided in *Appendix D*. For areas where infiltration facilities are not permitted, permeable pavement "surfaces" may be used because they are not categorized as infiltration facilities (refer to *Section 5.6.2*).
- **Subgrade soil infiltration rate**: The existing underlying subgrade soils are a principal factor for determining infiltration capacity. Lower infiltration rates will necessitate a deeper storage reservoir to achieve performance standards.
- **Site topography**: The recommended maximum surface slope for permeable pavement facilities is as follows:
    - 5 percent for porous asphalt
    - 10 percent for pervious concrete
    - 12 percent for permeable interlocking pavers
    - 6 to 12 percent for grid systems (check with manufacturer).

    While there is no maximum subgrade slope, steeper slopes require subsurface lateral impermeable barriers (e.g., check dams), which may increase construction complexity and cost.
- **Land use**: Because permeable pavement can clog with sediment, permeable paving facilities are not recommended under the following conditions:
    - Excessive sediment contamination is likely on the pavement surface (e.g., construction areas, landscaping material yards).
    - It is infeasible to prevent stormwater run-on to the permeable pavement from unstabilized erodable areas without pre-settling.
    - Regular, heavy application of sand is anticipated for maintaining traction during winter, or the facility is in close proximity to areas that will be sanded.
    - Sites where the risk of concentrated pollutant spills are more likely (e.g., gas stations, truck stops, car washes, vehicle maintenance areas, industrial chemical storage sites).
    - Pavement sealant application is possible.
- **Accessibility**: As for standard pavement design, ADA accessibility issues must be addressed when designing a permeable pavement facility, particularly when using pavers.

5.4.6.5. Design Criteria

This section provides descriptions, recommendations, and requirements for the common components of permeable pavement facilities. Typical components of a permeable pavement facility are shown in Figure 5.13 and a permeable pavement facility with check dams is shown in Figure 5.14Some, or all, of the components may be used for a given application depending on the permeable pavement type (e.g., porous asphalt, pavers, etc.), site characteristics and restrictions, and design objectives.

Design criteria are provided in this section for the following elements:

- Contributing area
- Flow Entrance/Pre-settling
- Wearing course
- Leveling course
- Storage reservoir
- Lateral impermeable barriers
- Overflow
- Geotextile
- Water quality treatment course
- Observation port

The structural design of permeable pavement to support anticipated loads is outside the scope of this manual.

The Puget Sound LID Manual provides additional guidance on permeable pavement design. Additional guidance for permeable pavement in the public right-of-way is provided in the Seattle Right-of-Way Improvements Manual.

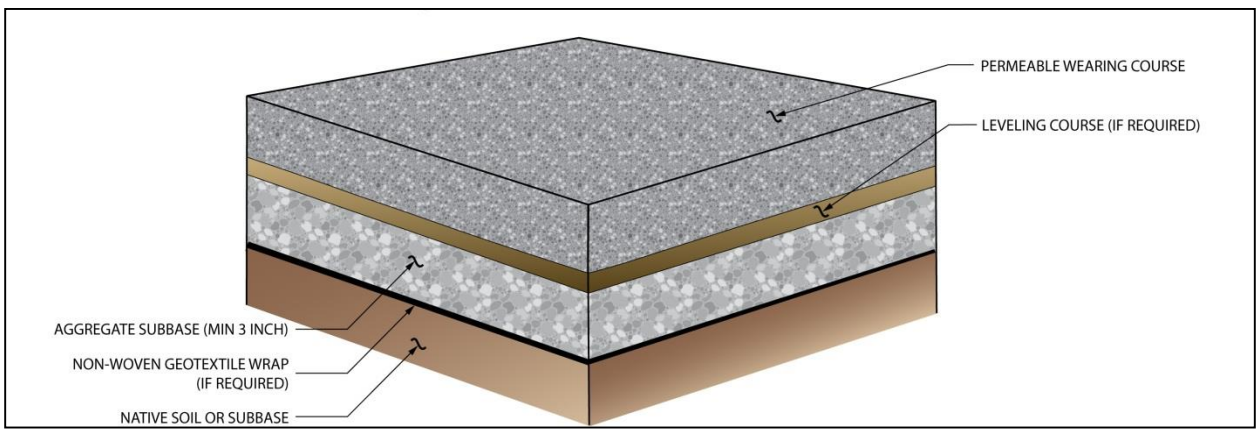


Figure 5.13. Permeable Pavement Facility.

(Under development)

Figure 5.14. Permeable Pavement Facility with Checkdams.

Contributing Area

Permeable pavement facilities may receive runoff from other contributing areas ("run-on"). When designed to take run-on, permeable pavement areas must be protected from sedimentation which can cause clogging and diminished facility performance (unless more frequent cleaning of the facility is conducted in order to ensure performance). The minimum requirements associated with the contributing area include the following:

- The contributing area must be no larger than specified by surface type below:
    - Pollution-generating impervious surfaces (e.g., roadways, parking lots): maximum run-on ratio of 2:1
    - Non-pollution generating impervious surfaces (e.g., roofs, sidewalks) and stabilized pervious surfaces: maximum run-on ratio of 5:1
    - For a mix of surface areas, the maximum run-on ratio shall be area-weighted (e.g., a contributing area comprised of half parking lot and half roof would be subject to a maximum run-on ratio of 3.5:1).
- To prevent sediment flowing onto the pavement, run-on must not occur from erodible/unstabilized areas or from impervious areas that receive run-on from unstabilized areas.
- Run-on shall not occur from tributary areas subject to the following land use:
    - Excessive sediment contamination is likely on the pavement surface (e.g., construction areas, landscaping material yards)
    - Regular, heavy application of sand is anticipated for maintaining traction during winter, or in close proximity to areas that will be sanded
    - Risk of a concentrated pollutant spill is more likely (e.g., gas stations, truck stops, car washes, vehicle maintenance areas, industrial chemical storage sites)

- Where run-on flows onto permeable pavement and flow is concentrated, these areas must be identified in the O&M plan as requiring more frequent cleaning and inspection to ensure that the overall facility is performing as designed.

Flow Entrance/Pre-settling

It is recommended that run-on should be directed to the permeable pavement facility in a distributed manner (e.g., sheet flow) rather than through concentrated flow, where possible. Specific requirements associated with the run-on flow entrance area provided below.

- If the run-on flow is concentrated and the contributing area exceeds 1,000 square feet, run-on must be dispersed to permeable pavement. Acceptable methods include sheet flow or subsurface delivery to the storage reservoir. If subsurface delivery is used, primary settling is required (e.g., via catch basin, hooded outlet, sump) followed by distribution to storage reservoir (e.g., via slotted drain pipe).

- If the run-on flow is concentrated and the tributary area is 1,000 square feet or less, concentrated run-on is permitted. However, the designer shall consider the concentrated flow velocity, permeable pavement slope and permeable pavement flow path to ensure that the run-on will be captured by the pavement.

- If run-on flow from an impervious surface is dispersed (e.g., via sheet flow), the flow path length on the tributary impervious surface shall not be more than 5 times the flow path length on the permeable pavement. The minimum flow path length on the permeable pavement shall be 4 feet.

Wearing Course

The surface layer of a permeable pavement facility is the wearing course. Categories of wearing courses include:

- **Porous Asphalt**: Porous asphalt concrete is open-graded asphalt with reduced fines and air pockets encased within it that allow water to drain to the base below. Aggregate binders and additives can be added to increase durability. Like conventional asphalt, it is laid with traditional asphalt paving equipment. Simple applications include a single wearing course. Advanced applications use binder course overlain by a wearing course.

- **Pervious Concrete***:* Pervious cement concrete is similar to porous asphalt in that the mixture omits the fines to create stable air pockets encased within it. Pervious concrete typically has a rougher surface than conventional concrete.

- **Permeable Interlocking Concrete Pavers***:* Permeable interlocking concrete paver blocks themselves are not typically permeable, but they are installed with gaps between them to allow stormwater to infiltrate into the subsurface. The gaps, typically 10 percent of the surface area, are filled with a permeable material, usually small clean stone.

- **Grid Systems***:* Open-celled paving grids consist of a rigid grid composed of concrete or a durable plastic that is filled with gravel or vegetation. The support base and the ring

walls prevent soil compaction and reduce rutting and erosion by supporting the weight of traffic and concentrated loads. Vegetated grid systems are filled with a mix of sand, gravel, and topsoil and planted with a variety of non-turf forming grasses or low-growing groundcovers. Vegetation in the spaces between the grids provides habitat for beneficial microbes, nutrient cycling, pollutant removal through root uptake, and stormwater volume reduction through evapotranspiration. Gravel-filled grid systems are filled with a clean aggregate mix specified by the manufacturer.

The wearing course must provide adequate porosity for stormwater infiltration. Minimum requirements associated with the wearing course design include the following:

- Wearing course material must be on the permeable pavement approved technology list on the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure)
- For all wearing course types, a minimum initial uncorrected infiltration rate of 100 inches per hour is required. To improve the probability of long-term performance, significantly higher initial infiltration rates are desirable. For measuring initial surface infiltration rates for porous asphalt, pervious concrete, or permeable interlocking concrete pavers, the Standard Test Method for Infiltration Rate of In Place Pervious Concrete (ASTM C1701) must be used. For grid systems, refer to manufacturers testing recommendations.
- Fill media for grid systems with grass vary per manufacturer from coarse sand to topsoil. Consult manufacturer to confirm that the fill media will provide adequate infiltration capacity and, at that rate, support healthy plant growth.
- For pervious concrete, City of Seattle standard specifications must be used (www.seattle.gov\util\greeninfrastructure).
- For porous asphalt, refer to the American Society of Civil Engineers (ASCE) Permeable Pavement Manual of Practice (currently being developed; http://www.asce.org/ewri/Books-and-Journals/Manuals/Manuals-of-Practice).

Leveling Course

Depending upon the type of wearing course, a leveling course (also called a bedding or choker course) may be required. A leveling course is often required for grid systems, permeable interlocking concrete pavers, and pervious concrete. This course is a layer of aggregate that provides a more uniform surface for laying pavement or pavers and typically consists of crushed aggregate smaller in size than the underlying storage reservoir. Course thickness will vary with permeable pavement type.

Leveling course material and thickness must be included as required per manufacturer recommendations. Leveling course material must be compatible with underlying storage reservoir material.

Storage Reservoir

Stormwater passes through the wearing and leveling courses to an underlying aggregate storage reservoir, also referred to as “base material”, where it is filtered and stored prior to

infiltration into the underlying soil. This aggregate also serves as the pavement's support base and must be sufficiently thick to support the expected loads. Design of the subgrade for loading is outside of the scope of this manual. A licensed engineer is needed to determine subsoil load bearing, minimum aggregate base thickness, and aggregate compaction for loading.

Minimum requirements associated with the storage reservoir design include the following:

- A 3-inch minimum depth of storage reservoir aggregate is required under the wearing course and leveling course (if any) for water storage.
- For walkways, aggregate material must be in accordance with City of Seattle Mineral Aggregate Type 24 or modified AASHTO #57 per WSDOT Section 9-03.1(4)C, with 0-2% passing #200 wet sieve; % fracture must be in accordance with requirements per WSDOT 9-03.9(2).
- For vehicular applications, aggregate material must be in accordance with City of Seattle Mineral Aggregate Type 13 or modified AASHTO #57 per WSDOT Section 9-03.1(4)C with 0-2% passing #200 wet sieve; % fracture must be in accordance with requirements per WSDOT 9-03.9(2).
- The storage reservoir must be laid partially or completely below the elevation of the surrounding grade.
- The storage reservoir must have a minimum total void volume of 25 percent after compacted in place.

Lateral Subsurface Impermeable Barriers

Sloped facilities have an increased potential for lateral flows through the storage reservoir aggregate along the top of relatively impermeable subgrade soil. This poses a risk of subsurface erosion and reduces the storage and infiltration capacity of the pavement facility. To address this, the subgrade must be designed to create subsurface ponding to detain subsurface flow, increase infiltration, and reduce structural problems associated with subgrade erosion on slopes (refer to Figure 5.14). Ponding must be provided using periodic lateral impermeable barriers (e.g. check dams, impermeable liners, or low conductivity geotextiles) oriented perpendicular to the subgrade slope. While the frequency of the barriers is calculated based on the required subsurface ponding depth and the subgrade slope, typical designs include barriers every 6 to 12 inches of grade loss.

Unless the subgrade slope is less than 0.5 percent and the storage reservoir aggregate is laid below surrounding subgrade, lateral impermeable barriers are required. Minimum requirements associated with lateral impermeable barriers include the following:

- Lateral impermeable barriers must be installed at regular intervals perpendicular to the subgrade slope to provide the average subsurface ponding depth in the storage reservoir required to meet the desired performance standard.
- The barriers must not extend to the elevation of the surrounding ground.

- Each barrier must have an overflow, as described below, or allow overtopping to the next downslope storage reservoir section without causing flows to express from the pavement surface or out the sides of the base materials that are above grade.

Overflow

Unless designed to provide full infiltration (*Section 5.4.1*), permeable pavement facilities must have an overflow (*Section 4.3.3*). Minimum requirements associated with the overflow design include the following:

- Overflow must be designed to convey excess flow to an approved point of discharge per *Section 4.3.2*. Options include:
    - Subsurface slotted drain pipe(s) set at the design ponding elevation to route flow to a conveyance system
    - Lateral flow through the storage reservoir to a daylighted conveyance system
- For facilities installed on a sloped subgrade, at least one overflow must be sited at the downslope extent of the facility.
- If a slotted overflow pipe is used to collect water in the pavement section, the pipe diameter and spacing must be designed based on the hydraulic capacity required. A cleanout must be connected to the drainpipe every 300 feet. For recommended specifications refer to the underdrain pipe specification on the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).
- A minimum surface slope of 1 percent is required to ensure positive surface drainage should the surface become clogged.
- The designer must consider the flow path of water when the permeable pavement section is fully saturated to the maximum design depth or when the wearing course is clogged to confirm there are no unanticipated discharge locations (e.g., impact to intersecting utility trenches, sheet flow to adjacent properties). The flow path must be described in the design submittal.
- If a permeable pavement facility is used in the roadway section, the roadway conveyance system must be designed as if the road surface were impermeable.

Geotextile

Generally, geotextiles and geogrids are used for the following purposes:

- As a filter layer to prevent clogging of infiltration surfaces
- To prevent fines from migrating to more open-graded material and causing associated structural instability
- To prevent downward movement of the aggregate base into the subgrade for soil types with poor structural stability

Geotextiles between the permeable pavement subgrade and aggregate base are not required or necessary for many soil types and, if incorrectly applied, can clog and reduce infiltration capability at the subgrade or other material interface. Therefore, the use of geotextiles is discouraged unless it is deemed necessary. As part of the pavement section design, the designer must review the existing subgrade soil characteristics and treatment layer if any, and determine if geotextile is needed. Additional guidance on geotextile design is provided in *Appendix E*.

Minimum requirements associated with the geotextile design, if used, include the following:

- Use geotextile recommended by the manufacturer's specifications and by a geotechnical engineer for the given subgrade soil type or treatment layer and base aggregate.
- Extend the fabric up the sides of the excavation. This is especially important if the base is adjacent to conventional paving surfaces to prevent migration of fines from dense-graded base material and soil subgrade to the open graded base. Geotextile is not required on the sides if concrete curbs extend the full depth of the base/sub-base.
- Overlap adjacent strips of fabric at least 24 inches.
- Use geotextile that passes water at a greater rate than the design infiltration rate for the existing subgrade soils.

Water Quality Treatment Course (Optional)

If the permeable pavement is being designed to provide water quality treatment, underlying soils must meet the requirements for treatment soil provided in *Section 5.4.1*. If the existing subgrade does not meet these requirements, a 6-inch water quality treatment course may be included between the subbase and the storage reservoir. The course must be comprised of a media meeting the treatment soil criteria (*Section 5.4.1*) or the sand material specification for sand filters in the SWMMWW.

Observation Port

If a permeable pavement facility is designed to meet flow control and/or treatment requirements and the permeable pavement area plus the run-on area (if any) is 5,000 square feet or greater, it must be equipped with an observation port to allow for monitoring of the drawdown time following a storm. The observation port must consist of a 4-inch minimum diameter perforated or slotted pipe with a secure well cap that extends to the bottom of the pavement section and keyed into the subbase. The port must be located at the downslope area of the pavement system. Additional ports are required for every additional 5,000 square feet of permeable pavement area plus run-on area.

5.4.6.6. BMP Sizing

On-site List Approach

The permeable pavement facility area meets the On-site List Requirement. Impervious surface contributing run-on to a permeable pavement facility also meets the On-site List requirement if it does not exceed the areas allowed in Table 5.24.

Table 5.24. On-Site List Sizing for Permeable Pavement Facilities.

Ponding Depth in Storage Reservoir	Subgrade Soil Design Infiltration Rate	Sizing Factor for Permeable Pavement Facility Area
		On-Site Performance Standard
6 inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	
12 inches	0.25 inch/hour	
	0.5 inch/hour	
	1.0 inch/hour	

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized permeable pavement facilities may be used to achieve On-site, Pre-developed Pasture, Peak Control and Treatment Standards. Sizing factors for permeable pavement facilities receiving runoff from an impervious surface are provided in Table 5.25. Factors are organized by performance standard and subgrade soil design infiltration rate. The design rate for the subgrade soil must be rounded down to the nearest infiltration rate in the pre-sized table (i.e., 0.25, 0.5, or 1.0 inch per hour).

To use these sizing factors to meet performance standards, the facility must meet the general requirements for permeable pavement facilities outlined in this section plus the following specific requirements:

- The permeable pavement area must be sized using the applicable sizing factor
- The selected subsurface ponding depth (i.e., 6 or 12 inches) must be provided in the storage reservoir. For subgrade slopes of 0.5 percent or greater, lateral impermeable barriers are required to provide this subsurface ponding depth, on average, across the facility. For intermediate ponding depths (between 6 and 12 inches), the sizing factor may be linearly interpolated.
- The storage reservoir must be composed of aggregate with a minimum void volume of 25 percent
- To meet the Treatment Standard, the underlying soil must meet the treatment soil requirements outlined in Section 5.4.1 or a water quality treatment course must be used.
- No underdrain or impermeable liner must be used.

Table 5.25. Sizing Factors for Permeable Pavement Facilities.

Ponding Depth in Storage Reservoir	Subgrade Soil Design Infiltration Rate	Sizing Factor for Permeable Pavement Facility Area (without underdrain)		
		Pre-developed Pasture Standard	Peak Control Standard	Water Quality Treatment Standard
6 inches	0.25 inch/hour	60.6%	131.4%	
	0.5 inch/hour	34.5%	52.4%	
	1.0 inch/hour	33.3%[a]	33.3%[a]	
12 inches	0.25 inch/hour	38.2%	75.8%	
	0.5 inch/hour	33.3%[a]	38.7%	
	1.0 inch/hour	33.3%[a]	33.3%[a]	

[a] The minimum sizing factor is 33.3 percent because the catchment area tributary to a facility is limited to 3 times the permeable pavement facility area.

Permeable Pavement Facility Area = Contributing Impervious Area x Factor (%)/100.

Impervious Area Mitigated = Permeable Pavement Facility Area ÷ Factor (%)/100.

The required permeable pavement facility area is calculated as a function of the impervious area routed to it. As an example, to meet the Pre-developed Pasture Standard, the permeable pavement area would be equal to 60.6 percent of the impervious area routed to it when the average water depth in the storage reservoir is 6 inches and the subgrade infiltration rate is between 0.25 and 0.5 inches per hour (Table 5.25).

The sizing factors for permeable pavement facilities are conservative. For infiltration rates of 0.5 and 1.0 inches per hour, modeling would likely yield ponding depth requirements less than 6 inches. Note that the minimum sizing factor is 33.3 percent because the catchment area tributary to a facility is limited to 3 times the permeable pavement facility area.

Alternatively, permeable pavement facilities can be sized using a continuous simulation hydrologic model as described below.

Modeling Approach

When using continuous simulation hydrologic modeling to size permeable pavement, the assumptions listed in Table 5.26 must be applied. It is recommended that permeable pavement be modeled as an impervious area with runoff routed to a gravel-filled infiltration trench (with the same area as the contributing impervious area). Runoff from other areas draining to the permeable pavement surface can also be routed to the trench. The tributary areas, pavement area, and average subsurface ponding depth in the aggregate storage reservoir should be iteratively sized until the Minimum Requirements for On-site Stormwater Management, Flow Control and/or Treatment are met (*Volume 1, see Chapter 2*). General sizing procedures for infiltration facilities are presented in *Section 5.4.1*. Specific modeling guidelines are outlined below:

- Only the average depth of the storage reservoir occupied by ponded water before check dam overtopping or overflow must be modeled. The storage reservoir aggregate above this depth, and the overlying leveling and wearing course are not modeled.

- Because the infiltration rates of the wearing course and leveling course are typically high, the infiltration through these layers may be neglected (i.e., not modeled).
- The area of subgrade covered by check dams or other lateral impermeable barriers must be excluded from gravel trench bottom area when these areas are significant relative to the pavement area.

Table 5.26. Continuous Modeling Assumptions for Permeable Pavement Facility.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Permeable Pavement Facility and Contributing Area	Option 1: The selected model may have a routine specifically developed for permeable pavement that simulates run-on from other catchment areas, precipitation falling on the pavement, infiltration through the pavement section, storage in the aggregate beneath the pavement, and infiltration into the underlying soil. Option 2: If a permeable pavement routine is not available, represent the pavement area as an impervious basin with runoff routed to a gravel-filled trench (of the same size as the pavement area) with infiltration to underlying soil. Other catchment areas draining to the pavement (surface flow and interflow), if any, are also routed to the gravel trench.
Precipitation Applied to Facility	If using Option 1, precipitation is applied to the pavement area. If using Option 2, do not apply precipitation to the trench bed because precipitation is already applied to basin before routing to trench
Evaporation Applied to Facility	If using Option 1, evaporation is applied to the pavement area. If using Option 2, while evaporation is applied to the impervious basin before routing to the trench, additional evaporation may be applied to the trench because additional evaporation occurs when water is stored in the storage reservoir.
Storage Reservoir Depth	Average subsurface water ponding depth in the pavement aggregate courses (average across the facility) before check dam overtopping or overflow.
Storage Reservoir Porosity	Assume maximum 25 percent unless test is provided showing higher porosity for aggregate compacted and in place.
Subgrade Soil Design Infiltration Rate	Measured infiltration rate with correction factor applied (*Section 5.4.1, Appendix D*).
Infiltration Across Wetted Surface Area	No, if subgrade sidewalls are steeper than 2H:1V (infiltration on bottom area only)
Outlet Structure	Unless the selected model represents surface sheet flow when pavement section is saturated, the overflow can be simulated as overtopping an overflow riser. Overflow elevation set at average maximum subsurface ponding depth. May be modeled as weir flow over riser edge or notch. Freeboard within the storage reservoir must be sufficient to allow the water surface elevation to rise above the weir or overflow pipe elevation to provide head for discharge.

5.4.6.7. Minimum Construction Requirements

Proper construction methods and pre-planning are essential for the successful application of any permeable paving facility. Over compaction of the underlying soil or excessive fine sediment contamination onto the existing subgrade and pavement section during construction will significantly degrade or effectively eliminate the infiltration capability of the facility.

General construction requirements for infiltration facilities are provided in *Section 5.4.1*. Additional minimum requirements associated with construction of a permeable pavement facility include the following:

- Conduct field infiltration and compaction testing of the optional water quality treatment course prior to placement of overlying courses.
- Prevent intermixing of the various base course materials with fines and sediment. Remove and replace all contaminated material.
- Complete final subgrade excavation during dry weather on the same day bottom aggregate course is placed, when practicable.
- Use traffic control measures to protect permeable pavement subgrade areas from heavy equipment operation or truck/vehicular traffic.
- Select excavation, grading, and compaction equipment to minimize the potential for over-compaction.
- Isolate the permeable pavement site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream. Alternatively, delay the excavation of the lowest 1 foot of material above the final subgrade elevation for the entire pavement area until after all sediment-producing construction activities have been completed and upstream areas have been permanently stabilized. Once the site is stabilized, the lowest 1 foot of material may be removed. For more information on site stabilization, refer to *Volume 2 Construction Stormwater Control*.
- Conduct field infiltration test of the permeable surface after the complete pavement section is installed to verify that it meets the minimum initial uncorrected infiltration rate of 100 inches per hour (refer to the *Wearing Course* section in *Section 5.4.6.5*).

For inspection and verification procedures used for facility approval by City staff, refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

5.4.6.8. Operations and Maintenance Requirements

Permeable pavement O&M requirements are provided in *Appendix G (BMP No. 25)*.

5.4.7. Perforated Stub-Out Connections

5.4.7.1. Description

A perforated stub-out connection is a length of perforated pipe within a gravel-filled trench that is placed between roof downspouts and a stub-out to the public drainage system.

5.4.7.2. Performance Mechanisms

Perforated stub-out connections are intended to provide some flow control via infiltration during drier months. During the wet winter months, they may provide little or no flow control.

5.4.7.3. Applicability

Perforated stub-out connections can be designed to provide on-site stormwater management. This BMP can be applied for meeting the performance standard listed below.

	On-site		Flow Control			Water Quality				
BMP	**List**	**Standard**	**Forest**	**Pasture**	**Peak**	**Basic**	**Enhanced**	**Oil Control**	**Phosphorus**	**Conveyance**
Perforated Stub-Out Connections	✓									

5.4.7.4. Site Considerations

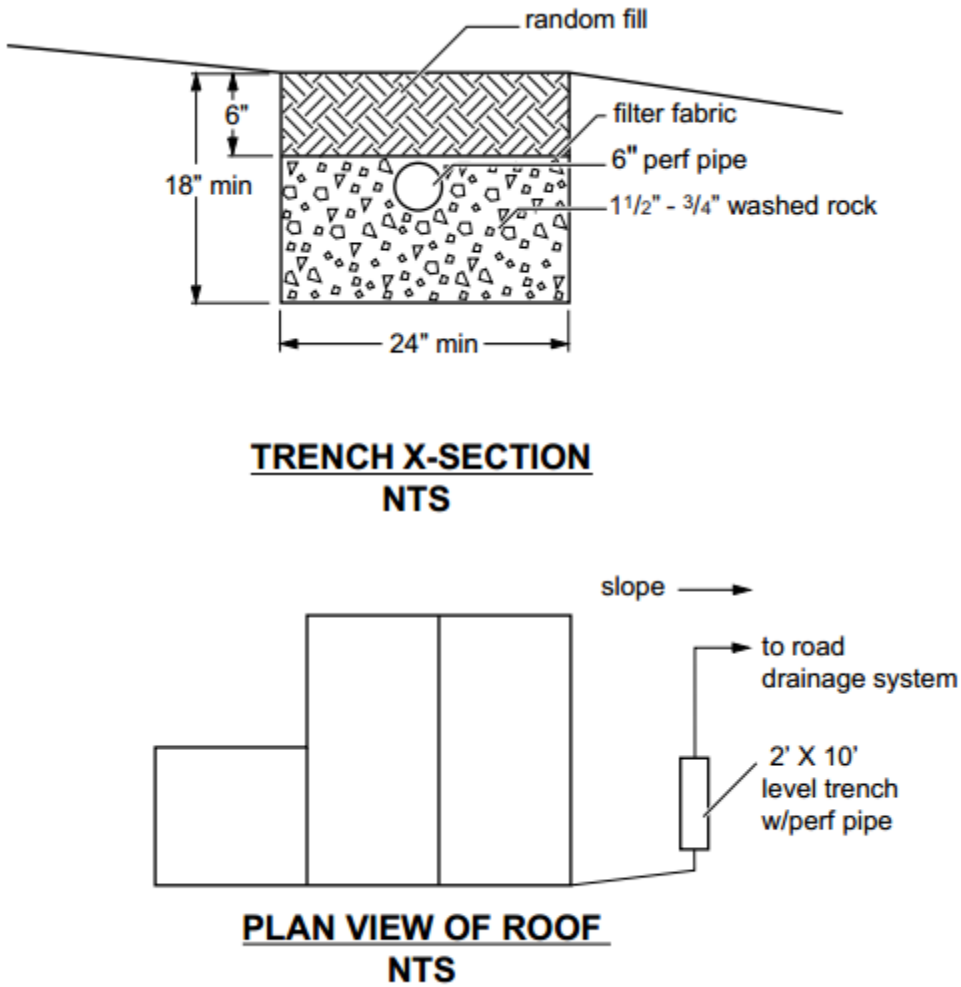
Stub-out connection should be sited to allow a maximum amount of runoff to infiltrate into the ground (ideally a dry, relatively well drained, location). Site considerations for the applicability of perforated stub-out connections include:

- **Setbacks and Separation***:* The perforated portion of the system must meet the requirements for infiltration facilities presented in *Section 5.4.1*. Requirements include horizontal setbacks and a minimum vertical separation from the bottom of the facility to the underlying water table, bedrock, or other impermeable layer.
- **Site Prohibitions***:* The perforated pipe portion of the system must not be located under impervious or heavily compacted (e.g., driveways and parking areas) surfaces.

5.4.7.5. Design Criteria

This section provides a description and requirements for the components of perforated stub-out connections. A typical stub-out connection is shown in Figure 5.15.Design criteria are provided in this section for the following elements:

- Stub-out pipe and trench
- Overflow



Source: King County

Figure 5.15. Perforated Stub-Out Connection.Stub-out Pipe and Trench.

The minimum requirements associated with the pipe and trench include the following:

- Perforated stub-out connections shall be at least 10 feet of perforated pipe per 5,000 square feet of roof area.
- The trench must be a minimum of 2 feet wide and 18 inches deep. The bottom of the trench must be level.
- The trench must be filled with uniformly-graded, washed gravel with a nominal size from 3/4– to 1-1/2-inch diameter. The minimum void volume must be 30 percent. These requirements can be met with City of Seattle Mineral Aggregate Type 4.
- The pipe length that extends through the trench must be a perforated or slotted pipe with a minimum diameter of 4 inches. The pipe must be placed level with the pipe invert a minimum of 8 inches above the bottom of the trench.

- The trench must be covered with filter fabric and 6 inches of fill.
- The pipe must be connected to a catch basin prior to connecting to the mainline stormwater drain pipe.

Overflow

Perforated stub-out connections overflow into the public drainage system.

5.4.7.6. BMP Credits

On-Site List Approach

The impervious surface area conveyed using a perforated stub-out meets the On-site List Requirement.

Pre-Sized Approach

Perforated stub-out connections are not included in the Pre-Sized Approach because this BMP is not eligible for flow control credits.

Modeling Approach

Any flow reduction is variable and unpredictable. No computer modeling techniques are allowed that would predict any reduction in flow rates and volumes from the connected area.

5.4.7.7. Minimum Construction Requirements

During construction, it is critical to prevent clogging and over-compaction of the subgrade. Construction requirements for infiltration facilities are provided in *Section 5.4.1*. Refer to the minimum construction requirements for infiltration trenches in *Section 5.4.2.7*.

5.4.7.8. Operations and Maintenance Requirements

General O&M requirements for infiltration facilities apply to perforated stub-out connections. Perforated stub-out connection O&M requirements are provided in *Appendix G (BMP No. 2)*.

5.4.8. Infiltration Basins

5.4.8.1. Description

Infiltration basins are large earthen impoundments used for the collection, temporary storage, and infiltration of stormwater runoff.

5.4.8.2. Performance Mechanisms

Pollutant removal and flow control occur through infiltration of stormwater into the underlying soils. Secondary pollutant removal mechanisms include filtration, biological uptake, and soil adsorption.

5.4.8.3. Applicability

An infiltration basin can be designed for both treatment and flow control of stormwater. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Infiltration basin			✓	✓	✓	✓[a]	✓[a]		✓[a]	

[a] Soil suitability criteria (SSC) (*Section 5.4.1*) and applicable drawdown requirements (*Section 5.4.1*) must be met.

5.4.8.4. Site Considerations

Refer to BMP T7.10 in Volume III of the SWMMWW for site considerations related to infiltration basins. Additional site considerations may apply depending on site conditions and other factors.

5.4.8.5. Design Criteria

Refer to BMP T7.10 in Volume III of the SWMMWW for infiltration basin design criteria.

5.4.8.6. BMP Sizing

Refer to BMP T7.10 in Volume III of the SWMMWW for infiltration basin sizing requirements.

5.4.8.7. Minimum Construction Requirements

Refer to BMP T7.10 in Volume III of the SWMMWW for infiltration basin minimum construction requirements. The following minimum construction requirements also apply to infiltration basins installed in Seattle:

- The development plan sheets must list the proper construction sequence so that the infiltration basin is protected during construction.
- The floor of an infiltration basin must be raked or deep tilled after final grading to restore infiltration rates.

5.4.8.8. Operations and Maintenance Requirements

Infiltration basin O&M requirements are provided in *Appendix G (BMP No. 2)*.

5.5. Rainwater Harvesting BMPs

Rainwater harvesting BMPs capture and store rainwater for beneficial use. The BMPs in this section include:

- Rainwater harvesting
- Single Family Residential (SFR) Cisterns

5.5.1. Rainwater Harvesting

5.5.1.1. Description

Rainwater harvesting is the capture and storage of rainwater for subsequent use. Runoff from non-pollution generating surfaces may be routed to cisterns for storage and beneficial non-potable uses, such as irrigation, toilet flushing, and cold water laundry.

Rainwater harvesting functions can be combined with the single family residential cistern and detention cistern BMPs (refer to *Sections 5.5.2 and 5.7.4*).

5.5.1.2. Performance Mechanisms

Rainwater harvesting can be used to achieve reductions in peak flows, flow durations and runoff volumes. The flow control performance of rainwater harvesting is a function of contributing area, storage volume and rainwater use rate.

5.5.1.3. Applicability

Rainwater harvesting systems can be designed to meet on-site stormwater management and flow control standards, and can be an effective volume reduction practice for projects where infiltration is not permitted or desired. Rainwater harvesting has higher stormwater management benefits when designed for uses that occur regularly through the wet season (e.g., toilet flushing and cold water laundry). The use of harvested rainwater for irrigation during the dry months provides less benefit.

This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality a				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Rainwater harvesting	✓	✓	✓	✓	✓					✓

[a] Rainwater harvesting is not approved for pollution-generating surfaces, so the water quality standard is not applicable.

5.5.1.4. Site Considerations

Rainwater harvesting can be used for new or retrofit projects. Depending upon site constraints, cisterns may be installed at grade, below ground, under a deck, or in a basement or crawl space. Cisterns may be used individually or connected to each other in a series for increased storage capacity.

5.5.1.5. Design Criteria

This section provides descriptions, recommendations, and requirements for the common components of rainwater harvesting systems. Design criteria are provided in this section for the following elements:

- Contributing area
- Collection system
- Screen/debris excluder
- Cistern/storage system
- Delivery and distribution system
- Water Treatment System
- Overflow
- Rainwater treatment and use equipment
- Backflow preventer

While the City accepts rainwater harvesting systems with indoor water use for compliance with flow control standards, the design requirements included in this section are focused on systems with outdoor use for irrigation purposes. The indoor use of harvested water is regulated by the Washington State Department of Health.

In addition to the requirements presented in this section, all components of a rainwater harvesting system must be designed and constructed in accordance with the manufacturer's recommendations and the City of Seattle Building and Residential Code, Uniform Plumbing Code (UPC), and the Seattle- King County Department of Health requirements, and all other applicable laws.

Refer to the Puget Sound LID Manual for general guidance for design of rainwater harvesting systems. Refer to the Puget Sound LID Manual and the Seattle- King County Department of Health for cistern design requirements specific to indoor use of harvested rainwater.

Links to resources on rainwater harvesting, including permit requirements, are available at the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

Contributing Area

The area contributing runoff to a rainwater harvesting system must not be pollution generating (e.g., surfaces subject to vehicular traffic are not acceptable).

To protect the water quality of the rainwater harvested, avoid collecting runoff from roof surfaces comprised of materials such as copper or zinc that may release contaminants into your system. Also avoid collecting runoff from roof materials treated with fungicides or herbicides.

Collection System

The collection system includes gutters and downspouts, as well as the piping and any other conveyance needed to route rainwater to the cistern.

Screen/Debris Excluder

Pre-storage treatment must be used to remove debris and/or treat “first flows” prior to entering the storage system. “First flows” are defined as the initial rain that falls during a typical rain shower. These waters convey sediment that has built up on the roof surface and typically contain the greatest concentration of pollutants. The pre-storage treatment for irrigation use must include a filter screen or other debris barrier to prevent insects, leaves, and other larger debris from entering and potentially clogging the system. A self-cleaning inlet filter is recommended.

Cistern/Storage System

Cisterns can be constructed from a variety of materials (e.g., plastic, concrete, fiberglass) and placed in various locations. They can include tanks, pipes, and enclosed portions of buildings — above or below ground level. The minimum requirements for all cistern systems include the following:

- Cisterns must be installed in accordance with manufacturer’s installation instructions, the City of Seattle Building Code, and all applicable laws, including foundation requirements.
- Cistern/storage systems must have both access points and drains to allow inspection and cleaning.
- Cistern openings must be designed to restrict entry from unauthorized personnel and appropriate signage must be provided. Any cistern/storage system opening that could allow the entry of personnel must be marked: “danger — confined space."
- Cleaning of any accumulated sediment on the bottom of the cistern must be possible by flushing through a drain or vacuuming.
- Cisterns must be designed to prevent mosquitoes and other nuisance insects and animals from entering the cistern system. This must be done with appropriate screening at all openings to the cistern.
- Opaque containers must be used for aboveground cisterns to minimize algal growth.

Minimum requirements specific to underground cistern design include the following:

- Cistern/storage systems that are buried below ground level must have a maintenance hole riser that protrudes a minimum of 8 inches above the surrounding ground. Maintenance hole covers must be secured and locked to prevent tampering.
- Cistern/storage systems must meet buoyancy requirements per manufacturer’s specifications, the City of Seattle Building Code and the UPC.

Delivery and Distribution System

Delivery may be accomplished by a gravity system or include pumps and pipes to move water from the storage system to the end use area. For irrigation use, an outlet spigot can be

installed near the bottom of the tank. Water must be drawn from at least 4 inches above the bottom of the tank.

Water Treatment System

Water quality treatment is typically required to protect the delivery and distribution system and to improve the quality of the collected water for the intended use. Screen systems and/or basic mechanical filtration are typically adequate for irrigation use (refer to the *Screen/Debris Excluder* Section above).

Treatment for indoor use is outside of the scope of this manual. Refer to the Puget Sound LID Manual for additional guidance on indoor use of harvested rainwater. Approval is required by the Seattle-King County Department of Health for any project routing harvesting water to an indoor plumbing system.

Overflow

Minimum requirements associated with overflow design include the following:

- Overflows must be designed to convey excess flow to the approved point of discharge per *Section 4.3.2*.
- The overflow pipe must have a conveyance capacity that is equal to or greater than all of the conveyance inlets delivering rainwater to the cistern. The minimum overflow pipe diameter must be 4 inches.

Backflow Preventer

Refer to the Seattle- King County Department of Health and the UPC for backflow prevention requirements.

5.5.1.6. BMP Sizing

On-site List Approach

TBD

Modeling Approach

To receive flow control credit for rainwater harvesting, runoff reduction must be demonstrated by a water balance of rooftop runoff, use of the harvested water, and overflows from the rainwater cistern. The water balance time step must be 1 day or more frequent. This fine time step will provide better representation of the timing, magnitude, and duration of overflows to allow proper sizing of supplemental detention, if needed, to meet flow control requirements for the site. The methods to be used are as follows.

Note: Obtain the Seattle 10-year precipitation series at a daily time step via link from the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

- Use a spreadsheet-based water balance model that calculates roof runoff (equal to rainfall volume), water use (e.g., irrigation, outdoor cleaning, and indoor plumbing), and overflow from the cistern. Refer to the SPU GSI website for additional guidance (http://www.seattle.gov/util/greeninfrastructure).

- If overflows do not occur, the designer may subtract the roof area from the site-wide model.
- If overflow occurs, design a downstream BMP to meet residual flow control needs using an approved continuous simulation hydrologic model of the site. Include the cisterns in the site-wide model so that the timing and volume of the overflows can be explicitly considered in the sizing of the downstream BMP. Specific modeling guidelines are listed below:
    - Repeat steps in the first two bullets above using the 10-year precipitation series at a 15-minute time step.
    - Import the 15-minute overflow timeseries into the site-wide model.
    - Import the 10-year precipitation series (15-minute time step) into the site-wide model.
    - Subtract the roof area routed to the cistern from the site-wide model.
    - Size the downstream BMP to meet flow control requirements for the cistern overflow time series.
    - Model report must be stamped by a licensed engineer.

5.5.1.7. Minimum Construction Requirements

Rainwater harvesting systems must be constructed according to the manufacturer's recommendations, the City of Seattle Building Code, the UPC, and all applicable laws.

5.5.1.8. Operations and Maintenance Requirements

Rainwater harvesting O&M requirements are provided in *Appendix G (BMP No. 23)*.
A plan must be submitted demonstrating how the O&M requirements will be met.

5.5.2. Single Family Residential (SFR) Cisterns

5.5.2.1. Description

Detention cisterns (*Section 5.7.4*) can be designed to allow rainwater harvesting of roof runoff for outdoor irrigation use. For single-family residential (SFR) projects, these combined harvesting and detention cisterns (referred to as "SFR cisterns"), are considered green stormwater infrastructure (GSI and encouraged. Guidance for the use of combined harvesting and detention cisterns for non-SFR projects is provided in *Section 5.7.4*.

The SFR cistern requires seasonal operation of a valve to detain water through the winter months.

5.5.2.2. Performance Mechanisms

SFR cisterns provide peak flow attenuation by slowly releasing low flows through an orifice. While there are volume reduction benefits of harvesting rainwater for irrigation, additional flow control credit (beyond credit for detention) is not applicable for this BMP.

5.5.2.3. Applicability

SFR cisterns do not receive flow control credit for the volume reduction associated with beneficial use. Therefore, the performance of these systems is the same as that for detention cisterns (refer to *Section 5.7.4*).

To receive credit for harvesting, refer to *Section 5.5.1 Rainwater Harvesting*.

5.5.2.4. Site Considerations

SFR cisterns can be used on any new or retrofit single-family residential project.

5.5.2.5. Design Criteria

The typical components of an SFR cistern are shown in Figure 5.16. The design criteria for the SFR cistern are the same as those presented for detention cisterns (refer to *Section 5.7.4*) with the following exceptions:

- Cisterns must be aboveground and have an orifice diameter of 0.25 inches.
- An operable spigot must be installed a minimum of 4 inches above the bottom of the cistern.
- Rainwater use must be for outdoor irrigation uses only.

5.5.2.6. BMP Sizing

On-site List Approach

SFR cisterns applied to meet the On-site List Approach shall have three feet of live storage between the low flow orifice and the overflow, and have a 0.25 inch diameter low flow orifice. The minimum cistern bottom area is provided in Table 5.27. For contributing areas up to 400 square feet, the minimum cistern bottom is 6.7 square feet. For larger contributing

areas, the minimum cistern bottom areas shall be calculated using the sizing factor or sizing equation provided.

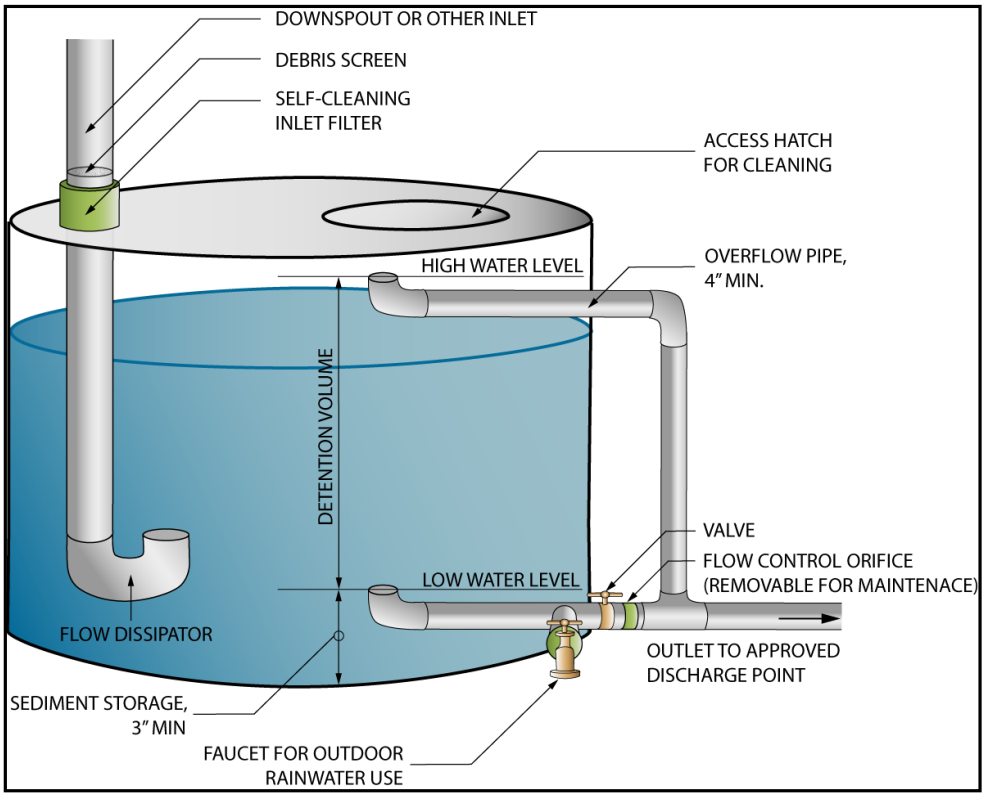


Figure 5.16. Detention Cistern with Harvesting Capacity for Single Family Residential Projects Only.

Table 5.27. On-Site List Sizing for SFR Cisterns.

Contributing Area (square feet)	Minimum Cistern Bottom Area On-Site Performance Standard
150-400	Cistern Bottom Area = 6.7 sf
401-500	Sizing Factor = 2%
501-750	Sizing Factor = 2.5%
751-1000	Sizing Factor = 3%
1001-1500	Sizing Factor = 4%
1501-2000	Sizing Factor = 4.5%
>2,000	Sizing Equation = 0.000531 x (A^1.59)

Pre-Sized Approach

Under the Pre-Sized Approach, pre-sized SFR cisterns may be used to achieve the Pre-developed Pasture and Peak Control Standards (refer to *Section 4.1.2*). No additional credit is given for the volume reduction associated with beneficial use.

Modeling Approach

Continuous modeling may be used to size SFR cisterns using the procedures presented for detention vaults in *Section 5.7.3*. The assumptions provided in Table 5.37 must be applied. No additional credit is given for the volume reduction associated with beneficial use.

5.5.2.7. Minimum Construction Requirements

Refer to the construction requirements presented for detention cisterns in *Section 5.7.4.7*.

5.5.2.8. Operations and Maintenance Requirements

SFR cistern O&M requirements are provided in *Appendix G (BMP No. 23)*.

The home owner must open the valve to engage the flow control orifice during the non-growing season (approximately October thru April or May). If the valve is not opened during this time, the cistern will fill and overflow, eliminating the detention benefits of the system. A plan must be submitted demonstrating how the O&M requirements will be met.

5.6. Alternative Surface BMPs

Alternative surface BMPs convert a conventional impervious surface to a surface that reduces the amount of stormwater runoff and also provides flow control. The BMPs in this section include:

- Vegetated roofs
- Permeable pavement surfaces

5.6.1. Vegetated Roofs

5.6.1.1. Description

Vegetated roofs are areas of living vegetation installed on top of buildings, or other above-grade impervious surfaces. 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 stormwater management function (see Figure 5.17). Design components vary depending on the vegetated roof type and site constraints, but may include a waterproofing material, a root barrier, a drainage layer, a separation fabric, a growth medium (soil), and vegetation. Vegetated roofs are categorized by the depth and the types of courses used in their construction.

- **Intensive roofs**: Intensive roofs are deeper installations, comprised of at least 6 inches of growth media and planted with ground covers, grasses, shrubs and sometimes trees.
- **Extensive roofs**: Extensive roofs are shallower installations, comprised of less than 6 inches of growth media and planted with a palette of drought-tolerant, low maintenance ground covers. Extensive vegetated roofs have the lowest weight and are typically the most suitable for placement on existing structures. Extensive systems are further divided into two types:
    - "Single-course" systems consist of a single media designed to be freely draining and support plant growth.
    - "Multi-course" systems include both a growth media layer and a separate, underlying drainage layer.

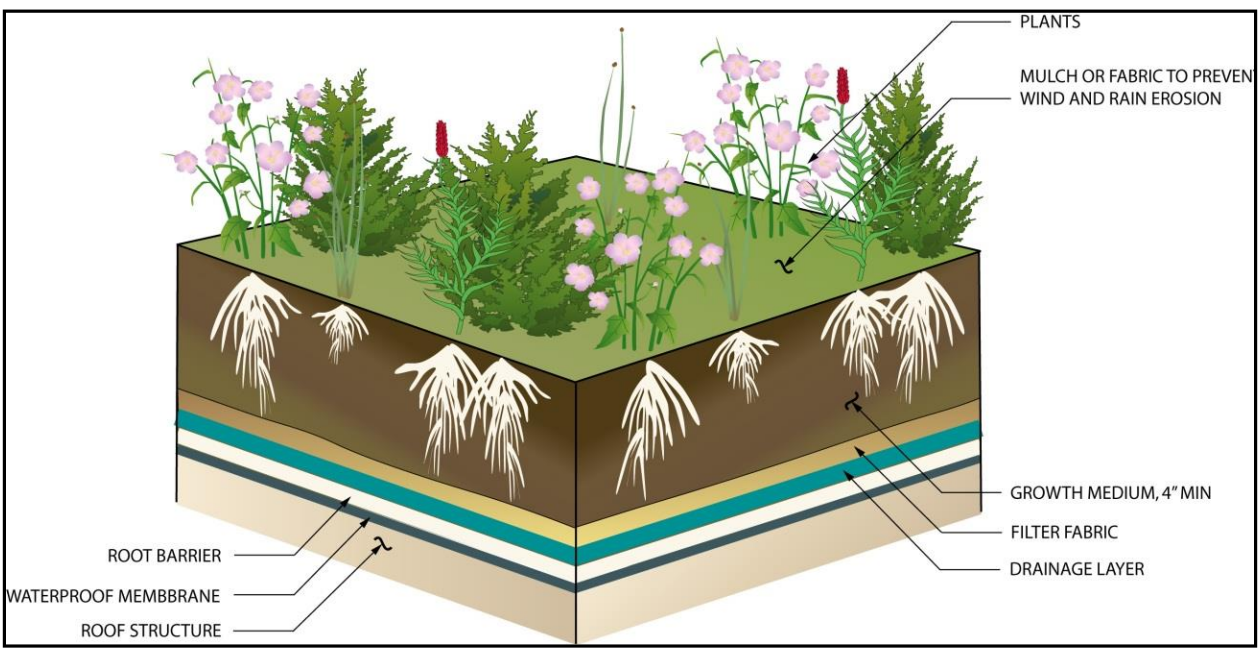


Figure 5.17. Vegetated Roof.

The following types of vegetated roofs are acceptable for flow control compliance:

- Intensive systems
- Extensive multi-course systems (and commercially available modular systems) with at least 4 inches of growth medium
- Extensive single-course systems with at least 4 inches of growth medium for areas less than 1,000 square feet

5.6.1.2. Performance Mechanisms

Vegetated roofs can provide flow control via attenuation, soil storage, and losses to interception, evaporation, and transpiration.

5.6.1.3. Applicability

Vegetated roofs can be designed to meet on-site stormwater management requirements and to receive credit towards meeting flow control standards. The degree of flow control provided by vegetated roofs varies depending on the growth medium (soil) depth, growth medium composition, drainage layer characteristics, vegetation type, roof slope, and other design considerations. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Vegetated Roof	✓	?	✓[a]	✓[a]	✓[a]					

[a] Standard may be partially achieved.

5.6.1.4. Site Considerations

Vegetated roofs are generally applicable to roof slopes between 1 and 22 degrees (0.2:12 and 5:12).

A primary consideration for the feasibility of vegetated roofs is the structural capability of the roof and building structure. Related factors, including design load, slipping and shear issues, and wind load, are outside the scope of this manual. Refer to the City of Seattle Building Code for structural requirements.

5.6.1.5. Design Criteria

The following sections provide a description and suggested specifications for the common components of vegetated roofs. Typical components of a vegetated roof are shown in Figure 5.17. Design criteria are provided in this section for the following elements:

- Roof slope

- Vegetation
- Growth medium
- Drainage layer
- Drain system and overflow

While vegetated roofs will include additional system components (e.g., waterproof membrane, root barrier, separation fabric for multi-course systems), the design and construction requirements for these components are outside of the scope of this manual.

Refer to the Puget Sound LID Manual for a more detailed description of the components of and design criteria for vegetated roofs, as well as additional references and design guidance. Also refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure) for a list of additional design references.

Roof Slope

Vegetated roofs can be applied to a range of rooftop slopes; however, steeper slopes may result in reduced flow control performance and may warrant a more complicated design (e.g., lateral support measures). Roofs with slopes between 5 and 22 degrees (1:12 and 5:12) are the easiest to install, are the least complex, and generally provide the greatest stormwater storage capacity per inch of growth medium.

For flow control compliance, the roof slope must be between 1 and 22 degrees (0.2:12 and 5:12). Roofs with slopes greater than 10 degrees (2H:12V) require an analysis of engineered slope stability.

Vegetation

Vegetation used on extensive vegetated roofs should be drought tolerant, self-sustaining, low maintenance, and perennial or self-sowing. Appropriate plants should also be able to withstand heat, cold, periodic inundation and high winds. Vegetation with these attributes typically includes succulents, grasses, herbs, and wildflowers that are adapted to harsh conditions. Refer to the Green Factor plant list on the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure). Refer to the Puget Sound LID Manual for additional vegetation guidance for vegetated roofs.

Minimum requirements associated with vegetation design include the following:

- Plans must specify that vegetation coverage of selected plants must achieve 90 percent coverage within 2 years or additional plantings must be provided until this coverage requirement is met.
- Plant spacing and plant size must be designed to achieve specified coverage by a licensed landscape architect.
- Vegetation must be suitable for rooftop conditions (e.g., hot, cold, dry, and windy).

- Plants must not require fertilizer, pesticides or herbicides after 2-year establishment period.

Growth Medium

Vegetated roofs use a light-weight growth medium with adequate fertility and drainage capacity to support plants and allow filtration and storage of water. Growth medium composition (fines content and water holding capacity) is key to flow control performance. Refer to the Puget Sound LID Manual for additional guidance on growth medium design.

Minimum requirements associated with the growth medium design include the following:

- The growth medium must be a minimum of 4 inches deep. Refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure) for a growth medium specification. Approved media testing labs and approved media products are also provided on the website.
- Growth medium depth and characteristics must support growth for selected plant species and must be approved by a licensed landscape architect.
- Vegetated roofs must not be subject to any use that will significantly compact the growth medium.
- Unless designed for foot traffic, vegetated roof areas that are accessible to the public must be protected (e.g., signs, railing, and fencing) from foot traffic and other loads.
- Mulch, mat, or other measures to control erosion of growth media must be maintained until 90 percent vegetation coverage is achieved.

Drainage Layer

Intensive and extensive multi-course vegetated roof systems must include a drainage layer below the growth medium. The drainage layer is a multipurpose layer designed to provide void spaces to hold a portion of the water that passes through the growth medium and to channel the water to the roof drain system. The drainage layer can consist of a layer of aggregate or a manufactured mat or board that provides an open free-draining area. Many manufactured products include “egg carton” shaped depressions that retain a portion of the water for eventual evapotranspiration.

Drain System and Overflow

Vegetated roofs must be equipped with a roof drainage system capable of collecting subsurface and surface drainage and conveying it safely to a downstream BMP or an approved point of discharge. To facilitate subsurface drainage, interceptor drains are often installed at a regular spacing to prevent excessive moisture build up in the media and convey water to the roof drain. Roof outlets must be protected from encroaching plant growth and loose gravel, and must be constructed and located so that they are permanently accessible.

5.6.1.6. BMP Credits

On-site List Approach

The impervious surface area covered by a vegetated roof meets the On-site List Requirement. To account for roof areas that cannot feasibility be covered by a vegetated roof system (e.g., access ways, roof vents), the entire roof area meets the On-site List Requirement if 80 percent of the roof is covered by a vegetated roof. If a smaller portion of the roof is covered by a vegetated roof, only the covered portion of the roof meets the On-site List Requirement and an additional BMP is required for the remaining area.

5.6.1.7. Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), flow control credits towards meeting the Pre-developed Pasture and Peak Control Standards may be partially achieved by vegetated roofs. Credits for vegetated roofs are provided in Table 5.28, organized by performance standard and growth medium depth. These credits can be applied to reduce the effective impervious surface area used in drainage calculations. Since the credits for vegetated roofs are less than 100 percent, the standard cannot be completely achieved and additional flow control measures will be required. As an example, for a site subject to the Peak Control Standard, a multi-course vegetated roof with 4 inches of growth medium would receive a 71 percent credit. Therefore, 71 percent of the impervious area covered by the vegetated roof can be excluded from drainage calculations. The effective impervious area (the area used to size the downstream flow control facility) would be calculated as 29 percent of the impervious area covered by the vegetated roof.

Table 5.28. Flow Control Credits for Vegetated Roofs.

Courses / Medium Depth	Credit (%)	
	Pre-developed Pasture Standard	Peak Control Standard
Single-Course / 4 inches	46%	71%
Multi-Course / 4 inches	46%	71%
Multi-Course / 8 inches	54%	79%

Impervious Area Mitigated = Vegetated roof Area x Credit (%)/100.

The flow control credits outlined above are applicable only if the vegetated roof meets the minimum design requirements outlined in this section and the minimum medium depth specified in Table 5.28.

Alternatively, vegetated roofs can be sized using a continuous model as described below.

Modeling Approach

When using continuous simulation hydrologic modeling to quantify the on-site stormwater management and/or flow control performance of vegetated roofs, the assumptions listed in Table 5.29 must be applied. It is recommended that vegetated roofs be modeled as layers of aggregate with surface flows, interflow, and exfiltrating flow routed to an outlet.

Table 5.29. Continuous Modeling Assumptions for Vegetated Roofs.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Inflows to Facility	None
Precipitation and Evaporation Applied to Facility	Yes
Depth of Material (inches)	Growth medium/soil depth (minimum of 4 inches). Currently, MGSFlood and the Western Washington Hydrology Model (WWHM) are not capable of representing the flow control benefits of the drainage layer or other storage beneath the growth medium.
Vegetative Cover	Ground cover or shrubs. Shrubs are appropriate only when growth medium is at least 6 inches.
Length of Rooftop (ft)	The length of the surface flow path to the roof drain
Slope of Rooftop (ft/ft)	The slope of the vegetated roof
Discharge from Facility	Surface flow, interflow and exfiltrated flow from vegetated roof module routed to downstream BMP or point of compliance. Note that the exfiltrated flow (flow infiltrated through the media and collected by the drainage layer) is tracked as "groundwater" in MGSFlood and WWHM.

The medium depth can be modified to achieve various degrees of flow control. Because the on-site stormwater management and flow control standards cannot typically be achieved using a vegetative roof, additional downstream flow control measures may be required.

5.6.1.8. Minimum Construction Requirements

The growth medium must be protected from over compaction during construction. For inspection and verification procedures used for facility approval by City staff, refer to SPU GSI website: (http://www.seattle.gov/util/greeninfrastructure).

5.6.1.9. Operations and Maintenance Requirements

Vegetated roof O&M requirements are provided in *Appendix G (BMP No. 27)*. A Landscape Management Plan shall be developed and implemented for vegetation O&M. If an irrigation system is included, an Irrigation Design and Operation Plan shall be included in the Landscape Management Plan.

5.6.2. Permeable Pavement Surfaces

5.6.2.1. Description

Permeable pavement is a paving system which allows rainfall to percolate into the underlying subgrade. Two categories of permeable pavement BMPs are included in this manual: permeable pavement "surfaces" and permeable pavement "facilities". A comparison of these BMPs is provided in Table 5.23.

A permeable pavement surface consists of a pervious wearing course and an aggregate subbase installed over subgrade soil (Figure 5.18). The aggregate subbase is designed to manage only the water which falls upon it and must not be designed to take significant runoff from other areas. A permeable pavement surface does not require lateral impermeable barriers (e.g., subsurface check dams) and overflow infrastructure. While permeable pavement surfaces are not always capable of achieving performance standards, they can always achieve partial credit towards stormwater management goals.While similar to "surfaces", permeable pavement "facilities" may be designed to receive run-off from other areas and are subject to more onerous design requirements (refer to *Section 5.4.6*).

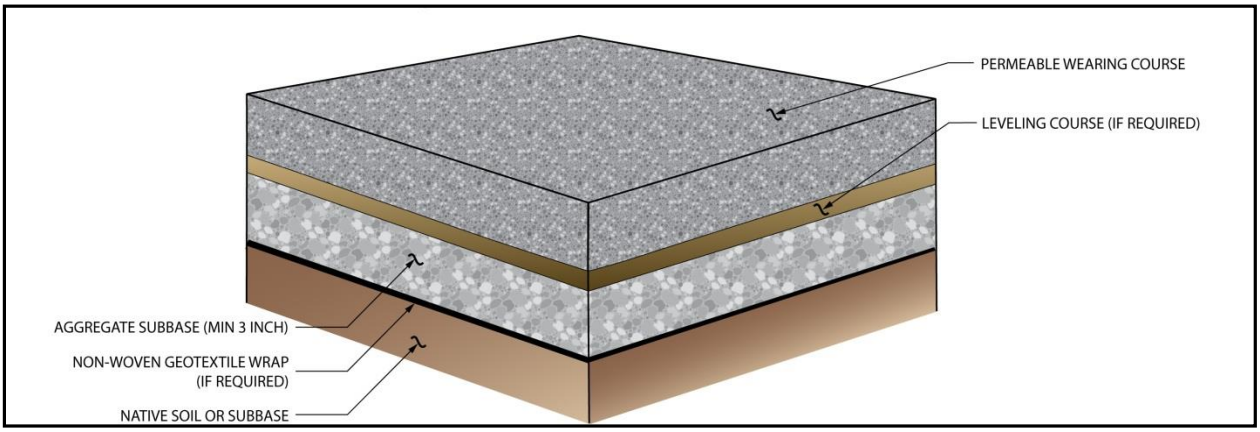


Figure 5.18. Permeable Pavement Surface.

5.6.2.2. Performance Mechanisms

Flow control occurs through temporary storage of stormwater runoff in the voids of the aggregate material and subsequent infiltration of stormwater into the underlying soils. Pollutant removal mechanisms include infiltration, filtration and sedimentation, biological decomposition, and soil adsorption.

5.6.2.3. Applicability

The flow control performance of a permeable pavement surface is a function of the infiltration rate of the underlying subgrade soil.

Permeable pavement surfaces can meet water quality treatment requirements when the underlying soil meets the treatment soil requirements outlined in *Section 5.4.1* or a water quality treatment course is included.

This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Permeable pavement surface	✓	✓	✓[a]	✓[a]	✓[a]	✓[a,b]	✓[a,b]			

[a] Standard may be partially or completely achieved depending upon subgrade slope, infiltration rate of subgrade soil, and whether aggregate subbase is laid above or below surrounding grade.

[b] Underlying soil must meet the treatment soil requirements outlined in *Section 5.4.1* or a water quality treatment course must be included.

5.6.2.4. Site Considerations

Since permeable pavement surfaces are not designed to receive runoff from other surfaces and are designed to function as a permeable land surface, they are not considered infiltration facilities. Therefore, the restrictions related to infiltration facilities (e.g., setbacks, separation from groundwater) are not applicable. The considerations regarding topography, land use, and accessibility are the same as those presented for permeable pavement facilities (refer to *Section 5.4.6*). In addition, permeable pavement should not be sited:

- Within 10 feet of an underground storage tank (or connecting underground pipes) used to store petroleum products, chemicals, or liquid hazardous wastes.
- Where the site is a contaminated site or abandoned landfill

5.6.2.5. Design Criteria

This section provides descriptions, recommendations, and requirements for the common components of permeable pavement surfaces. Some, or all, of the components may be used for a given application depending on the permeable pavement type (e.g., porous asphalt, pavers, etc.), site characteristics and restrictions, and design objectives. Typical components of a permeable pavement surface are shown in Figure 5.18. The design criteria for the following components are the same as those presented for permeable pavement facilities (refer to *Section 5.4.6*):

- Wearing course
- Leveling course
- Geotextile
- Water quality treatment course

The requirements for the following components differ from permeable pavement facilities listed below and the design criteria for these components follow.

- Contributing area
- Aggregate subbase
- Lateral impermeable barriers
- Overflow

Note that unlike permeable pavement facilities, observation ports are not required, and flow entrances, presettling and underdrains are not applicable.

The structural design of permeable pavement to support anticipated loads is outside the scope of this manual.

The Puget Sound LID Manual provides additional guidance on permeable pavement design. Additional guidance for permeable pavement in the public right-of-way is provided in the Seattle Right-of-Way Improvements Manual.

Contributing Area

Permeable pavement surfaces must not be designed to take significant runoff from other areas ("run-on"). In no case must the surface receive run-on from an impervious area greater than 10 percent of the permeable pavement area. Any run-on must be dispersed. To prevent sediment flowing onto the pavement, run-on must not occur from erodible/unstabilized areas or from impervious areas that receive run-on from unstabilized areas.

Aggregate Subbase

The aggregate subbase in a permeable pavement surface is the support base for the road, parking, or pedestrian area. The subbase must be sufficiently thick to support the expected loads and be free draining. Design of the subbase for loading is outside of the scope of this manual. A licensed engineer is needed to determine the minimum aggregate base thickness and analyze subsoil load bearing for traffic loading.

Minimum requirements associated with the aggregate subbase design include the following:

- A 3-inch minimum depth of aggregate subbase is required under the wearing course and leveling course (if any).
- For walkways, aggregate material must be in accordance with City of Seattle Mineral Aggregate Type 24 or modified AASHTO #57 per WSDOT Section 9-03.1(4)C with 0-2% passing #200 wet sieve; % fracture must be in accordance with requirements per WSDOT 9-03.9(2).
- For vehicular applications, aggregate material must be in accordance with City of Seattle Mineral Aggregate Type 13 or modified AASHTO #57 per WSDOT Section 9-03.1(4)C with 0-2% passing #200 wet sieve; % fracture must be in accordance with requirements per WSDOT 9-03.9(2).
- The aggregate base must have a minimum total void volume of 25 percent after compacted in place.

Lateral Subsurface Impermeable Barriers

Sloped facilities have an increased potential for lateral flows through the aggregate subbase along the top of the relatively impermeable subgrade soil. This poses a risk of subsurface erosion and reduces the storage and infiltration capacity of the pavement facility. To address this, the subgrade may be designed to create subsurface ponding to detain subsurface flow, increase infiltration, and reduce structural problems associated with subgrade erosion on slopes (refer to Figure 5.14).

Unless a geotechnical evaluation of subgrade soils shows that erosion control measures along the interface are unnecessary, permeable pavement surfaces with subgrade slopes greater than 5 percent must include lateral impermeable barriers to reduce structural problems associated with subgrade erosion on slopes. Minimum requirements associated with lateral impermeable barriers include the following:

- Lateral impermeable barriers must be installed at regular intervals perpendicular to the subgrade slope to reduce flow velocities and the potential for erosion of the subgrade.
- The barriers must not extend to the elevation of the surrounding ground.

5.6.2.6. BMP Sizing/Credits

On-site List Approach

The permeable pavement surface area meets the On-site List Requirement.

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized permeable pavement surfaces receive credits toward meeting the Pre-developed Pasture and Peak Control Standards. Credits for permeable pavement surfaces are provided in Table 5.30, organized by performance standard and subgrade slope. These credits can be applied to reduce the effective impervious surface area used in drainage calculations. If partial credit (less than 100 percent) is received, the standard is not completely achieved and additional measures will be required. As an example, for a site subject to the Pre-developed Pasture Standard, a permeable pavement surface on subgrade with a slope between 2 and 5 percent would receive a 45 percent credit. Therefore, 45 percent of the permeable pavement surface can be excluded from drainage calculations. The effective impervious area (the area used to size the downstream flow control facility) would be calculated as 55 percent of the permeable pavement surface area.

Table 5.30. Credits for Permeable Pavement Surfaces.

Subgrade Slope	Credit (%)		
	Pre-developed Pasture Standard	Peak Control Standard	Treatment Standard
Up to 2%	100%	100%	
2 to 5%	45%	70%	

Impervious Area Mitigated = Permeable Pavement Surface Area x Credit (%)/100.

To use these flow control credits to meet on-site and flow control standards, the BMP must meet the general requirements for permeable pavement surfaces outlined in this section plus the following specific requirements:

- The aggregate subbase must be at least 3 inches in depth.
- The permeable pavement area must be sized using factor in Table 5.25.
- The aggregate subbase must be composed of aggregate with a minimum void volume of 25 percent.
- Subgrade slope must be as specified.
- To meet the Treatment Standard, the underlying soil must meet the treatment soil requirements outlined in *Section 5.4.1* or a water quality treatment course must be used.
- No underdrain or impermeable liner must be used.

For subgrade slopes between 2 and 5 percent flow control performance is lower. For improved performance, the surface may be designed as a permeable pavement facility with subsurface ponding and/or increased aggregate subbase depth. In this case, the surface must be evaluated as a facility (refer to *Section 5.4.6*).

Alternatively, the performance of permeable pavement surfaces can be evaluated using a continuous simulation hydrologic model as described below.

Modeling Approach

The approved continuous simulation hydrologic modeling methods for permeable pavement surfaces vary depending upon the slope of the underlying subgrade and whether or not the aggregate subbase is below the surrounding grade (Tables 5.31, 5.32 and 5.33).

For flat and low slope permeable pavement surface installations (0 to 2 percent) with subgrade below the surrounding grade, the aggregate subbase depth may be iteratively sized until the performance standard(s) are met. For other scenarios, partial credit towards meeting standards can be achieved and runoff from the pavement area can be routed to a downstream BMP.

5.6.2.7. Minimum Construction Requirements

The construction specifications and criteria for permeable pavement surfaces are the same as those presented for permeable pavement facilities (refer to *Section 5.4.6.7*).

5.6.2.8. Operations and Maintenance Requirements

Permeable pavement O&M requirements are the same as those presented for permeable pavement facilities in *Appendix G (BMP No. 25)*.

Table 5.31. Modeling Methods for Permeable Pavement Surfaces.

Subbase	Wearing Course	Subgrade Slope	Modeling Representation	Performance
Subbase below (or partially below) the surrounding grade	Any	0-2%	Model as an impervious area with runoff routed to a gravel-filled infiltration trench (of the same size as the pavement area). The trench depth should be set at the depth of the aggregate below the surrounding grade. Refer to Table 5.32.	The aggregate subbase may be sized to meet performance standards
			Represent surface with land cover approximation. Refer to Table 5.33.	Partial credit towards performance standard may be achieved
		>2%	Model as an impervious area with runoff routed to a gravel-filled infiltration trench (of the same size as the pavement area) with nominal ponding depth of 1/2-inch. Refer to Table 5.32.	Partial credit towards performance standard may be achieved. To achieve 100% credit towards performance standards on sloped subgrade, use permeable pavement facility (refer to *Section 5.4.6*).
			Represent surface with land cover approximation. Refer to Table 5.33.	
Subbase above surrounding grade	Porous Asphalt or Pervious Concrete	Any	Represent surface with land cover approximation. Refer to Table 5.33.	Partial credit towards performance standard may be achieved
	Grid System	Any	Represent surface with land cover approximation. See Table 5.33.	Partial credit towards performance standard may be achieved
	Interlocking Paver	Any	Represent surface with land cover approximation. See Table 5.33.	Partial credit towards performance standard may be achieved

Table 5.32. Continuous Modeling Assumptions for Permeable Pavement Surface (Explicit Representation).

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Permeable Pavement Surface	Option 1: The selected model may have a routine specifically developed for permeable pavement that simulates precipitation falling on the pavement, infiltration through the pavement section, storage in the aggregate beneath the pavement, and infiltration into the underlying soil Option 2: If a permeable pavement routine is not available, represent the pavement area as an impervious basin with runoff routed to a gravel-filled trench (of the same size as the pavement area) with infiltration to underlying soil. No additional areas must drain to the pavement.
Precipitation Applied to Facility	If using Option 1 precipitation is applied to the pavement area If using Option 2, do not apply precipitation to the trench bed because precipitation is already applied to basin before routing to trench
Evaporation Applied to Facility	If using Option 1 evaporation is applied to the pavement area If using Option 2, while evaporation is applied to the impervious basin before routing to the trench, additional evaporation may be applied to the trench because additional evaporation occurs when water is stored in the aggregate subbase
Aggregate Subbase Depth	When subbase is below the surrounding grade, use the depth of the aggregate subbase. When the subbase is above the surrounding grade, use a nominal depth of ½-inch.
Aggregate Subbase Porosity	Assume maximum 25 percent unless test is provided showing higher porosity for aggregate compacted and in place.
Subgrade Soil Design Infiltration Rate	Measured infiltration rate with correction factor applied (*Section 5.4.1*, *Appendix D*).
Infiltration Across Wetted Surface Area	No (infiltration on bottom area only)

Table 5.33 Continuous Modeling Assumptions for Permeable Pavement Surface (LanCover Approximation).

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Basin	Model surface area as land cover approximation : Porous Asphalt or Pervious Concrete: grass on underlying soil type (till or outwash) Grid System: grass on underlying soil type (till or outwash) Interlocking Paver: 50% grass on underlying soil type (till or outwash) and 50% impervious

5.7. Detention BMPs

Detention facilities provide for the temporary storage of stormwater runoff. Stormwater is then released through a control structure at an attenuated rate to meet flow control performance standards. The BMPs in this section include:

- Detention ponds
- Detention pipes
- Detention vaults
- Detention cisterns
- Other detention options

5.7.1. Detention Ponds

5.7.1.1. Description

Detention ponds are basins that temporarily store runoff and control release rates. Detention ponds may be designed to drain completely between storm events, or designed as a combination water quality treatment and flow control facility. The combination of water quality treatment and flow control functions is summarized in *Section 5.8.9*.

5.7.1.2. Performance Mechanisms

Detention ponds provide peak flow attenuation by slowly releasing low flows through an outlet control structure.

5.7.1.3. Applicability

A detention pond is designed for flow control of stormwater. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Detention Pond			✓	✓	✓					✓

5.7.1.4. Site Considerations

Detention ponds require a large amount of area. In addition to the area required for the pond, maintenance access must be provided, which can affect the footprint of the pond and in part determine whether they are feasible for a particular site. In a highly developed area like the City of Seattle, large open ponds are somewhat uncommon.

Setback requirements for detention ponds are intended to protect neighboring properties from flooding and protect receiving waters and critical areas from water quality impacts. The City has developed more stringent setback requirements than Ecology for detention ponds installed in Seattle. The following setback requirements apply to detention ponds installed within the City limits:

- A 5-foot setback is required from the toe of the exterior slope of the property line.
- The property line on a pond cut slope must be set back 5 feet from the emergency overflow water surface.
- Geotechnical analysis is required for facilities within 20 feet of any structure or property line or within 50 feet up-slope of a building when the slope is greater than 15 percent.

- All facilities must be a minimum of 50 feet from the top of any slope steeper than 15 percent. A geotechnical analysis and report must be prepared addressing the potential impact of the facility on the slope.

5.7.1.5. Design Criteria

The design criteria in this section are for detention ponds. However, many of the criteria also apply to infiltration basins (*Section 5.4.8*), as well as wet ponds and combined detention/wet pools (*Section 5.8.9*).

The following provides a description and requirements for the components of detention ponds. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section or in Volume III of the SWMMWW for the following elements:

Design Element	SWMMWW Design Criteria	Seattle-specific Design Criteria
Detention pond geometry	✓	✓
Access to cells for maintenance	✓	✓
Fencing	✓	✓
Embankments and failure analysis	✓	✓
Dam safety	✓	✓
Vegetation and landscaping	✓	✓
Design and construction of access roads	✓	
Overflow	✓	
Emergency overflow spillway	✓	

Refer to Detention Ponds in Volume III of the SWMMWW for specific detention pond design criteria. The City's design criteria for specific design elements are summarized below.

Detention Pond Geometry

Refer to Detention Ponds in Volume III of the SWMMWW for detention pond design considerations. The following additional requirements must be followed for detention ponds installed in Seattle:

- Vertical retaining walls must be used when the pond is fenced and designed for sediment removal by vactor.
- Any pond cell allowing or requiring entry for maintenance, including vegetation maintenance, must have a section of interior side slopes of 4H:1V for safe egress.

Access to Cells for Maintenance

Refer to Detention Ponds in Volume III of the SWMMWW for access design considerations. The following additional requirement must be followed for detention ponds installed in Seattle:

- An access plan is required for sediment removal from all cells. Early conversation with SPU is encouraged and Director's approval is required.

Fencing

Refer to Detention Ponds in Volume III of the SWMMWW for fencing considerations. The City has developed a set of Standard Plans that can be used instead of WSDOT's Standard Plans (referred to in the *Fencing Considerations* section of the SWMMWW). Refer to City of Seattle Standard Plan Number 450a for a Type 1 or Type 3 chain link fence.

Embankments and Failure Analysis

Refer to Detention Ponds in Volume III of the SWMMWW for embankment design requirements. The following additional requirements must be followed for detention ponds installed in Seattle:

- If an embankment is proposed to impound water, early conversations with SPU are encouraged and Director's approval is required. Impoundment of a water volume exceeding 10-acre-feet is considered a dam and is regulated by Ecology.
- A failure analysis describing impacts of embankment failure must be provided.

Dam Safety

Refer to Detention Ponds in Volume III of the SWMMWW for dam safety requirements. The following additional requirement must be followed for detention ponds installed in Seattle:

- Detention facilities that can impound 10-acre-feet (435,600 cubic feet; 3.26 million gallons) or more with the water level at the embankment crest must meet the state's dam safety requirements, even if water storage is intermittent and infrequent (WAC 173-175-020(1)). The principal safety concern is for the downstream population at risk if the dam should breach and allow an uncontrolled release of the pond contents.

Ecology contact information and electronic versions of the guidance documents in PDF format are available on the Ecology website at (http://www.ecy.wa.gov/programs/wr/dams/dss.html).

Vegetation and Landscaping

Refer to Detention Ponds in Volume III of the SWMMWW for vegetation and landscaping requirements. The following additional requirements must be followed for detention ponds installed in Seattle:

- A plan for landscape establishment is required. Early conversation with SPU is encouraged. Consider installation of a hose bib and water service for watering.
- All planted slopes must be accessible for vegetation maintenance.
- Use of ornamental plantings in the vicinity of a detention pond are discouraged and may not be allowed to due concerns regarding seed transport.

5.7.1.6. BMP Sizing

Refer to Detention Ponds in Volume III of the SWMMWW for BMP Sizing considerations.

5.7.1.7. Minimum Construction Requirements

The following construction requirements should be considered during construction of a detention pond:

- Detention ponds may be used for sediment control during site construction, but sediment must be removed upon completion.
- Exposed earth on the pond bottom and interior side slopes must be vegetated or seeded with an appropriate seed mixture.

5.7.1.8. Operations and Maintenance Requirements

Detention pond O&M requirements are provided in *Appendix G (BMP No. 1)*.

5.7.2. Detention Pipes

5.7.2.1. Description

Detention pipes are underground storage facilities for stormwater.

5.7.2.2. Performance Mechanisms

Detention pipes provide peak flow attenuation by slowly releasing low flows through an orifice.

5.7.2.3. Applicability

A detention pipe is designed for flow control of stormwater. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Detention Pipe			✓	✓	✓					✓

5.7.2.4. Site Considerations

The primary site considerations for detention pipes include conflicts with existing underground utilities. While there are no specific setback requirements for detention pipes, DPD must approve the detention pipe location and pipe material or require geotechnical analysis.

Additional site considerations may apply depending on site conditions and other factors.

5.7.2.5. Design Criteria

The following provides a description and requirements for the components of detention pipes. Some or all of the components may be used for a given application depending on the site characteristics and restrictions and design objectives. Design criteria are provided in this section for the following elements:

- Detention pipe materials and specifications
- Pipe bedding
- Structural stability
- Access

Typical design guidelines for detention pipes are shown in City of Seattle Standard Plans 270 through 272 and provided in the City of Seattle Side Sewer Directors' Rule which can be found

on DPD's website (http:seattle.gov/dpd). Flow control structure details are shown in *Appendix E*.

Detention Pipe Materials and Specifications

The material, diameter, and specification of the detention pipe must be indicated on the Side Sewer Permit application, required before installing the drainage facility. The following materials are approved for detention pipes installed in Seattle:

- Corrugated Polyethylene (PE) Drain Pipe (for detention pipes located on private property) – Minimum 12-inch diameter, maximum 60-inch diameter, AASHTO M 294, Type S (material not approved for use in buildover applications). Refer to City of Seattle Standard Specification 9-05.5(2).
- Steel Pipe for Detention – AASHTO M 36 Type I (Material not approved for use in the Public Place nor as a detention facility in landslide-prone areas nor in buildover applications). Refer to City of Seattle Standard Specification 9-05.7(5).
- Aluminum Pipe for Detention – AASHTO M 196 Type I (Material not approved for use in the Public Place nor as a detention facility in landslide-prone areas nor in buildover applications). Refer to City of Seattle Standard Specification 9-05.6(4).

Pipe Bedding

The City has developed the following guidelines for pipe bedding:

- All detention pipe bedding installed on public property must be per the City of Seattle Standard Specifications for Road, Bridge and Municipal Construction.
- All detention pipe bedding installed on private property must comply with the following bedding requirements:
    - Bedding for flexible pipe (Corrugated PE), must be Class B Bedding per City of Seattle Standard Specification 7-17.3(1)B3, and filled and compacted to 6 inches above the top of the pipe with Type 22 aggregate (crushed gravel – 3/4").
    - Bedding materials must be in place and inspected by the DPD Site Inspector for compliance and approval prior to backfilling trench. Material recommendations may be provided by the project's geotechnical engineer with approval from the DPD Site Inspector.

Structural Stability

Detention pipes must meet structural requirements for overburden support, buoyancy, and traffic loading if appropriate. When a detention pipe is located under a building, provide a load analysis. The pipe must not be located under the foundation or have pressure exerted on it by the foundation. In moderately pervious soils where seasonal groundwater may induce flotation, buoyancy tendencies must be balanced either by ballasting with backfill or concrete backfill, providing concrete anchors, or increasing the total weight.

When corrugated metal pipe is selected, end plates must be designed for structural stability at maximum hydrostatic loading. Flat end plates generally require thicker gage material than the pipe and/or require reinforcing ribs. Corrugated metal pipe is not allowed for use in the right-of-way, critical areas, geologic hazard areas, or underneath buildings.

Detention pipes must be placed on a stable, well consolidated foundation, have suitable bedding, and must follow City of Seattle Standard Specifications for Road, Bridge, and Municipal Construction. Detention pipes must not be placed in fill slopes, unless a geotechnical analysis is provided for stability and constructability.

Access

Within the right-of-way, access must be provided as shown on City of Seattle Standard Plan 270. Truck access is required at each maintenance hole location.

Detention pipes on a parcel have an option to follow City of Seattle Standard Plan 270 or, when using corrugated metal pipe, City of Seattle Standard Plan 271. In addition, the following access requirements apply:

- Detention pipes more than 50 feet long must provide a cleanout. Detention pipes more than 100 feet long must have access risers at each end to allow for maintenance and repair. Detention pipes over 200 feet long must have an access riser at the upstream end and a cleanout at least every 100 feet.
- Access openings must be positioned a maximum of 50 feet from any location within the detention pipe.
- All detention pipe access openings must have round, solid locking lids (usually 1/2 to 5/8-inch diameter Allen-head cap screws).
- Access must be provided by 36-inch minimum diameter corrugated metal pipe (CMP) riser-type maintenance holes of the same gage as the detention pipe material along the length of the detention pipe, and at the upstream terminus of the detention pipe in a backup system. The top slab is separated (1-inch minimum gap) from the top of the riser to allow for deflections from vehicle loadings without damaging the riser pipe.
- All detention pipe access openings must be readily accessible by maintenance vehicles (including flow control structures located under buildings).

5.7.2.6. BMP Sizing

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized detention pipes may be used to achieve Pre-developed Pasture and Peak Control Standards. Sizing factors for detention pipe receiving runoff from an impervious surface are provided in Table 5.34. Sizing factors are organized by pipe diameter, contributing area, and flow control standard. To use these sizing factors to meet flow control standards, the facility must meet the general requirements for detention pipes outlined in this section plus the following specific requirements:

- Sizing equations are applicable for contributing impervious surface areas between 2,000 and 10,000 square feet.
- Pipe length must be sized using the applicable sizing equation.
- The low flow orifice diameter must be 0.5 inches.
- Detention pipe must be the designated diameter (24 or 36 inches). For intermediate diameters (between 24 and 36 inches), the pipe length may be linearly interpolated.
- The entire volume of the pipe must be available for storage.

Table 5.34. Sizing Equations for Detention Pipe.

Detention Pipe Diameter	Contributing Area	Sizing Equation for Pipe Length	
		Pre-developed Pasture Standard	Peak Control Standard
24 inches	2,000 – 5,000 sf	0.0000263 x [A^1.94]	0.00000508 x [A^2.10]
	5,000 – 10,000 sf	[0.120 x A] – 235	[0.123 x A] – 314
36 inches	2,000 – 5,000 sf	0.000000219 x [A^2.40]	0.00000277 x [A^2.05]
	5,000 – 10,000 sf	[0.0515 x A] – 110	[0.0546 x A] – 167

A- contributing impervious area; ft- feet; sf- square feet.
For A < 5,000sf: Pipe Length (ft) = Factor x [A (sf)^Integer].
Impervious Area Mitigated (sf) = [Pipe Length (ft) ÷ Factor]^(1 ÷ Integer).
For A 5,000 to 10,000 sf: Pipe Length (ft) = [Factor x Area (sf)] +Integer.
Impervious Area Mitigated (sf) = [Pipe Length (ft)- Integer]÷ Factor.

The pipe length is calculated as a function of the impervious area routed to it. As an example, for the Pre-developed Pasture Standard, the pipe length for a 24-inch diameter pipe receiving runoff from between 5,000 to 10,000 square feet of impervious surface would be calculated as: 0.120 x impervious area (square feet) - 235 feet. All area values must be in square feet and length values must be in feet.

Alternatively, detention pipes for small sites can be sized using a continuous model as described in the subsequent section.

Modeling Approach

When using the continuous runoff model vault module for pipe sizing, the assumptions listed in Table 5.35 must be applied. It is recommended that pipes be modeled as horizontal cylinders with an outlet structure that includes a low flow orifice. The tributary areas, pipe diameter, pipe length and orifice configuration should be iteratively sized until the Minimum Requirements for Flow Control are met (refer to *Volume 1, Chapter 3*).

In some instances, the minimum diameter for the low flow orifice (0.5-inch for below ground detention and 0.25-inch for aboveground detention) will be too large to meet standard release rates, even with minimal head (refer to *Section 5.7.2.3 Applicability*). Designers should iteratively increase detention area and decrease live storage depth until the performance criteria are met. However, live storage depth should not be reduced to less than 3 feet in an attempt to meet the flow control standards.

Table 5.35. Continuous Modeling Assumptions for Detention Pipe.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Inflows to Facility	Surface flow and interflow from drainage area should be connected to facility.
Precipitation and Evaporation Applied to Facility	No
Infiltration	No
Total Depth	The total depth is the pipe diameter.
Outlet Structure	Low flow orifice, riser height and diameter
Low Flow Orifice	Minimum diameter of 0.5 inches, set 1 foot below the pipe invert.

As a rule of thumb, flow control standards can be achieved using a 0.5-inch diameter bottom orifice with a 3-foot live storage depth in the following scenarios:

- Pre-developed Forest Standard can be achieved when the contributing impervious area is greater than approximately 35,000 square feet.
- Pre-developed Pasture Standard can be achieved when the contributing impervious area is greater than approximately 26,000 square feet.
- Peak Control Standard can be achieved when the contributing impervious area is greater than approximately 2,600 square feet.

In these cases, the following design/modeling approach is recommended:

- **Step 1**: Size the detention facility with 3 feet of head to meet the flow control standard with an optimized orifice size (orifice diameter may be lower than minimum allowed in this step).
- **Step 2**: Use the facility size (e.g., length and diameter) obtained in Step 1 and increase the orifice diameter to the minimum size.

5.7.2.7. Minimum Construction Requirements

Refer to the construction-related issues outlined above as part of the design criteria. Additional construction requirements are as follows:

- The bedding required for detention pipes is the same as for other pipes in the drainage system. Use washed, crushed aggregate Type 22 for corrugated metal pipes. Use 3/8-inch washed gravel (City of Seattle–Mineral Aggregate, Type 9) for other pipes. Place at least 4 inches of gravel under the pipe. The gravel must fill the trench to a point half–way up the sides of the pipe (to the "spring line").
- Provide at least 2 feet of cover over a detention pipe. For single family and duplex residences, 18 inches of cover is allowable. Before a side sewer permit is signed–off

as completed, a City inspector must approve the installed system, including the detention pipe and the flow control structure, after it is bedded but before it is covered with soil.

- The standard slope for detention pipes is 0.5 percent. The inlet pipe to the detention pipe and the outlet pipe from the flow control structure must have at least a 2 percent slope, the same as required for other service drain pipes.
- Field changes to the flow control device assembly, including elevation changes, require submittal to the Engineer of Record for confirmation that the device still meets the design requirements.

5.7.2.8. Operations and Maintenance Requirements

Detention pipe O&M requirements are provided in *Appendix G (BMP No. 3)*.

5.7.3. Detention Vaults

5.7.3.1. Description

Detention vaults are underground storage facilities for stormwater.

5.7.3.2. Performance Mechanisms

Detention vaults provide peak flow attenuation by slowly releasing low flows through an orifice.

5.7.3.3. Applicability

A detention vault is designed for flow control of stormwater. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Detention Vault			✓[a]	✓[b]	✓[c]					✓

Flow control standards can be achieved in Seattle using a 0.5-inch diameter bottom orifice with a 3-foot live storage depth in the following scenarios:

[a] Pre-developed Forest Standard can be achieved when the contributing impervious area is greater than approximately 35,000 square feet.

[b] Pre-developed Pasture Standard can be achieved when the contributing impervious area is greater than approximately 26,000 square feet.

[c] Peak Control Standard can be achieved when the contributing impervious area is greater than approximately 2,600 square feet.

5.7.3.4. Site Considerations

Detention vaults can be shallower than detention pipes, since they can utilize a greater area. Primary site considerations for a detention vaults include providing sufficient access points for maintenance, incorporating the access requirements into a site, conflicts with existing underground utilities, and site setback requirements. While there are no specific setback requirements for detention vaults, DPD must approve the detention vault location and may specify vault material, or require geotechnical analysis.

Note that belowground detention facilities are discouraged for single-family residential sites and are not required to meet flow control standards.

5.7.3.5. Design Criteria

The following provides a description and requirements for the components of detention vaults (Figure 5.19). Flow control structure details are outlined in *Appendix E*. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section for the following elements:

- Materials
- Structural stability
- Access

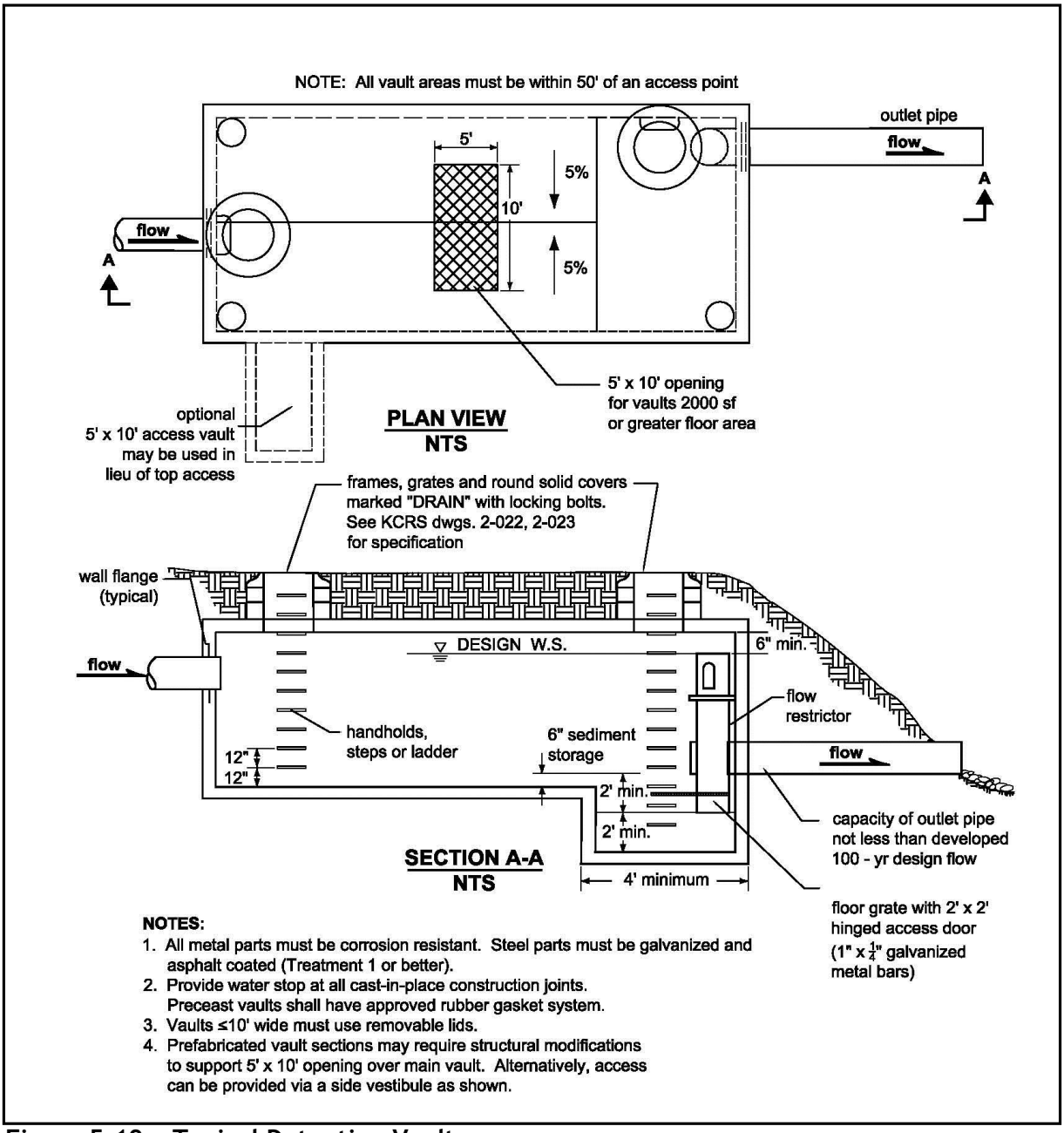


Figure 5.19. Typical Detention Vault.

Design criteria are summarized below for each of these design elements.

Materials

Minimum 3,000 psi structural reinforced concrete must be used for detention vaults. All construction joints must be provided with water stops.

Structural Stability

The following structural requirements apply to detention vaults:

- Detention vaults must meet structural requirements for overburden support, buoyancy, and traffic loading if appropriate.
- Design of detention vaults shall be water tight.
- When detention vaults are incorporated into or underneath a building, they must meet all structural requirements for the building or demonstrate no structural interaction, including no loading on the vault from the building foundation.
- Detention vaults must be placed on a stable, well-consolidated foundation and bedding material.
- Detention vaults must not be placed in fill slopes, unless a geotechnical analysis for stability and constructability is provided.

Detention pipe is preferred over detention vaults for the public drainage system. Early conversations with SPU are encouraged, if considering installation of a detention vault in the right-of-way.

Access

The following access requirements apply to detention vaults:

- Access must be provided for visual inspection of the flow control structure and for cleaning the entire floor area of the detention vault. A plan for access, including maintenance equipment access is required.
- Access may be provided by use of removable panels, hatches, or ring and cover. For any detention vault requiring entry for maintenance, ladders must be installed so that the egress path does not exceed 25 feet.
- All access must be readily accessible by maintenance vehicles, including structures located under buildings.
- The maximum depth from finished grade to the detention vault invert is 17 feet.
- Access must be provided over both the inlet pipe and outlet structure. Access openings must be positioned a maximum of 50 feet from any location within the detention vault. Additional access points may be needed on large vaults. Vaults are designed to slope at least 5 percent from each side towards the center, forming a broad “v” to facilitate sediment removal. If more than one “v” is provided in the vault floor to minimize vault depth, access to each “v” must be provided.
- Internal structural walls of large vaults must be provided with openings sufficient for maintenance access between cells. The openings must be sized and situated to allow access to the maintenance “v” in the vault floor.

- The recommended minimum internal height is 7 feet from the highest point of the vault floor (not sump), and the recommended minimum width is 4 feet. However, concrete vaults may be a minimum 3 feet in height and width if used as detention pipes with access maintenance holes at each end, and if the width is no larger than the height. The minimum internal height requirement may not be needed for any areas covered by removable panels.

5.7.3.6. BMP Sizing

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized detention vaults may be used to achieve Pre-developed Pasture and Peak Control Standards. Sizing factors for rectangular detention vaults receiving runoff from an impervious surface are provided in Table 5.36. Sizing factors are organized by detention depth, contributing area, and flow control standard. To use these sizing factors to meet flow control standards, the facility must meet the general requirements for vaults outlined in this section plus the following specific requirements:

- Sizing equations are applicable for contributing impervious surface areas between 2,000 and 10,000 square feet.
- Vault area must be sized using the applicable sizing equation.
- The low flow orifice diameter must be 0.5 inches.
- Invert of overflow must be set at the designated detention depth (3 or 4 feet) above the invert of the low flow orifice. For intermediate depths (between 3 and 4 feet), the vault area may be linearly interpolated.
- The vault must have vertical walls to the designated overflow height.

Table 5.36. Sizing Equations for Detention Vaults.

Detention Depth	Contributing Area	Sizing Equation for Vault Area	
		Pre-developed Pasture Standard	Peak Control Standard
3 feet	2,000 – 5,000 sf	0.0000428 x [A^1.87]	0.0000616 x [A^1.77]
	5,000 – 10,000 sf	[0.121 x A] – 255	[0.0700 x A] – 130
4 feet	2,000 – 5,000 sf	NA	0.00000441 x [A^2.04]
	5,000 – 10,000 sf	NA	[0.0508 x A] – 98.0

A- contributing impervious area; NA- not applicable; sf- square feet.
For A < 5,000sf: Vault Area (sf) = Factor x [A (sf)^Integer].
Impervious Area Mitigated (sf) = [Vault Area (sf) ÷ Factor]^(1 ÷ Integer).
For A 5,000 to 10,000 sf: Vault Area (sf) = [Factor x A (sf)] + Integer.
Impervious Area Mitigated (sf) = [Vault Area (sf)- Integer] ÷ Factor.

The vault area is calculated as a function of the impervious area routed to it. As an example, for the Peak Control Standard, the area for a vault with an overflow invert set at 4.0 feet above the low flow orifice and receiving runoff from less than 5,000 square feet of impervious surface would be calculated as: 0.00000441 x impervious area (square feet) ^2.04. All area units must be square feet.

A vault with 4 feet of head above the low flow orifice is not applicable for sites subject to the Pre-developed Pasture Standard because the designer is required to reduce the head to at least 3 feet in an attempt to meet this standard (refer to *Section 4.1.2*).

Facility Modeling

When using the continuous runoff model for vault sizing, the assumptions listed in Table 5.37 must be applied. It is recommended that vaults be modeled as a flat-bottomed detention vault or tank with an outlet structure that includes a low flow orifice. The tributary areas, detention bottom area, overflow depth and orifice configuration should be iteratively sized until the Minimum Requirements for Flow Control (*Volume 1, Chapter 3*) are met.

Table 5.37. Continuous Modeling Assumptions for Detention Vaults.

Variable	Assumption
Precipitation Series	Seattle 158-year, 5-minute series
Computational Time Step	5-minutes
Inflows to Facility	Surface flow and interflow from drainage area connected to facility
Precipitation and Evaporation Applied to Facility	No
Infiltration	No
Total Depth	Vault height (including freeboard) above the vault bottom
Outlet Structure	Low flow orifice, riser height and diameter
Overflow	The top of the overflow orifice set a minimum of 6 inches below the top of the vault
Low Flow Orifice	Invert of low flow orifice set at a minimum of 6 inches above the bottom of the vault

In some instances, the minimum diameter for the low flow orifice (0.5-inch) will be too large to meet standard release rates, even with minimal head (*refer to Section 5.7.3.3 - Applicability*). Designers should iteratively increase detention area and decrease live storage depth until the performance criteria are met. However, live storage depth should not be reduced to less than 3 feet in an attempt to meet the flow control standards.

In these cases, the following design/modeling approach is recommended:

> A detention vessel should be sized with an orifice of minimum diameter and a 3-foot live storage depth such that there are no overflows during the 158-year period of record.

5.7.3.7. Minimum Construction Requirements

Refer to the construction-related issues outlined above as part of the design criteria. Additional construction requirements are as follows:

- Conduct infiltration or exfiltration testing of the detention vault.

- Submit field changes to the flow control device assembly, including elevation changes, to the Engineer of Record for confirmation that the device still meets the design requirements.

5.7.3.8. Operations and Maintenance Requirements

Detention vault O&M requirements are provided in *Appendix G (BMP No. 3)*.

5.7.4. Detention Cisterns

5.7.4.1. Description

Detention cisterns are tanks used for the capture and detention of stormwater runoff. Runoff from roof downspouts can be routed to cisterns for detention and slow release to an approved point of discharge. Like other detention facilities, cisterns can be used to achieve reductions in peak flows and flow durations.

Detention cisterns can be combined with rainwater harvesting (refer to *Sections 5.5.1 and 5.5.2*).

5.7.4.2. Performance Mechanisms

Detention cisterns provide peak flow attenuation by slowly releasing low flows through an orifice. The flow control performance of a detention cistern is a function of contributing area, storage volume, cistern height, and orifice size.

5.7.4.3. Applicability

Detention cisterns are designed for flow control of stormwater. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Detention Cistern	✓	✓	✓[a]	✓	✓					✓

[a] Detention cisterns are typically not capable of achieving the Pre-developed Forest Standard for small sites.

5.7.4.4. Site Considerations

Detention cisterns can be used to detain rooftop runoff in any type of new or retrofit development project. Cisterns may be used individually or connected to each other in series for greater detention and storage capacity. Detained stormwater and system overflows may be conveyed to an approved point of discharge or to another BMP such as bioretention.

5.7.4.5. Design Criteria

The following provides recommendations and requirements for the common components of cistern detention systems. A schematic for a typical detention cistern in shown in Figure 5.20. Design criteria are provided in this section for the following elements:

- Collection system
- Screen/debris excluder
- Cistern
- Flow control orifice
- Overflow

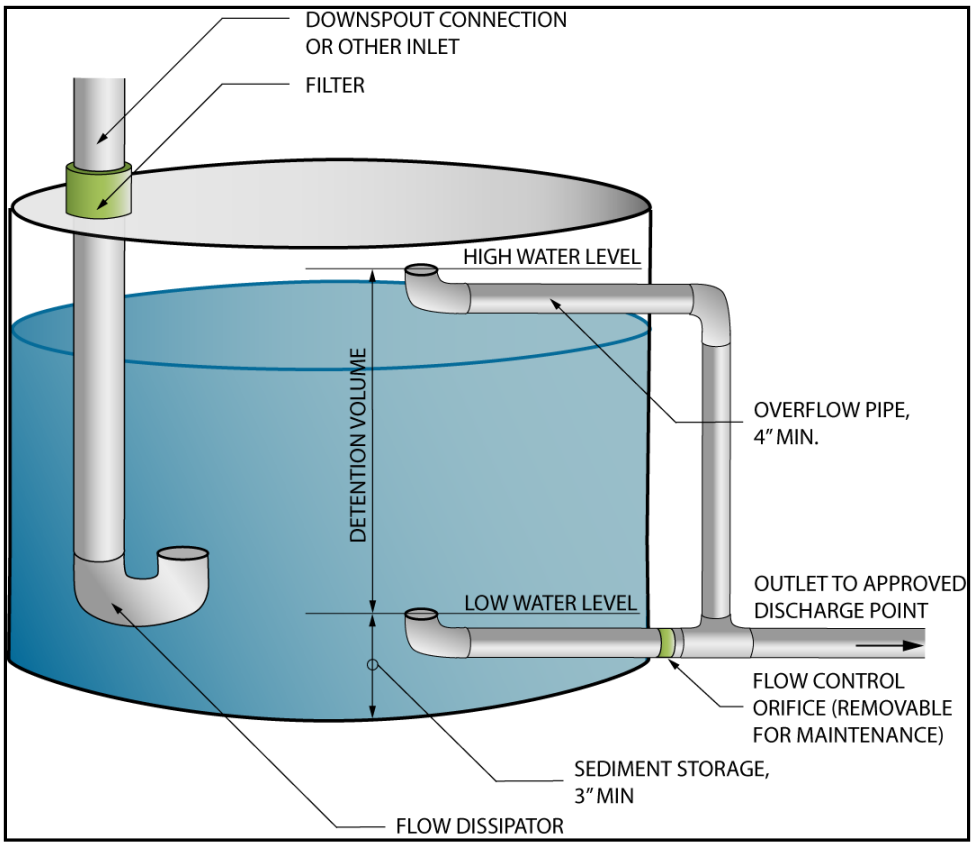


Figure 5.20. Detention Cistern.

Collection System

Collection systems include gutters and downspouts, as well as piping and any other conveyance needed to route runoff from the roof to the cistern.

Screens/Debris Excluder

A filter screen or other debris barrier is required to prevent insects, leaves, and other larger debris from entering the system. A self-cleaning inlet filter is recommended.

Cistern

Cisterns are commonly constructed of fiberglass, polyethylene, concrete, metal, or wood. Tanks can be installed at or below grade, and individually or in series.

Minimum requirements associated with cistern design include the following:

- All cisterns must be installed in accordance with manufacturer's installation instructions.
- Cisterns must be designed to prevent mosquitoes and other nuisance insects and animals from entering the cistern system. This can be done with tight-fitting covers and appropriate screening at all openings to the cistern.
- Opaque containers must be used for aboveground cisterns to prevent penetration of sunlight to minimize algal growth.

- Minimum cistern size must be that of a rain barrel (typically 55 gallons).

Flow Control Orifice

Minimum requirements associated with flow control orifice design include the following:

- As with other detention systems, the minimum diameter must be 0.25 inches for orifices located above ground, and 0.5 inches for orifices located below ground. (Note: belowground facilities are not permitted for single-family residential sites unless approved by the Director.)
- The flow control orifice invert must be at least 3 inches above the bottom of the cistern to prevent entraining sediment.

Overflow

Cisterns must have an overflow to convey water exceeding the detention capacity of the system to an approved point of discharge or another BMP (e.g., bioretention area, vegetated cell, or infiltration trench) per *Section 4.3.2*. Conveyance may be provided by gravity flow or by pumps, but gravity flow is preferred.

5.7.4.6. BMP Sizing

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized detention cisterns may used to achieve Pre-developed Pasture and Peak Control Standards. Sizing factors for aboveground cisterns receiving runoff from an impervious surface are provided in Table 5.38. Factors are organized by flow control standard, cistern overflow depth and contributing area. To use these sizing factors to meet flow control standards, the facility must meet the general requirements for cisterns outlined in this section plus the following specific requirements:

- The cistern area must be sized using the applicable sizing equation.
- The flow control orifice diameter must be 0.25 inches.
- The invert of the overflow must be set at the designated detention depth (3 or 4 feet) above the invert of the flow control orifice. For intermediate ponding depths (between 3 and 4 feet), the cistern area may be linearly interpolated.
- The cistern must have vertical walls to the designated overflow height.

Table 5.38. Sizing Equations for Aboveground Detention Cisterns.

Detention Depth	Contributing Area	Sizing Equation for Cistern Area	
		Pre-developed Pasture Standard	Peak Control Standard
3 feet	< 6,140 sf	0.00599 x [A^1.35]	0.000531 x [A^1.59]
	6,140 – 8,000 sf	760 sf	
	8,000 – 10,000 sf	[0.131 x A] – 289	
4 feet	NA	NA	0.000417 x [A^1.58]

A–contributing impervious area; NA-not applicable; sf-square feet.
Cistern Area (sf) = [Factor x A (sf)] + Integer or Factor x [A (sf)^Integer].
Impervious Area Mitigated (sf) = [Cistern Area (sf) – Integer] ÷ Factor or [Cistern Area (sf) ÷ Factor]^(1 ÷ Integer)

The cistern bottom area is calculated as a function of the impervious area routed to it. As an example, to meet the Peak Control Standard, the area of a cistern with an overflow invert set at 3 feet above the flow control orifice and receiving runoff from less than 6,140 square feet would be calculated as: 0.00599 x contributing impervious area (square feet) ^1.35. All areas values must be in units of square feet. For the same cistern receiving runoff from between 6,140 and 8,000 square feet, the cistern area would be 760 square feet.

A cistern with 4 feet of head above the flow control orifice is not applicable for sites subject to the Pre-developed Pasture Standard because the designer is required to reduce the head to at least 3 feet to meet this standard (refer to *Section 4.1.2*).

Alternatively, cisterns can be sized using a continuous model as described in the next section.

Modeling Approach

Continuous modeling may be used to size detention cisterns using the procedures presented for detention vaults in *Section 5.7.3*. The assumptions provided in Table 5.37 must be applied.

5.7.4.7. Minimum Construction Requirements

Refer to the construction-related issues outlined above as part of the design criteria. An additional construction requirement is as follows:

- Submit field changes to the flow control device assembly, including elevation changes, to the Engineer of Record for confirmation that the device still meets the design requirements.

5.7.4.8. Operations and Maintenance Requirements

Detention cistern O&M requirements are provided in *Appendix G (BMP No. 23)*. A plan must be submitted demonstrating how the O&M requirements will be met.

5.7.5. Other Detention Options

Designers and developers are encouraged to consider creative opportunities for providing detention, when it is required. Athletic fields, roofs, parking lots that are not continually in use, and other large surface areas may provide opportunities for stormwater storage. This section presents other design options for detaining flows to meet flow control requirements.

5.7.5.1. Use of Parking Lots for Additional Detention

Private parking lots may be used to provide additional detention storage for runoff events greater than the 50 percent annual probability (2-year recurrence interval), provided all of the following conditions are met:

- Depth of storage in parking lots must be 3 inches or less for parking lots serving retail and office buildings, and 6 inches or less for parking serving commercial truck traffic only, for runoff events up to and including the storm event with a 1 percent annual probability (100-year recurrence interval flow).
- The emergency overflow path must be identified and noted on the engineering plan. The overflow must not create a significant adverse impact to downhill properties or drainage system.
- Fire lanes used for emergency equipment must be free of ponding water for all runoff events up to and including the storm event with a 1 percent annual probability (100-year recurrence interval flow).

5.7.5.2. Use of Roofs for Detention

Detention ponding on roofs may be used to meet flow control requirements provided all of the following conditions are met:

- The roof support structure must be analyzed by a structural engineer to address the weight of ponded water.
- The roof area must be sufficiently waterproofed to achieve a minimum service life of 30 years.
- The minimum pitch of the roof area must be 1/4 inch per foot.
- An overflow system must be designed to safely convey the peak flow with a 1 percent annual probability (100-year recurrence interval flow).
- A mechanism must be included in the design to allow the ponding area to be drained for maintenance purposes or in the event the restrictor device is plugged.

5.8. Non-Infiltrating BMPs

Non-infiltrating BMPs are designed to remove pollutants contained in stormwater runoff. Some non-infiltrating BMPs may provide low levels of flow control as a secondary benefit. The BMP categories in this section include:

- Non-Infiltrating Bioretention
- Biofiltration Swales
- Filter Strips/Drains
- Sand Filters
- Wet Ponds
- Wet Vaults
- Stormwater Treatment Wetlands
- Combined Detention and Wet Pool Facilities
- Oil/Water Separators
- Proprietary and Emerging Water Quality Treatment Technologies

5.8.1. Design Requirements for Non-Infiltrating BMPs

5.8.1.1. Site and Design Considerations

General site considerations applicable to non-infiltrating BMPs include setbacks, side slopes, and safety:

- **Setbacks**: Setback requirements are intended to protect adjacent properties, receiving waters, and other critical areas (i.e., landslide prone areas). Identify topographic features that may be impacted and the required setbacks or other proposed methods for mitigating risk. Review the City of Seattle Environmentally Critical Areas Ordinance SMC, Chapter 25.09 for constraints from natural features such as topography, landslide prone areas, sensitive habitat areas, and the related requirements for the specific application to the proposed development.

  The following general setbacks from steep slopes and septic drain fields are applicable to all of the non-infiltrating BMPs included in this section:

  - All facilities must be a minimum of 50 feet from the top of any steep (greater than 15 percent) slope. A geotechnical analysis and report must be prepared addressing the potential impact of the facility on a slope steeper than 15 percent.
  - The water surface at the outlet invert elevation must be set back 100 feet from existing septic system drain fields. This setback may be reduced with written approval of the Seattle-King County Department of Public Health.

- **Side Slopes**: The design of side slopes needs to take safety, aesthetics, and BMP function into consideration. The following requirements must be followed when designing side slopes.

  - Gentle side slopes (4H:1V and flatter) are preferred if space *is available*.
  - Interior side slopes for non-infiltrating BMPs must not exceed 3H:1V, unless fencing is provided.
  - Non-infiltrating bioretention must not exceed a maximum planted side slope of 2.5H:1V. If the total facility depth exceeds 3 feet, the maximum planted side slope is 3H:1V.
  - If steeper sides are necessary, rockery, concrete walls, or steeper soil wraps may be used.

- **Safety**: Maintenance access points must comply with all confined space requirements which include, but are not limited to, the preparation of ventilation plans and clearly marking entrances to confined space areas.

5.8.1.2. Sequence of BMPs

The Phosphorus Removal and Enhanced Treatment performance goals, described in *Sections 3.3.2.2* and *3.3.2.3*, respectively, include treatment train options in which more than

one type of BMP is used and the sequence of BMPs is prescribed. The specific pollutant removal role of the second or third BMP in a treatment train often assumes that significant solids settling has already occurred.

This section summarizes the placement of non-infiltrating BMPs in relation to detention BMPs as shown in Table 5.39. Also note that oil control BMPs must be located upstream of non-infiltrating BMPs and detention BMPs, and as close to the source of the oil-generating activity as possible.

Table 5.39 Non-infiltrating BMP Placement in Relation to Detention BMP.

Non-infiltrating BMP	Preceding Detention BMP	Following Detention BMP
Basic biofiltration swale (*Section 5.8.3*)	Allowed	Allowed—prolonged flows may reduce vegetation survival. Consider wet biofiltration swale instead.
Wet biofiltration swale (*Section 5.8.3*)	Allowed	Allowed
Filter strip (*Section 5.8.4*)	Allowed	Not allowed—must be installed before flows concentrate; cannot effectively be re-dispersed.
Basic or large sand filter or sand filter vault (*Section 5.8.5*)	Allowed—presettling and control of floatables needed	Allowed—sand filters downstream of detention BMPs may require field adjustments if prolonged flows cause sand saturation, anoxic conditions, and phosphorus release.
Basic or large wet pond (*Section 5.8.6*)	Allowed	Allowed—less water level fluctuation in ponds downstream of detention may improve aesthetic qualities and performance.
Wet vault (*Section 5.8.7*)	Allowed	Allowed
Stormwater treatment wetland/pond (*Section 5.8.8*)	Allowed	Allowed—less water level fluctuation and better plant diversity are possible if the stormwater wetland is located downstream of the detention BMP.
Proprietary and Emerging Technologies (*Section 5.8.11*)	Allowed	Allowed—depending on the type of technology

5.8.2. Non-Infiltrating Bioretention

5.8.2.1. Description

Non-infiltrating bioretention facilities are earthen depressions or containers (e.g., concrete planter) with a designed soil mix and plants adapted to the local climate and soil moisture conditions. Stormwater is stored as surface ponding before it filters through the underlying bioretention soil. Stormwater that exceeds the surface storage capacity overflows to an adjacent drainage system. Treated water is collected by an underdrain and discharged.

Unlike infiltrating bioretention (refer to *Section 5.4.4*), non-infiltrating bioretention facilities include a liner or other impermeable barrier to prevent infiltration to the underlying soil.

Two variations of non-infiltrating bioretention facilities are included in this section:

- **Non-infiltrating bioretention facility**: These bioretention facilities can have either sloped sides (e.g., an earthen depression with a liner) or vertical sides (e.g., vertical walled impermeable container). Non-infiltrating bioretention must have an underdrain. These facilities may or may not have an outlet control structure to attenuate underdrain flows prior to release.

- **Non-infiltrating bioretention facility series**: Non-infiltrating bioretention facilities with sloped sides or vertical sides may be connected in a series, with the overflows of upstream cells directed to downstream cells to provide additional flow control and/or treatment, and conveyance.

5.8.2.2. Performance Mechanisms

Non-infiltrating bioretention provides flow control via detention, attenuation, and losses due to interception, evaporation, and transpiration. Water quality treatment is accomplished through sedimentation, filtration, uptake, or biodegradation and transformation of pollutants by soil organisms, soil media, and plants.

5.8.2.3. Applicability

Non-infiltrating bioretention can be designed to provide on-site stormwater management and/or water quality treatment. This BMP can be applied for meeting the performance standards listed below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Non-infiltrating bioretention	✓				✓	✓	✓			✓[a]

[a] Non-infiltrating bioretention facilities may be connected in series, with the overflows of upstream cells directed to downstream cells to provide conveyance.

5.8.2.4. Site Considerations

Because non-infiltrating bioretention facilities do not infiltrate water to surrounding soils (water discharges via an underdrain and surface overflow), these BMPs may be employed regardless of subgrade soil infiltration rate, depth to water table, and topography.

Non-infiltrating bioretention is not permitted if the underdrained water would be routed to a nutrient-critical receiving water.

5.8.2.5. Design Criteria

Typical components of non-infiltrating bioretention facilities with sloped sides and vertical sides are shown in Figures 5.21 and 5.22, respectively.

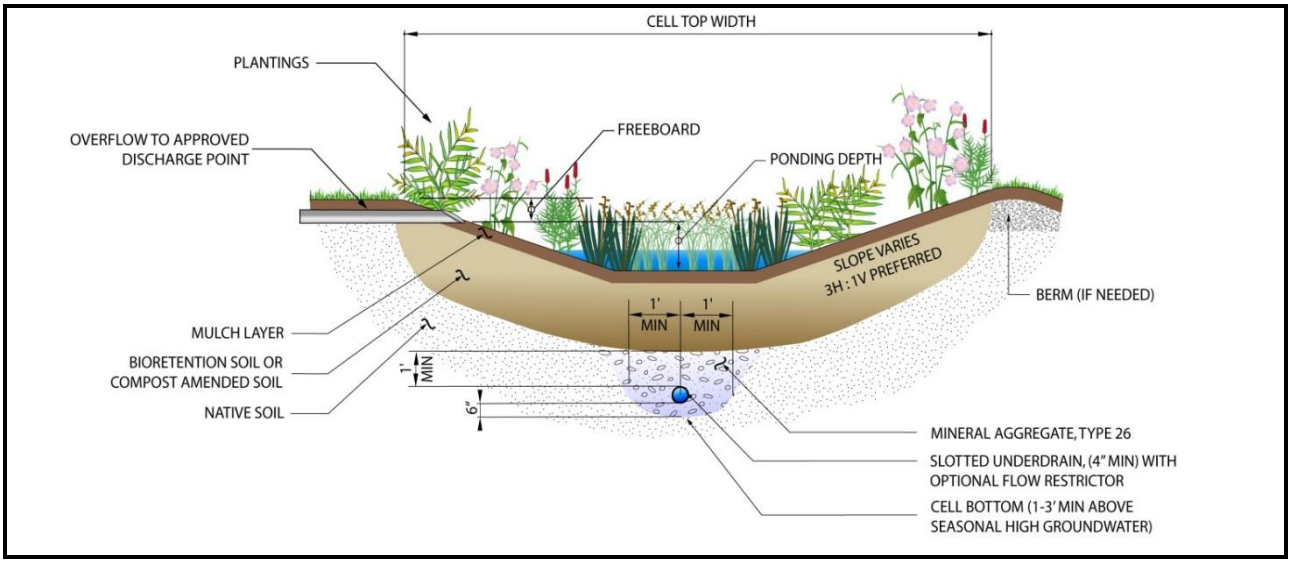


Figure 5.21. Non-infiltrating Bioretention Facility with Sloped Sides.

The design criteria for non-infiltrating bioretention is the same as presented for infiltrating bioretention in *Section 5.4.4*, with the following exceptions:

- The facility must include a hydraulic restriction layer to prevent infiltration to surrounding soils. The facility may be composed of a low permeability (e.g., concrete) container with a closed bottom, or may be lined with a low permeability material (e.g., clay, geomembrane liner) to prevent infiltration.
- The facility must be equipped with an underdrain.

5.8.2.6. BMP Sizing

On-site List Approach

Non-infiltrating bioretention applied to meet the On-site List Approach shall be sized according to the sizing factors provided in Table 5.40. Factors are organized by configuration (i.e., sloped sides or vertical sides), performance standard, facility ponding depth, and subgrade soil design infiltration rate. A 2-, 6-, or 12-inch facility ponding depth may be selected. To use these pre-sized facilities to meet performance standards, the bioretention

facility must meet the general requirements for bioretention facilities outlined in this section plus the following specific requirements:

- The bottom area shall be sized using the applicable sizing factor. When used to meet the Peak Control Standard, the facility size shall not be larger than prescribed by the sizing factor because flow control performance may be diminished for larger facilities.
- The bottom area shall be flat (0 percent slope).
- For facilities with sloped sides, the side slopes within ponded area shall be no steeper than 3H:1V.
- The bioretention soil depth shall be a minimum of 18 inches.
- The minimum ponding depth shall be set at the designated height (2, 6, or 12 inches). For intermediate ponding depths (between 2 and 12 inches), the sizing factor may be linearly interpolated.

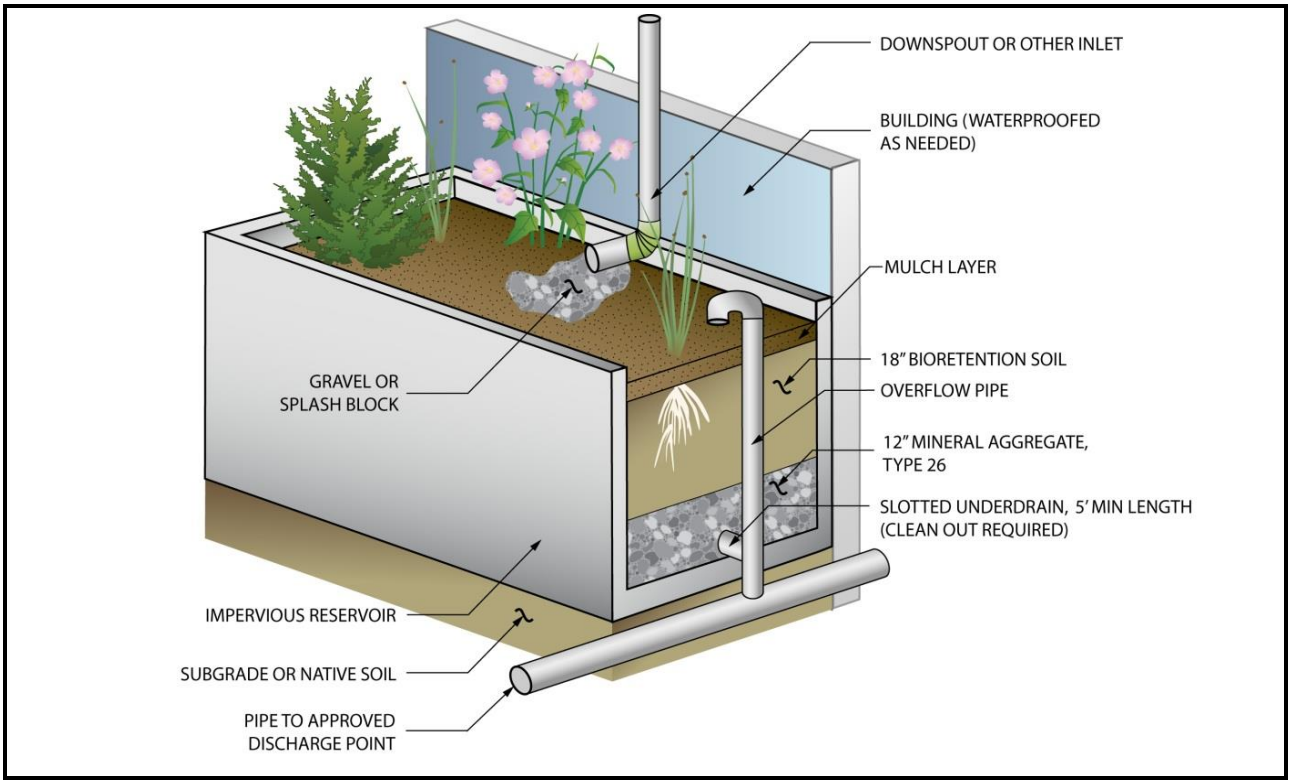


Figure 5.22. Non-infiltrating Bioretention Facility with Vertical Sides.

The *bottom* area for the bioretention facility area is calculated as a function of the impervious area routed to it. As an example, to meet the Peak Control Standard, the bottom area of the bioretention facility with vertical sides would be equal to 6.5 percent of the impervious area routed to it when the ponding depth is 12 inches. For facilities with sloped sides, the total facility footprint area (top area) can be calculated as a function of the bottom area, the side slopes and the total facility depth (i.e., ponding and freeboard depth).

Table 5.40. On-Site List Sizing for Non-Infiltrating Bioretention.

Bioretention Configuration	Ponding Depth	Sizing Factor for Facility Bottom Area On-Site Performance Standard
Sloped sides	6 inches	3.3%
	12 inches	TBD
Vertical sides	6 inches	5%
	12 inches	TBD

Bioretention Facility Bottom Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Bioretention Facility Bottom Area ÷ Factor (%)/100

Pre-Sized Approach

Under the Pre-Sized Approach (refer to *Section 4.1.2*), pre-sized non-infiltrating bioretention facilities may be used to achieve the Peak Flow Control and Treatment Standards. Sizing factors for non-infiltrating bioretention facilities with underdrains are provided in Table 5.41. Factors are organized by configuration (i.e., sloped sides or vertical sides), performance standard, facility ponding depth, and subgrade soil design infiltration rate. A 2-, 6-, or 12-inch facility ponding depth may be selected. To use these pre-sized facilities to meet performance standards, the bioretention facility must meet the general requirements for bioretention facilities outlined in this section plus the following specific requirements:

- The bottom area must be sized using the applicable sizing factor. When used to meet the Peak Control Standard, the facility size must not be larger than prescribed by the sizing factor because flow control performance may be diminished for larger facilities.
- The bottom area must be flat (0 percent slope).
- For facilities with sloped sides, the side slopes within the ponded area must be no steeper than 3H:1V.
- The bioretention soil depth must be a minimum of 18 inches.
- The minimum ponding depth must be set at the designated height (2, 6, or 12 inches). For intermediate ponding depths (between 2 and 12 inches), the sizing factor may be linearly interpolated.

Table 5.41. Sizing Factors for Non-Infiltrating Bioretention.

Bioretention Configuration	Ponding Depth	Sizing Factor for Facility Bottom Area	
		Peak Control Standard	Water Quality Treatment
Sloped sides	6 inches		
	12 inches		
Vertical sides	6 inches	NA	2.6%
	12 inches	6.5%	2.0%

– sizing factors not provided; NA- not applicable
Bioretention Facility Bottom Area = Contributing Impervious Area x Factor (%)/100
Impervious Area Mitigated = Bioretention Facility Bottom Area ÷ Factor (%)/100

The bottom area for the bioretention facility area is calculated as a function of the impervious area routed to it. As an example, to meet the Peak Control Standard, the bottom area of the bioretention facility with vertical sides would be equal to 6.5 percent of the impervious area routed to it when the ponding depth is 12 inches. For facilities with sloped sides, the total facility footprint area (top area) can be calculated as a function of the bottom area, the side slopes and the total facility depth (i.e., ponding and freeboard depth).

Alternatively, non-infiltrating bioretention facilities can be sized using a continuous simulation hydrologic model as described in the subsequent section.

Modeling Approach

When using continuous simulation hydrologic modeling to size non-infiltrating bioretention, the assumptions listed for infiltrating bioretention in Table 5.21 must be applied, with the exception that there is no infiltration to underlying soil. Note that using currently available modeling methods, non-infiltrating bioretention is not capable of meeting the Pre-developed Forest or Pre-developed Pasture Standard. Facilities may be sized to achieve the Peak Control Standard with an optimized ratio of planter area and contributing surface area, but performance may diminish with larger and smaller ratios.

5.8.2.7. Minimum Construction Requirements

Minimum construction requirements associated with non-infiltrating bioretention facilities include the following:

- Place bioretention soil in accordance with the requirements of City of Seattle Standard Specifications.
- Protect bioretention soil in planter boxes from sediment during construction and do not use planter boxes as sediment control facilities.
- For inspection and verification procedures used for facility approval by City staff, refer to the SPU GSI website (http://www.seattle.gov/util/greeninfrastructure).

5.8.2.8. Operations and Maintenance Requirements

Non-infiltrating bioretention O&M requirements are provided in *Appendix G (BMP No. 22)*.

5.8.3. Biofiltration Swales

5.8.3.1. Description

A biofiltration swale is an open, gently sloped, vegetated channel designed to treat stormwater. Biofiltration swales are designed so that stormwater will flow evenly across the entire width of a densely vegetated channel. The four biofiltration swales described in this section are:

1. Basic biofiltration swale: a standard swale, with all runoff entering at the head of the swale.
2. Wet biofiltration swale: similar to the basic swale, but due to site conditions and/or influent conditions, this swale is designed to accommodate saturated soil conditions. It is appropriate for locations where the longitudinal slope is very low, water tables are high, or continuous low base flow is present.
3. Continuous inflow biofiltration swale: same as the basic swale, but runoff enters at multiple locations along the length of the swale. The basic swale design is modified by increasing the swale length to achieve an equivalent average residence time.
4. Compost-amended biofiltration swale: same as the basic swale, but with a 3-inch compost blanket on top of the swale.

5.8.3.2. Performance Mechanisms

Pollutant removal occurs by filtration as stormwater moves through the vegetation, which enhances sedimentation, and traps pollutants which adhere to the vegetation.

5.8.3.3. Applicability

A swale can be designed for water quality treatment and conveyance of stormwater flow. This combined use can reduce development costs by eliminating the need for separate conveyance and treatment systems. Biofiltration swales are typically configured as flow-through systems, with little or no detention or storage. This BMP can be applied for meeting different levels of water quality treatment as summarized below.

	On-site		Flow Control			Water Quality				
BMP	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	Conveyance
Basic biofiltration swale						✓	TT-A or TT-B		TT-A	✓
Wet biofiltration swale						✓	TT-A or TT-B		TT-A	✓
Continuous inflow biofiltration swale						✓	TT-A or TT-B		TT-A	✓
Compost-amended biofiltration swale						✓	✓	✓		✓

TT-A = Treatment Train A (must be followed by a Basic Sand Filter or Sand Filter Vault)
TT-B = Treatment Train B (must be followed by a Media Filter)

5.8.3.4. Site Considerations

The following are common considerations for determining the feasibility of biofiltration swales for a particular site:

- Biofiltration swales are suitable for relatively small sites (generally less than 5 acres of contributing area).
- Biofiltration swales may be used for linear areas along roadways, driveways, and parking lots.
- Swales may be incorporated into a project's landscape design with either a mowable grass swale or water tolerant vegetation.
- Shaded areas, including deep channels, with less than 6 hours of sunlight during the summer months can inhibit vegetation growth.
- Stormwater runoff containing high concentrations of oil and grease impairs the treatment capability of a swale. Oil control options described in *Section 5.8.10* should be applied in these situations.
- Most biofiltration swales are designed to be on-line facilities with flows above the water quality design flow or volume passing through the facility with lesser or no pollutant removal. However, an off-line design (where flows above the water quality design flows or volume are bypassed around the facility) may be preferred in some cases to avoid scour and damage to vegetation during high flows. An additional benefit of designing swales to be off-line is that the stability check, which may make the swale larger, is not necessary (refer to *Sections 5.8.3.5 - Design Criteria and 5.8.3.6 - BMP Sizing* below).
- Minimum footprint is 100 feet by 20 feet. The actual footprint will depend on the bottom width, side slopes, and length, which are all dependent on the design flows (refer to *Section 5.8.3.6 - BMP Sizing*).
- Alignment should avoid sharp bends where erosion of the swale side slope can occur. However, gradual meandering bends in the swale are desirable for aesthetic purposes and to promote slower flow.
- Leaves and needles that can smother the grass or clog part of the swale flow path can be a maintenance concern. Landscaping plans should take into consideration the problems that falling leaves and needles can cause for swale performance and maintenance. Landscape planter beds should be designed and located so that soil does not erode from the beds and enter a nearby biofiltration swale.
- Wet biofiltration swales are applied where a basic biofiltration swale is desired but not allowed or advisable because one or more of the following conditions exist:
    - The swale is on till soils and is downstream of a detention pond providing flow control.

- Saturated soil conditions are likely because of seeps, continuous base flow, or high groundwater on the site.
- Longitudinal slopes are slight (generally less than 2 percent).

- A continuous inflow biofiltration swale is recommended when the following conditions exist:
  - Inflows are not concentrated or when flow enters at frequent points along the swale.
  - Unconcentrated inflow occurs along roadways that that have no curbs, where runoff sheet flows across the shoulder to the swale.
- A continuous inflow swale is not appropriate when significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale length must be recalculated from the point of entry to provide adequate treatment for the increased flow.

Additional site considerations may apply depending on site conditions and other factors.

5.8.3.5. Design Criteria

The following provides a description and requirements for the components of biofiltration swales. Typical plan and profile views of a biofiltration swale are provided in Figure 5.23. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section or in Volume V of the SWMMWW for the following elements:

Design Element	SWMMWW Design Criteria	Seattle-specific Design Criteria
Level spreaders	✓	✓
Underdrain (if any)	✓	✓
Low-flow drains (if any)		✓
Outlet and overflow		✓
Access		✓
Soil amendment		✓
Planting requirements	✓	✓
Dividing berm	✓	
Check dams or steps (if any)	✓	
High-flow bypass (if any)	✓	

Refer to BMP T9.10 – Basic Biofiltration Swale, BMP T9.20 – Wet Biofiltration Swale, and BMP T9.30 – Continuous Inflow Biofiltration Swale in Volume V of the SWMMWW for specific design criteria. Refer to the WSDOT Highway Runoff Manual under BMP RT.04 – Biofiltration Swale for design criteria for compost-amended biofiltration swales (CABS). In addition to

criteria developed by Ecology and WSDOT, the City has also developed specific design criteria for several design elements which are summarized below.

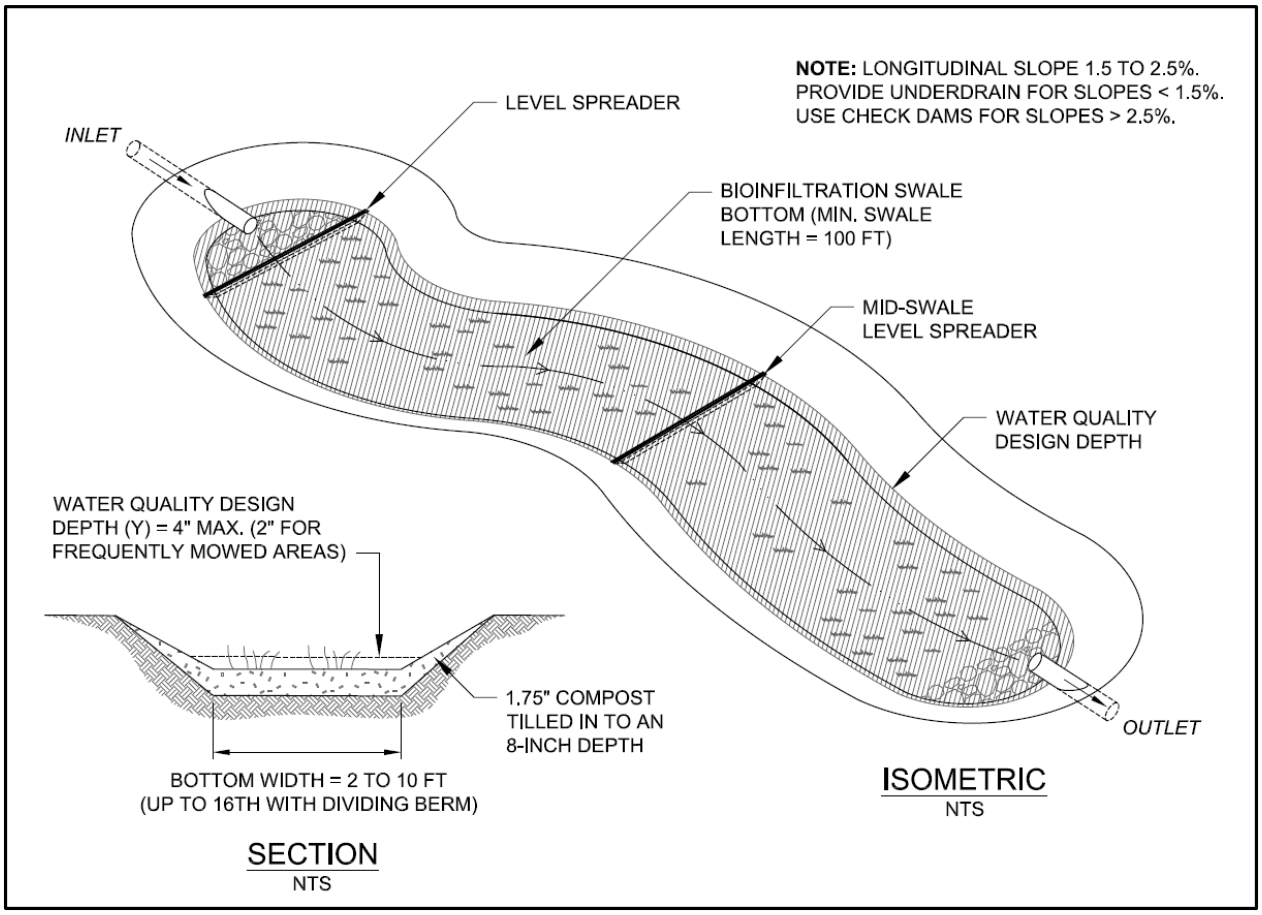


Figure 5.23. Biofiltration Swale Plan and Profile.

Level Spreaders

Refer to BMP T9.10 – Basic Biofiltration Swale, BMP T9.20 – Wet Biofiltration Swale, and BMP T9.30 – Continuous Inflow Biofiltration Swale in Volume V of the SWMMWW for biofiltration swale design considerations.

In addition, the City of Seattle requires level spreaders at the toe of vertical drops (check dams). Design guidelines and example design figures for level spreaders are provided in *Appendix E*.

Underdrains

Refer to BMP T9.10 – Basic Biofiltration Swale, BMP T9.20 – Wet Biofiltration Swale, and BMP T9.30 – Continuous Inflow Biofiltration Swale in Volume V of the SWMMWW for design considerations.

In addition, the City of Seattle requires underdrains for swales greater than 1.5 percent longitudinal slope on till soils. Refer to *Appendix E* for required geotextile properties.

Low Flow Drains

Low-flow drains are narrow surface drains filled with pea gravel that run lengthwise through the swale to bleed off base flows; they should not be confused with underdrains. The following requirements must be followed for biofiltration swales installed in Seattle:

- If a swale will receive base flows because of seeps and springs on site, then either a low-flow drain must be provided or a wet biofiltration swale must be used. In general, base flows less than 0.01 cubic feet per second (cfs) per acre can be handled with a low-flow drain. If flows are likely to be in excess of this level, a wet biofiltration swale should be used. Low-flow drains are not required for wet biofiltration swales.
- If a low-flow drain is used, it must extend the entire length of the swale.
- The low-flow drain must be a minimum of 6 inches deep, and its width must be no greater than 5 percent of the calculated swale bottom width. Adjust the bottom width accordingly to maintain the necessary design bottom width for treatment.
- If an anchored plate or concrete sump is used for flow spreading at the swale inlet, the plate or sump wall must have a v-notch (maximum top width equal to 5 percent of swale width) or holes to allow preferential exit of low flows into the drain.

Additional design guidelines for level spreaders are provided in *Appendix E*.

Outlet and Overflow

All biofiltration swales must include an outlet and overflow to an approved point of discharge per *Section 4.3.2.*

Access

Access requirements specific to biofiltration swale installations in Seattle are summarized below.

Access Requirement	Basic and Continuous Inflow Biofiltration Swale	Wet Biofiltration Swale
Access locations	Half the length of the swale	Inflow and outflow only
Access road width	Minimum of 10 feet	
Access road curves	Minimum width of 15 feet and a minimum outside radius of 40 feet	
Wheel strips made of modular grid pavement (see Figure 5.23) [a]	• Support 16,000 pound vehicle • Firm native soil or structural fill (not amended topsoil) • Fill or cover with native soil (no amendments) and seed with grass • Strip width = 18 inches • Not counted as treatment area • Not allowed in biofiltration swales with underdrains	Not allowed

[a] If a low-flow drain is also needed, a portion of the wheel strip may be filled with pea gravel as appropriate to form the drain.

Soil Amendment

The following requirements must be followed for biofiltration swales installed in Seattle:

- The condition of the soil is critical to support healthy grass growth. Native topsoil that has been stockpiled on site or in-situ soil may be used provided that it meets the soil quality criteria described in *Section 5.4.1*. Soil amendments are required if native soil is not suitable. Refer to *Section 5.1* for information regarding Soil Amendment BMP requirements.

- If the longitudinal slope is less than 1.5 percent (requiring the use of underdrains along the swale length), the subgrade should contain 10 percent or more of sand to promote infiltration of standing water. If sand is added to promote drainage, the soil or sand substrate must still be amended with compost.

Planting Requirements

Refer to BMP T9.10 – Basic Biofiltration Swale, BMP T9.20 – Wet Biofiltration Swale, and BMP T9.30 – Continuous Inflow Biofiltration Swale in Volume V of the SWMMWW for biofiltration planting requirements. The following additional planting requirements must be followed for biofiltration swales installed in Seattle:

- Grass must be established throughout the entire treatment area of the biolfiltration swale subject to the following provisions:

    - Seeding is best performed in spring (mid-March to June) or fall (late September to October). For summer seeding, sprinkler systems or other measures for watering grass seed must be provided.

    - Seed may be applied via hydroseeding or broadcast application.

    - Irrigation is required during the first summer following installation if seeding occurs in spring or summer. Swales seeded in the fall may not need irrigation. Site planning must address the need for sprinklers or other means of irrigation.

- Swales are subject to both dry and wet conditions and accumulation of sediment and debris. A mixture of dry-area and wet-area grass species that can continue to grow through silt deposits is most effective. Acceptable grass seed mixes for the Seattle area are provided in the City of Seattle Standard Specifications (9-14). As an alternative to these mixes, a horticultural or erosion control specialist may develop a seed specification tailored to the site. *Appendix E* includes a plant list for biofiltration swales that lists grasses or other plants that are particularly tolerant of wet conditions.

- Sod may be used where needed to initiate adequate growth. If sod is used, the sod must be grown from a seed mix suitable for a biofiltration swale and clay content must be less than 10 percent.

- During seeding, slow-release fertilizers may be applied to speed the growth of grass. If the swale is located in a nutrient-critical watershed, low phosphorus fertilizers (such

as formulations in the proportion 3: 1: 3 N-P-K or less) or a slow-release phosphorus formulation such as rock phosphate or bone meal should be used. A typical fertilizer application rate should be 2 pounds per 1,000 square feet. If animal manures are used in the fertilizer, they must be sterilized to avoid leaching fecal coliform bacteria into receiving waters.

- A grassy swale should be incorporated into the project site landscape design. Shrubs may be planted along the edges of a swale (above the water quality treatment level) provided that exposure of the swale bottom to sunlight and maintenance accessibility are not compromised. *Note*: For swales used to convey high flows, the plant material selected must bind the soil adequately to prevent erosion.

5.8.3.6. BMP Sizing

Refer to BMP T9.10 – Basic Biofiltration Swale, BMP T9.20 – Wet Biofiltration Swale, and BMP T9.30 – Continuous Inflow Biofiltration Swale in Volume V of the SWMMWW for BMP Sizing considerations.

Biofiltration swale design procedures are described in the SWMMWW for the following steps:

- Preliminary steps (P)
- Design steps (D)
- Stability check steps

Seattle-specific guidance for Preliminary Step P-1 includes the following:

- For off-line swales, the high flow bypass must be designed so that all flows up to and including the water quality design flow rate are directed to the swale. The water quality design flow rate (Q) is calculated by multiplying the design flow determined by an approved continuous runoff model by an offline ratio of 3.0.
- For on-line swales, Q is determined by multiplying the design flow determined by an approved continuous runoff model by an on-line ratio of 1.65.

5.8.3.7. Minimum Construction Requirements

Minimum construction requirements associated with biofiltration swales include the following:

- Grade swales to attain uniform longitudinal and lateral slopes.
- Avoid compaction during construction.
- Do not put biofiltration swales into operation until areas of exposed soil in the contributing drainage catchment have been sufficiently stabilized. Deposition of eroded soils can impede the growth of grass in the swale and reduce swale treatment effectiveness. Thus, effective erosion and sediment control measures must remain in place until the swale vegetation is established (refer to *Volume 2, Construction Stormwater Control*).

- Protect newly constructed swales from stormwater flows until grass has been established by diverting flows or by covering the swale bottom with clear plastic until the grass is well rooted. If these actions are not feasible, place an erosion control blanket per City of Seattle Standard Plan 9-14.5(2) over the freshly applied seed mix. Sod may be used as a temporary cover during the wet season, but sodded areas must be reseeded with a suitable grass mix as soon as the weather is conducive to seed germination. Remove sod before reseeding.

5.8.3.8. Operations and Maintenance Requirements

Basic, wet, and continuous inflow biofiltration swale O&M requirements are provided in *Appendix G (BMP No. 9 and 10)*. Compost-amended biofiltration swale O&M requirements can be found in the WSDOT Highway Runoff Manual under BMP RT.04 – Biofiltration Swale.

5.8.4. Filter Strips/Drains

5.8.4.1. Description

A filter strip is a grassy slope that receives unconcentrated runoff from adjacent impervious areas such as a parking lots, driveways, or roadways. Filter strips are graded to maintain sheet flow over their entire width. Compost and other amendments can be incorporated into filter strips designs to provide enhanced (dissolved metals) treatment. The following three types of filter strip BMPs are described in this section:

1. **Basic filter strip**: a flat filter strip with no side slopes. Polluted stormwater is distributed as sheet flow across the inlet width of the filter strip.

2. **Compost-amended vegetated filter strip (CAVFS)**: An enhanced treatment option, similar to the basic filter strip, but the filter area is compost-amended to improve infiltration characteristics, increase surface roughness, and improve plant sustainability. Once permanent vegetation is established, the advantages of the CAVFS are higher surface roughness, greater retention and infiltration capacity, improved removal of soluble cationic contaminants through sorption, improved overall vegetative health, and a reduction of invasive weeds. Compost-amended systems have somewhat higher construction costs due to more expensive materials, but require less land area for runoff treatment, which can reduce overall costs.

3. **Media filter drain (MFD)**: previously referred to as the *ecology embankment*, a linear flow-through stormwater treatment device that can be sited along roadway side-slopes (conventional design) and medians (dual MFD), borrow ditches, or other linear depressions. Cut-slope applications may also be considered. MFDs have four basic components: a gravel no-vegetation zone, a vegetated filter strip, the MFD mix bed, and an optional gravel-filled underdrain trench or layer of crushed surfacing base course (CSBC). The layer of CSBC must be porous enough to allow treated flows to freely drain away from the MFD mix.

5.8.4.2. Performance Mechanisms

Filter strips remove pollutants primarily by filtration as stormwater moves through the grass blades. This enhances sedimentation and traps pollutants which adhere to the grass and thatch. Pollutants can also be adsorbed by the underlying soil when infiltration occurs, but the extent of infiltration depends on the type of soil, the density of grass, and the slope of the filter strip. The MFD removes suspended solids, phosphorus, and metals from roadway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration.

5.8.4.3. Applicability

A filter strip can be designed for both treatment and conveyance of stormwater flow. This combined use can reduce development costs by eliminating the need for separate conveyance and treatment systems. Basic filter strips, CAVFS, and MFDs are typically configured as flow-through systems, with little or no detention or storage. This BMP can be applied for meeting different levels of water quality treatment as summarized below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Basic filter strip						✓	TT-A or TT-B		TT-A or TT-B	✓
CAVFS						✓	✓			✓
Media filter drain						✓	✓			✓

1. TT-A = Treatment Train A (must be followed by a Linear Sand Filter)
2. TT-B = Treatment Train B (must be preceded by a Linear Sand Filter)

5.8.4.4. Site Considerations

The following are site considerations for determining the feasibility of filter strips for a particular site:

- Filter strips are suitable for sites with a maximum longitudinal slope along the contributing surface of 2 percent.
- Filter strips are suitable for sites with a maximum cross-slope along the contributing surface of 5 percent. Contributing drainage areas with slopes steeper than 5 percent should either use a different BMP or must provide energy dissipation and flow spreading mechanisms upslope of the upper edge of the filter strip.
- Filter strips are designed as on-line facilities. They are designed to receive continuous sheet flow from contributing surfaces and should not be located downstream of detention facilities or other concentrated flows.
- The MFD can be used in the following situations:
    - Areas with lateral gradients generally less than 25 percent (4H:1V)
    - Areas with longitudinal gradients less than 5 percent

Additional site considerations may apply depending on site conditions and other factors.

5.8.4.5. Design Criteria

Refer to BMP T9.40 – Basic Filter Strip, BMP T7.40 – CAVFS, and BMP T8.40 – MFD in Volume III of the SWMMWW for filter strip design criteria. Additional descriptions, applications, and design details are provided in the WSDOT Highway Runoff Manual under BMP RT.02 – Vegetated Filter Strip and RT.07 – MFD. The City allows the use of MFDs per the Ecology-approved designs outlined in the WSDOT Highway Runoff Manual.

5.8.4.6. BMP Sizing

Filter strips must be designed to meet the criteria listed in Table 5.42. Refer to BMP T9.40 – Basic Filter Strip, BMP T7.40 - CAVFS, and BMP T8.40 – MFD in Volume III of the SWMMWW for additional information on filter strip sizing methods.

Table 5.42. Basic and Compost Amended Vegetated Filter Strip Design and Sizing Criteria.

Design Parameter	Basic Filter Strip	CAVFS	Media Filter Drain
Longitudinal Slope	1% - 33%	1% - 15%	2% – 25%
Maximum velocity	0.5 feet/second		NA
Maximum water depth	1 inch		NA
Manning's roughness coefficient	0.35	0.40 to 0.55 [a]	NA
Minimum hydraulic residence time at Water Quality Design Flow Rate	9 minutes	NA	NA
Minimum length	100 feet	100 feet	NA
Maximum side slope	Inlet edge ≥ 1 inch lower than contributing paved area		NA
Max. tributary drainage flow path	150 feet		
Max. longitudinal slope of contributing area	5% (steeper than 5% need upslope flow spreading and energy dissipation)		5%
Max. lateral slope of contributing area	2% (at the edge of the strip inlet)[b]		NA

[a] Manning's n ranges from 0.40 (hydroseeded, grass maintained at 95% density and 4-inch length via mowing, periodic reseeding, and possible landscaping with shrubs) to 0.55 (top-dressed with ≥ 3 inches compost or mulch [seeded or landscaped]).

[b] A stepped series of flow spreaders installed at the head of the strip could compensate for slightly steeper slopes.

5.8.4.7. Minimum Construction Requirements

Minimum construction requirements associated with filter strips include the following:

- Do not put filter strips into operation until areas of exposed soil in the contributing drainage catchment have been sufficiently stabilized. Deposition of eroded soils can impede the growth of grass in the filter strip and reduce treatment effectiveness. Erosion and sediment control measures must remain in place until the filter strip vegetation is established (Refer to *Volume 2*, Construction Stormwater Control for erosion and sediment control BMPs).
- Avoid compaction of the filter strip areas during construction.

5.8.4.8. Operations and Maintenance Requirements

Basic filter strip O&M requirements are provided *Appendix G (BMP No. 11)*. CAVFS and MFD O&M requirements can be found in the WSDOT Highway Runoff Manual under BMP RT.02 – Vegetated Filter Strip and RT.07 – MFD.

5.8.5. Sand Filters

5.8.5.1. Description

Sand filters are used to provide water quality treatment. The following three sand filter BMPs are described in this section:

1. Sand filter basins: Like an infiltration pond, the sand filter basin is an impoundment that temporarily stores stormwater runoff so that it can infiltrate, but instead of infiltrating through the native soil, stormwater passes through a constructed sand bed. Sand filters can be sized as either a basic or a large facility to meet different water quality objectives. Sand filter basins are designed with underdrains to collect and route runoff following treatment to the downstream conveyance system.

2. Sand filter vaults: A sand filter vault is similar to a sand filter basin, except that the entire facility is installed below grade in a vault. It typically consists of a presettling cell (if pretreatment is not already provided) and a sand filtration cell. Like a sand filter basin, a vault can be sized as either a basic or a large facility to meet different water quality objectives.

3. Linear sand filters: Linear sand filters are similar to sand filter vaults, except the vault is configured as a long, shallow, linear system. The vault contains two cells or chambers, one for removing coarse sediment and the other containing sand overlying an underdrain. Runoff usually enters the settling chamber as unconcentrated flow from an adjacent impervious area and overflows a central weir into the sand portion of the vault.

5.8.5.2. Performance Mechanisms

Sand filters treat stormwater primarily via physical filtration. As stormwater passes through the sand media, pollutants are trapped in the small spaces between sand grains, or adhere to the sand surface. Over time, soil bacteria may also grow in the sand bed and some biological removal may occur.

Sand filter media can also be amended with steel fiber and crushed calcitic limestone to increase dissolved metals removal. Use of amended sand filters requires Director's approval.

5.8.5.3. Applicability

A sand filter BMP can be applied for meeting different levels of water quality treatment as summarized below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Basic Sand Filter						✓	TT-A, TT-B, or TT-C		TT-A, TT-B, TT-C, or TT-D	✓
Large Sand Filter						✓	✓		✓	✓
Sand Filter Vault						✓	TT-A, TT-B, or TT-C		TT-A, TT-B, TT-C, or TT-D	✓
Large Sand Filter Vault						✓	✓		✓	✓
Linear Sand Filter						✓	TT-E or TT-F	✓[a]	TT-E or TT-F	✓

TT-A = Treatment Train A (must be preceded by a Basic Wet Pond, Wet Vault, Basic Combined Detention/Wetpool)
TT-B = Treatment Train B (must be preceded by a Biofiltration Swale)
TT-C = Treatment Train C (must be followed by a Media Filter)
TT-D = Treatment Train D (must be preceded by a Stormwater Treatment Wetland)
TT-E = Treatment Train E (must be followed by a Filter Strip)
TT-F = Treatment Train F (must be preceded by a Filter Strip)
[a] Linear sand filter may not be used for oil control if it is used to satisfy any other treatment requirement

5.8.5.4. Site Considerations

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for site considerations related to sand filters. The following site considerations also apply to sand filters installed in Seattle:

- A sand filter can add landscape interest and should be incorporated into the project landscape design.
- Interior side slopes may be stepped with flat areas to provide informal seating with a game or play area below. Note: Examples of areas with stepped side slopes can be found at the Ballard Locks in Seattle and at Luther Burbank Park on Mercer Island.
- Perennial beds can be planted above the overflow water surface elevation. However, large shrubs and trees are not recommended because shading limits evaporation and can inhibit drying of the filter surface. In addition, falling leaves and needles can clog the filter surface, requiring more frequent maintenance.

Additional site considerations may apply depending on site conditions and other factors.

5.8.5.5. Design Criteria

The following provides a description and requirements for the components of sand filters. Some or all of the components may be used for a given application depending on the site

characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section or in Volume V of the SWMMWW for the following elements:

Design Element	SWMMWW Design Criteria	Seattle-specific Design Criteria
Pretreatment	✓	✓
Liner	✓	✓
Geometry and composition	✓	✓
Structural requirements	✓	✓
Underdrains (if any)	✓	✓
Sand media	✓	✓
Vegetation (if any)		✓
Access	✓	✓
Offline/on-line facilities	✓	
Inlets and outlets	✓	

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter basin and sand filter vault design criteria. In addition to Ecology's criteria, the City has also developed specific design criteria for several design elements which are summarized below.

Pretreatment

Pretreatment is required to prevent clogging and extend the service life of the sand filter media. Pretreatment design requirements are described in Section 5.8, but generally consists of a presettling basin integrated into the sand filter, or a dedicated pretreatment BMP upstream of the filter. Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter basin and sand filter vault pretreatment requirements.

The following additional criteria apply specifically to sand filter vaults installed in Seattle:

- The presettling cell bottom may be longitudinally level or inclined toward the inlet.
- To facilitate sediment removal, the presettling cell bottom must also slope from each side towards the center at a minimum of 5 percent, forming a broad "v".
- More than one "v" may be used to minimize presettling cell depth.

Liners

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter liner requirements.

In addition to Ecology's requirements, the City requires a liner if the site is located within a critical aquifer recharge area.

Refer to *Appendix E* for additional information on liner design criteria.

Geometry and Composition

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter basin and sand filter geometry and composition requirements.

The following additional criterion applies to all sand filter types installed in Seattle:

- Depth of storage over the filter media (d) must be 6 feet maximum

The following additional criterion applies specifically to linear sand filters installed in Seattle:

- If separated from traffic areas, a linear sand filter may be covered or open, but if covered, the cover must be removable for the entire length of the filter. Covers must be grated if flow to the filter is from sheet flow.

Structural Requirements

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter structural requirements.

The following additional criteria apply specifically to linear sand filters installed in Seattle:

- A linear sand filter vault must be concrete (precast/prefabricated or cast-in-place). The concrete must conform to the "Material" requirements for wet vaults (refer to Section 5.7.4.2).
- At the discretion of DPD, the sediment cell may be made of materials other than concrete, provided water can be evenly spread for uniform delivery into the sand filter cell.
- Where linear sand filters are located in traffic areas, they must meet the structural requirements specified for wet vaults (refer to *Section 5.8.7.5*). The sediment cell must have a removable grated cover that meets HS-25 traffic loading requirements. The cover over the sand filter cell may be either solid or grated.

Underdrains

Underdrains are required to allow the sand media to dry out between events. Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter underdrain requirements.

The following additional requirements for underdrains also apply to sand filters installed in Seattle:

- If a drain strip is used for lateral drainage, the strip must be placed at the slope specified by the manufacturer but at least at 0.5 percent. All drain strips must extend to the central collector pipe. Drain strip installations must be analyzed for conveyance because manufactured products vary in the amount of flow they are designed to handle.
- Internal diameters of underdrain pipes must be a minimum of 6 inches and two rows of 3/8-inch holes spaced 6 inches apart longitudinally (maximum), with rows 120 degrees apart (laid with holes downward). Maximum perpendicular distance between two feeder pipes must be 10 feet. All piping must be schedule 80 PVC or greater wall thickness. Drain piping may be installed in basin and trench configurations.
- Main collector underdrain pipe must be at a slope of 1.0 percent minimum.
- A geotextile fabric (refer to specifications in *Appendix E*) must be used between the sand layer and drain rock or gravel and placed so that 2 inches of drain rock/gravel is above the fabric. Drain rock must be 3/4- to 1-1/2 inch rock or gravel backfill, washed free of clay and organic material. Cover the geotextile fabric with 1-inch of drain rock/gravel. Use 3/4- to 1-1/2-inch drain rock or gravel backfill, washed free of clay and organic material.

Sand Media

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter media requirements.

The following additional requirement for sand media also applies to sand filters installed in Seattle:

- Sand filters must drain freely. Sand media cannot be saturated for extended periods because under these conditions, oxygen can be depleted, releasing pollutants such as dissolved metals and phosphorus that are more mobile under anoxic conditions. To prevent this release of pollutants that have accumulated in the media, sand filters must be designed to drain the water quality design storm volume within 72 hours.

Vegetation

Vegetation requirements for basic and large sand filter basins are not included in Volume V of the SWMMWW; however, the City has developed the following guidelines for grass cover for sand filter basins installed in Seattle:

- No top soil may be added to sand filter beds because fine-grained materials (e.g., silt and clay) reduce the hydraulic capacity of the filter.
- Grass must tolerate the demanding environment of the sand bed. Sand filters experience long periods of saturation during the winter wet season, followed by extended dry periods during the summer. Modeling predicts that sand filters will be dry about 60 percent of the time in a typical year. Consequently, vegetation must be capable of surviving drought, as well as wet conditions.

- *Appendix E* includes a plant list for sand filters. These species can generally survive approximately 1 month of submersion while dormant in the winter (until about February 15), but they can only withstand about 1 to 2 weeks of submersion after mid-February.
- Several grass species in the plant list in *Appendix E* can withstand summer drying and are fairly tolerant of infertile soils. In general, planting a mixture of three or more species is recommended. This ensures better coverage since tolerance of the different species is somewhat different, and the best adapted grasses will spread more rapidly than the others. Legumes, such as clover, fix nitrogen and can thrive in low-fertility soils such as sands. This makes them particularly good choices for planting the sand filter bed.
- A sport-field sod grown in sand may be used on the sand surface. No other sod may be used due to the high clay content in most sod soils.
- To prevent overuse that could compact and potentially damage the filter surface, permanent structures (e.g., playground equipment or bleachers) are not permitted. Temporary structures or equipment must be removed for filter maintenance.
- A horticultural specialist should be consulted for advice on planting.
- Seed should be applied in spring or mid to late fall unless irrigation is provided. If the filter is seeded during the dry summer months, surface irrigation is needed to ensure that the seeds germinate and survive. Seed should be applied at 80 pounds/acre.
- Slow-release fertilizers may be applied to improve germination.
- Low phosphorus fertilizers (such as formulations in the proportion 3: 1: 3 N-P-K or less) or a slow-release phosphorus formulation should be used.

Access

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter access requirements.

The following additional criteria apply specifically to sand filter vaults installed in Seattle:

- Provision for access is the same as for wet vaults. However, the arch culvert sections allowed for wet vaults may not be used for sand filter vaults. Free access to the entire sand bed is needed for maintenance. Removable panels must be provided over the entire sand bed. Removable panels must be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.
- An access road must be provided to the inlet and outlet of a sand filter for inspection and maintenance purposes.

5.8.5.6. BMP Sizing

Sand filters must be designed to capture and treat 91 percent of the total runoff volume (95 percent for large sand filters) as calculated by an approved continuous runoff model. Only 9 percent of the total runoff volume (5 percent for large sand filters) may bypass or overflow from the sand filter facility. The following design criteria apply to all sand filters, unless otherwise noted for Sand Filter Vaults and Linear Sand Filters.

Two methods are provided for sizing sand filters (Simplified Sizing Approach and Facility Modeling), both of which are based on Darcy's law:

$$Q = KiA$$

Where:

Q = water quality design flow (cfs)
K = hydraulic conductivity of the media (fps)
A = surface area perpendicular to the direction of flow (sf)
I = hydraulic gradient (ft/ft) for a constant head and constant media depth

$$i = \frac{h+L}{L}$$

Where:

h = average depth of water above the filter (ft), defined as d/2
d = maximum water storage depth above the filter surface (ft)
L = thickness of sand media (ft)

Although it is not seen directly, Darcy's law underlies both the simple and the modeling design methods. V, or more correctly, 1/V, is the direct input in the sand filter design. The relationship between V and K is revealed by equating Darcy's law and the equation of continuity, Q = VA. (Note: When water is flowing into the ground, V is commonly called the filtration rate. It is ordinarily measured via a soil infiltration test.)

Specifically:

$$Q = KiA \quad \text{and} \quad Q = VA \text{ so,}$$

$$VA = KiA \quad \text{or} \quad V = Ki$$

Note that $V \neq K$. The filtration rate is not the same as the hydraulic conductivity, but they do have the same units (distance per time). K can be equated to V by dividing V by the hydraulic gradient i, which is defined above. The hydraulic conductivity K does not change with head nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. The hydraulic conductivity of 1 inch per hour (2.315×10^{-5} fps) used in this design is based on bench-scale tests of conditioned rather than clean sand. This design hydraulic conductivity represents the average sand bed condition as silt is captured and held in the filter bed. Unlike the hydraulic conductivity, the filtration rate V changes with head

and media thickness, although the media thickness is constant in the sand filter design. Table 5.43 shows values of V for different water depths d (d=2h).

Table 5.43. Sand Filter Design Parameters.

	Sand Filter Design Parameters					
Facility ponding depth d (ft)	1	2	3	4	5	6
Filtration rate V (in/hr) [a]	1.33	1.67	2.00	2.33	2.67	3.00
1/V (min/in)	45	36	30	26	22.5	20

[a] The filtration rate is not used directly, but is provided for information. V equals the hydraulic conductivity, K, times the hydraulic gradient, i. The hydraulic conductivity used is 1 inch/hr. The hydraulic gradient = (h + L)/L, where h = d/2 and L = the sand depth (1.5 ft).

Simplified Sizing Approach

The simplified sizing approach is taken from the *King County Surface Water Design Manual*. It uses standard values to define filter hydraulic characteristics for determining the sand surface area. This method is useful for planning purposes, for a first approximation to begin iterations in the modeling method, or when use of a computer model is not desired or available. The simplified sizing method very often results in a larger filter than the modeling method. More robust calculation methods, using an approved continuous runoff model, may be used (refer to the following section on modeling method).

King County developed the simplified sizing approach to design sand filters that meet the required treatment volume without performing detailed modeling. Steps for the simplified sizing approach are summarized below.

- **Step 1: Determine maximum depth of water above sand filter**. This depth is defined as the depth at which water begins to overflow the reservoir pond, and it depends on site topography and hydraulic constraints. The depth is chosen by the designer.
- **Step 2: Determine site characteristics**. Determine the total number of impervious acres and the total number of grass acres draining to the sand filter. Determine whether the site is on till or outwash soils.
- **Step 3: Calculate minimum required surface area for the sand filter**. Determine the sand filter area by multiplying the values in Table 5.44 by the site acreage from Step 2 using the following equation:

$$A_{sf} = 0.7(T_i A_i + T_{tg} A_{tg} + T_{og} A_{og})$$

Where:

A_{sf} = sand filter area (sf)
0.7 = adjustment factor to account for routing effect on size
$T_{i,tg,og}$ = tributary area per soil/cover type (acres)
$A_{i,tg,og}$ = filter area per soil/cover type (sf/acre) from Table 5.44.

Table 5.44. Sand Filter Area Increments for Various Soil and Cover Types.

Treatment Goal	Maximum Depth above Filter (ft)	SOIL AND COVER TYPES [filter area (sf) / tributary area (acre)]		
		A_i Impervious	A_t Till Grass	A_{og} Outwash Grass
BASIC	6	760	160	140
	3	1,140	240	210
	1	1,711	360	314
LARGE	6	1,179	279	250
	3	1,769	419	370
	1	2,654	629	550
Forested areas may be ignored. Vegetated areas other than grass may still be represented as grass for the simple sizing method, or the detailed routing method may be employed using actual cover types.				

The values in Table 5.44 were derived as follows. Flows were estimated using the KCRTS model for one acre of the cover types selected in the table. Darcy's law ($Q = Ki\ A$) was then used to determine sand filter area using this flow Q, the hydraulic gradient i for the various ponding depths given, and a hydraulic conductivity k of 2.3 X 10^{-5} fps (1 inch/hr). The hydraulic gradient i was calculated as $(h+l)/\ l$, where h = the average depth of water above the filter, taken to be the ponding depth $d/2$, and l = the thickness of the sand layer, which is 1.5 feet. The hydraulic conductivity represents a partially plugged sand condition found by bench-scale testing using successive trials with turbid water.

For depths between the values given in the table, areas can be interpolated. For depths outside the range presented in the table, the Facility Modeling method must be used.

- **Step 4. Size the underdrain system.** The underdrain system is sized to convey the peak filtered flows to the outlet. Underdrains can be used in lieu of analyzing conveyance capacity for feeder pipes (refer to *Design Criteria* section). Strip drains, if used, must be analyzed for conveyance per manufacturer's specifications.

  The collector pipe (i.e., the pipe collecting flows from the rest of the underdrain system) must be sized to convey the 2-year, 15-minute peak flow with 1 foot of head above the invert of the upstream end of the collector pipe.

Intent: The underdrain must be able to remove standing water from beneath the sand. If standing water remains, the sand will remain saturated. This could cause oxygen depletion and reduced conditions in the sand, allowing some pollutants to become mobile and be released from the filter to downstream receiving waters.

Simple Method Sizing Example:

For a site with 2 acres of impervious area and 2 acres of till grass draining to the sand filter, and 3 feet of head above the filter, the required sand area for a basic size sand filter would be as follows:

Site Areas		Table 5.44 Values for Basic Size		
2 acres	x	1,140 sf/acre	=	2,280 sf
+ 2 acres	x	240 sf/acre	=	480 sf
			=	2,760 sf

Because the site is located in Seattle, the "regional scale factor (refer to Step 1) is 1.0. Multiply 2,760 square feet by the 0.7 adjustment factor (refer to Step 4).

2,760 sf x 1.0 x 0.7 = 1,930 sf

The required sand bed area is therefore 1,930 square feet.

Note: Find the total facility area by adding 3H:1V side slopes for the 3-foot ponding depth plus extra vertical height to convey the 100-year flow. If the total pond depth is 3.5 feet, the sand filter will require a total land area of (44 feet + 10.5 feet) x (44 feet + 10.5 feet) = 2.970 square feet, plus access and setback requirements.

Facility Modeling

When using continuous modeling to size a sand filter, apply the assumptions listed in Table 5.45.

Table 5.45. Sand Filter Design and Sizing Criteria.

Variable	Basic Sand Filter Basin	Large Sand Filter Basin	Sand Filter Vault	Linear Sand Filter
Precipitation Series	Seattle 158-year, 5-minute series			
Computational Time Step	15-minutes			
Inflows to Facility	Continuous model output for applicable water quality design flow rate and volume			
Ponding Depth	Maximum water depth over the filter media			Maximum of 1 foot
Precipitation Applied to Facility	Yes		No	Yes (grated cover), No (solid cover)
Evaporation Applied to Facility	Yes		No	Yes (grated cover), No (solid cover)
Media depth	18 inches or other as designed			Minimum of 12 inches of sand and 8 inches of drain rock
Sand Media Hydraulic Conductivity	1 inch per hour			
Use Wetted Surface Area	Only if side slopes are 3H:1V or flatter		No	No

5.8.5.7. Minimum Construction Requirements

Refer to BMP T8.10 – Basic Sand Filter Basin, BMP T8.11 – Large Sand Filter Basin, BMP T8.20 – Sand Filter Vault, and BMP T8.30 – Linear Sand Filter in Volume V of the SWMMWW for sand filter minimum construction requirements.

5.8.5.8. Operations and Maintenance Requirements

Sand filter O&M requirements are provided in *Appendix G (BMP No. 15 and 16)*.

5.8.6. Wet Ponds

5.8.6.1. Description

Wet ponds are constructed stormwater ponds that retain a permanent pool of water (i.e., a wet pool or dead storage) at least during the wet season.

As an option, a shallow marsh area can be created within the permanent pool volume to provide additional treatment for nutrient removal. Peak flow control can be provided in the "live storage" area above the permanent pool.

5.8.6.2. Performance Mechanisms

The volume of the wet pool, which slows down the velocity of incoming stormwater, allows particulates and particulate-bound pollutants to settle and is a key factor in determining wet pond effectiveness. Biological uptake also acts as a secondary pollutant removal mechanism.

5.8.6.3. Applicability

Wet ponds can be applied for meeting different levels of water quality treatment as summarized below. Wet ponds can be combined with detention storage to provide flow control (refer to *Section 5.8.9*).

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Basic wet pond						✓	TT-B		TT-A	✓
Large wet pond [a]						✓	✓		✓	✓

TT-A = Treatment Train A (must be followed by a Basic Sand Filter or Sand Filter Vault)
TT-B = Treatment Train B (must be followed by a Sand Filter or Sand Filter Vault or Media Filter)
[a] A large wet pond requires a wet pool volume at least 1.5 times larger than for a basic wet pond.

5.8.6.4. Site Considerations

Site considerations for wet ponds are the same as those outlined for detention ponds under *Section 5.7.1.4.* Wet ponds require a larger area than a biofiltration swale or a sand filter, but can be integrated into the contours of a site fairly easily and function well for any size project.

Wet ponds work best when the water already in the pond is moved out en masse by incoming flows, a phenomenon called "plug flow". Because treatment works on this displacement principle, the wet pool storage of wet ponds may be provided below the groundwater level without interfering unduly with treatment effectiveness. However, if combined with a detention function, the live storage must be above the seasonal high groundwater level.

Setbacks for wet ponds are the same as those outlined for detention ponds under *Section 5.7.1.4*.

5.8.6.5. Design Criteria

Design criteria for wet ponds are generally the same as those outlined for detention ponds under *Section 5.7.1.5*. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section or in Volume V of the SWMMWW for the following elements:

Design Element	SWMMWW Design Criteria	Seattle-specific Design Criteria
Pond geometry	✓	✓
Berms and baffles	✓	Refer to Detention Ponds (Section 5.7.1.5)
Overflow structure	✓	Refer to Detention Ponds (Section 5.7.1.5)
Access	✓	Refer to Detention Ponds (Section 5.7.1.5)
Vegetation and Landscaping	✓	✓
Inlets and Outlets	✓	

Refer to BMP T10.10 – Wet ponds in Volume V of the SWMMWW for wet pond design criteria. In addition to Ecology's criteria, the City has also developed specific design criteria for several design elements which are summarized below.

Pond Geometry

A wet pond typically consists of two cells that are separated by a baffle or a berm. A baffle is a vertical divider placed across the entire width of the pond, stopping short of the bottom. A berm is a vertical divider typically built up from the bottom, or if in a vault, connects all the way to the bottom.

Seattle specific requirements include the following:

- The first cell must contain between 25 to 35 percent of the total wet pool volume. The baffle or berm volume must not count as part of the total wet pool volume.

  The full-length berm or baffle promotes plug flow and enhances quiescence and laminar flow through as much of the entire water volume as possible. Alternative methods to the full-length berm or baffle that provide equivalent flow characteristics may be approved on a case-by-case basis by the City.

- Sediment storage must be provided in the first cell. The sediment storage must have a minimum depth of 1 foot. A fixed sediment depth monitor must be installed in the first cell to gauge sediment accumulation unless an alternative gauging method is proposed.

- The minimum depth of the first cell must be 4 feet, exclusive of sediment storage requirements. The depth of the first cell may be greater than the depth of the second cell.

- Maximum pond depth (excluding sediment storage) must not exceed 8 feet. Deep ponds (greater than 8 feet) may stratify during summer and create low oxygen conditions near the bottom resulting in re-release of phosphorus and other pollutants back into the water. For wet pool depths in excess of 6 feet, it is recommended that some form of recirculation be provided in the summer, such as a fountain, aerator, or small amount of base flow, to prevent stagnation and low dissolved oxygen conditions.
- The ratio of flow path length to width from the inlet to the outlet must be at least 3:1. The flow path length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth can be calculated as follows: width = (average top width + average bottom width)/2.
- Wet ponds with wet pool volumes less than or equal to 4,000 cubic feet may be single celled (i.e., no baffle or berm is required). However, it is especially important in this case that the flow path length be maximized. The ratio of flow path length to width must be at least 4:1 in single celled wet ponds, but should preferably be 5:1. In addition, a gravity drain for maintenance must be provided 12 to 18 inches from the pond bottom.

Berms and Baffles

A berm or baffle must extend across the full width of the wet pond and tie into the wet pond side slopes. Berm and baffle design criteria for wet ponds are the same as those outlined for detention ponds under *Section 5.7.1.5*.

Overflow Structure

Overflow structure design criteria for wet ponds are the same as those outlined for detention ponds under *Section 5.7.1.5*.

Access

Access requirements for wet ponds are the same as those outlined for detention ponds under *Section 5.7.1.5*.

Vegetation and Landscaping

Refer to BMP T10.10 – Wet ponds in Volume V of the SWMMWW for vegetation and landscaping requirements.

Additional vegetation and landscaping requirements for wet ponds installed in Seattle include:

- Exposed earth on the pond bottom and interior side slopes must be sodded or seeded with an appropriate seed mixture. All remaining areas of the tract must be vegetated or stabilized before the pond is put into operation.
- No trees or shrubs may be planted within 10 feet of inlet or outlet pipes or drainage structures such as spillways or flow spreaders. Species with roots that seek water, such as willow or poplar, must be avoided within 50 feet of pipes or drainage structures.

- If the wet pond discharges to a nutrient critical receiving water, shrubs that form a dense cover should be planted on slopes above the water quality design water surface on at least three sides. The purpose of planting is to discourage waterfowl use of the pond and to provide shading. *Appendix E* includes a plant list for wet pond peripheries.

- Planting is restricted on berms that impound water either permanently or temporarily during storms. Note: This restriction does not apply to cut slopes that form pond banks, only to berms.

    - Trees or shrubs may not be planted on portions of water-impounding berms taller than 4 feet high. Only grasses may be planted on berms taller than 4 feet.

    - Trees planted on portions of water-impounding berms less than 4 feet high must be small, not higher than 20 feet mature height, and have a fibrous root system. Table 5.45 provides a list of small trees with these characteristics.

      These trees reduce the likelihood of blow-down trees, or the possibility of channeling or piping of water through the root systems, which may contribute to structural failure on berms that retain water.

- All landscape material, including grass, must be planted in good topsoil. Native underlying soils may be suitable for planting if amended per Soil Amendment BMP requirements in *Section 5.1*.

- Soil in which trees or shrubs are planted may require additional enrichment or additional compost top-dressing. Consult a certified arborist for site-specific recommendations.

- For a naturalistic effect, as well as ease of maintenance, trees or shrubs should be planted in clumps to form "landscape islands" rather than evenly spaced.

- The landscaped islands must be a minimum of 6 feet apart, and if set back from fences or other barriers, the setback distance should also be a minimum of 6 feet. Where tree foliage extends low to the ground, the 6 feet of setback should be counted from the outer drip line of the trees (estimated at maturity). This setback allows a 6-foot wide mower to pass around and between clumps.

- Evergreen trees and other trees that produce relatively little leaf-fall (such as Oregon ash, mimosa, or locust) are preferred.

- Trees should be set back so that branches do not extend over the pond (to prevent leaf-drop into the water).

- Drought tolerant species are recommended.

5.8.6.6. BMP Sizing

Refer to BMP T10.10 – Wet Ponds in Volume V of the SWMMWW for BMP Sizing considerations.

5.8.6.7. Minimum Construction Requirements

Refer to BMP T10.10 – Wet Ponds in Volume V of the SWMMWW for minimum construction requirements. Additional minimum construction requirements for wet ponds installed in Seattle are the same as those outlined for detention ponds under *Section 5.7.1.7*.

5.8.6.8. Operations and Maintenance Requirements

Wet pond O&M requirements are provided in *Appendix G (BMP No. 12)*.

5.8.7. Wet Vaults

5.8.7.1. Description

Wet vaults are drainage facilities that contain permanent pools of water that are filled during the initial runoff from a storm event. They are similar to wet ponds, except the wet pool is constructed below grade.

5.8.7.2. Performance Mechanisms

Wet vaults are designed to optimize water quality treatment by dissipating energy and providing retention time in order to settle out particulate pollutants. Being underground, the wet vault lacks the biological pollutant removal mechanisms, such as algae uptake, present in surface wet ponds. Wet vaults are believed to be ineffective in removing dissolved pollutants such as soluble phosphorus or metals, such as copper.

5.8.7.3. Applicability

A wet vault can be applied for meeting different levels of water quality treatment as summarized below. Wet vaults can be combined with detention storage to provide flow control (refer to *Section 5.8.9*).

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Wet Vault						✓	TT-A[a] or TT-B		TT-B	✓
Wet Vault and API oil/water separator						✓		✓		✓

[a] The Media Filter media must be of a nature that has the capability to remove dissolved metals effectively as approved by Ecology and accepted by the Director

TT-A = Treatment Train A (must be followed by Basic Sand Filter, Sand Filter Vault, or Media Filter[4])

TT-B = Treatment Train B (must be followed by Basic Sand Filter or Sand Filter Vault)

5.8.7.4. Site Considerations

The following site considerations can help determine the feasibility of a wet vault for a particular site:

- Consider wet vaults where there are space limitations precluding the use of other treatment BMPs.
- Consider how the wet vault grates and access points fit within a site plan, including restrictions for safety considerations and restriction of pollutants entering through grates. Grates are not to operate as inlets. Generally, the surrounding area should be sloped away from grates.
- Consider how access will be provided for vactor trucks for sediment removal

Additional site considerations may apply depending on site conditions and other factors.

5.8.7.5. Design Criteria

As with wet ponds, the primary design factor that determines the removal efficiency of a wet vault is the volume of the facility. The larger the volume, the higher the potential for pollutant removal. Performance is also improved by avoiding dead zones (like corners) where little exchange occurs, using large length-to-width ratios, dissipating energy at the inlet, and ensuring that flow rates are uniform to the extent possible and not increased between cells.

The methods for designing the wet vault are identical to the methods for designing wet ponds. The following provides a description and requirements for the components of wet vaults. Typical design details and concepts for the wet vault are shown in Figure 5.24. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section for the following elements:

- Wet vault geometry
- Wet vault configuration
- Inlet, outlet and bypass, if used
- Modifications if combining with a baffle oil/water separator
- Modifications if combining with detention
- Access to cells for maintenance
- Structural requirements

Wet Vault Geometry

The minimum flow length-to-width ratio is 3:1. A greater ratio is desirable. The inlet and outlet should be at opposing corners of the vault to increase the flow path, if possible. Wet pool depths for vaults are the same as specified for wet ponds except for the following modifications:

- The sediment storage must average 1 foot.
- The depth above sediment storage to the water quality design water surface must be a minimum of 4 feet deep since planting cannot be used to prevent resuspension of sediment in shallow water (as it can in open ponds) and to provide for a submerged inlet.
- The maximum depth from finished grade to the vault invert must be 17 feet to allow for removing sediment by vactor.

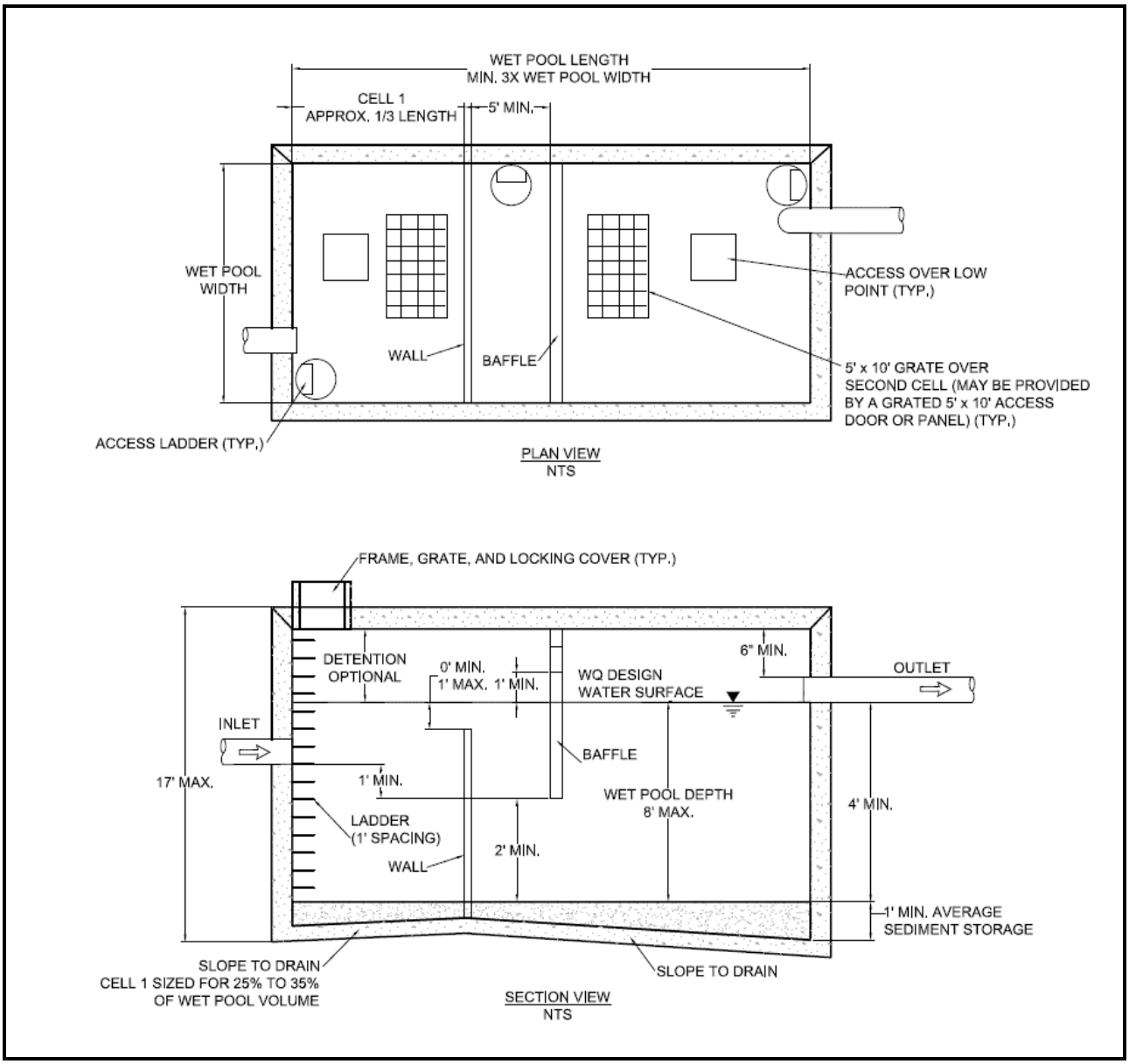


Figure 5.24. Typical Wet Vault.

Wet Vault Configuration

The vault must be separated into three cells by a wall and a baffle (baffle can be removable). The following criteria apply:

- A wall must be placed at approximately one-third of the wet vault length.
- The wall height must be set no higher than the water quality design water surface, and no lower than 1 foot below.
- A baffle must be placed downstream of the wall, with a minimum distance between the wall and the baffle of 5 feet.

- The baffle must extend from a minimum of 1 foot above the water quality design water surface to a minimum of 1 foot below the invert elevation of the inlet pipe.
- The lowest point of the baffle must be a minimum of 2 feet from the bottom of the vault, and greater if feasible.

Note: If the vault is less than 2,000 cubic feet (inside dimensions), the vault may be one-celled.

Inlet, Outlet and Bypass

The following criteria apply to inlets, outlets, and bypasses:

- The number of inlets to the wet vault should be limited, and the flow path length must be maximized from inlet to outlet for all inlets to the vault.
- The inlet to the wet vault must be submerged with the inlet pipe invert a minimum of 3 feet from the vault bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible.

  The submerged inlet is to dissipate energy of the incoming flow. The distance from the bottom is to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.
- Unless designed as an off-line facility, the capacity of the outlet pipe and available head above the outlet pipe must be designed to convey the design flow for developed site conditions with a 1 percent annual probability (100-year recurrence) without overtopping the vault. The available head above the outlet pipe must be a minimum of 6 inches.
- In single cell wet vaults (without a baffle), the outlet pipe must be back-sloped or have a tee section, the lower arm of which must extend 1 foot below the water quality design water surface to provide for trapping of oils and floatables in the vault.
- In a combination wet vault with detention, the outlet pipe must have a flow control riser tee that extends a minimum of 2 feet below the water quality design water surface.
- Where pipes enter and leave the vault they must be watertight.
- Valved and piped bypass of flows for maintenance is preferred. This isolates the wet vault for safe entry, prevents resuspension of particle pollutants during a cleaning operation, and manages the volume of water for disposal during cleaning.

Modifications if Combining with a Baffle Oil/Water Separator

If the project site is a high-use site and a wet vault is proposed, the vault may be combined with a baffle oil/water separator to meet the water quality treatment requirements with one facility rather than two. Structural modifications and added design criteria are provided below. However, the maintenance requirements for baffle oil/water separators must be adhered to, in addition to those for a regular wet vault. This will result in more frequent

inspection and cleaning than for a wet vault. Refer to *Section 5.8.10.8* for information on maintenance of baffle oil/water separators.

The sizing procedures for the baffle oil/water separator (*Section 5.8.10.6*) must be run as a check to ensure the vault is large enough. If the oil/water separator sizing procedures result in a larger vault size, increase the wet vault size to match.

An oil retaining baffle must be provided near the vault outlet. The baffle must not contain a high-flow overflow, or else the retained oil will be washed out of the vault during large storms.

Additional design criteria for a combined wet vault with baffle oil/water separator are as follows:

- The vault must have a minimum length-to-width ratio of 5:1.
- The vault must have a design water depth-to-width ratio of between 1:3 to 1:2.
- The vault must be watertight and must be coated to protect from corrosion.
- Separator vaults must have a shutoff mechanism on the outlet pipe to prevent oil discharges during maintenance and to provide emergency shut-off capability in case of a spill. A valve box and riser must also be provided. Refer to previous section for valve box requirements.
- Wet vaults used as oil/water separators must be off-line and must bypass flows greater than the off-line water quality design flow (i.e., the water quality design flow multiplied by the off-line factor of 3.0.

  This design minimizes the entrainment and/or emulsification of previously captured oil during very high flow events.

Modifications if Combining with Detention

The design criteria for detention vaults and wet vaults must both be met, with the exception of the modifications included in BMP T10.40 – Combined Detention and Wetpool Facilities in Volume V of the SWMMWW.

Access to Cells for Maintenance

Refer to the access criteria listed under Detention Vaults (*Section 5.7.3.5*). Access must be provided to allow personnel to enter and provide emergency egress from all cells of a wet vault using the following criteria:

- For vaults with greater than 1,250 square feet of floor area, a 5-foot by 10-foot removable panel must be provided over the inlet pipe (instead of a standard frame, grate and solid cover). Alternatively, a separate access vault may be provided.
- For vaults under roadways, the removable panel must be located outside the travel lanes. Alternatively, multiple standard locking maintenance hole covers may be provided. Vaults providing maintenance hole access at 12-foot spacing need not provide corner ventilation pipes.

- All access openings, except those covered by removable panels, must have round, solid locking lids, or 3-foot square, locking diamond plate covers.
- Vaults with widths 10 feet or less must have removable lids.
- Internal structural walls of large vaults must be provided with separate access risers or openings sufficient for maintenance access between cells. The openings must be sized and situated to allow access to the maintenance "v" in the floor.

Structural Requirements

Wet vaults must conform with the "Materials" and "Structural Stability" criteria specified for detention vaults in *Section 5.7.3.5.*

Additional structural design criteria for a combined wet vault with baffle oil/water separator are as follows:

- The vault floor must be sloped to drain to access points with the intent to allow flushing to vactor points for sediment removal.
- A minimum of 50 square feet of grate must be provided over each cell. For vaults in which the surface area of the second cell is greater than 1,250 square feet, 4 percent of the top must be grated. This requirement may be met by one grate or by many smaller grates distributed over the second cell area. Note: a grated access door can be used to meet this requirement.

  The grate allows air contact with the wet pool in order to minimize stagnant conditions which can result in oxygen depletion, especially in warm weather.
- All metal parts must be corrosion-resistant. Galvanized materials must not be used since galvanized metal contributes zinc to stormwater, sometimes in very high concentrations. Grates must be coated for corrosion resistance with elastomeric epoxy or marine paint without zinc.
- The cells of a wet vault must not be divided into additional subcells by internal walls. If internal structural support is needed, it is preferred that post and pier construction be used to support the vault lid rather than walls. Any walls used within cells must be positioned so as to lengthen, rather than divide, the flow path.

  Treatment effectiveness in wet pool facilities is related to the extent to which plug flow is achieved and short-circuiting and dead zones are avoided. Structural walls placed within the cells can interfere with plug flow and create significant dead zones, reducing treatment effectiveness.

5.8.7.6. BMP Sizing

Facility Modeling

Refer to wet ponds *(Section 5.8.6.6)* for BMP Sizing information.

5.8.7.7. Minimum Construction Requirements

Refer to the construction-related issues outlined above as part of the design criteria. Additional construction requirements include:

- Vault floor must be sloped to drain.
- Extiltration or infiltration testing is required. Contractor must propose a test method.
- All sediment must be removed at the end of construction.

5.8.7.8. Operations and Maintenance Requirements

Wet vault O&M requirements are provided in *Appendix G (BMP No. 13)*.

5.8.8. Stormwater Treatment Wetlands

5.8.8.1. Description

Stormwater treatment wetlands are similar to wet ponds, but also provide a shallow marsh area to allow the establishment of emergent wetland aquatic plants, which improves pollutant removal.

5.8.8.2. Performance Mechanisms

Stormwater treatment wetlands remove sediment, metals, and pollutants that bind to humic or organic acids primarily through settling and biological uptake. Secondary performance mechanisms include filtration and soil adsorption. Phosphorus removal in stormwater wetlands is highly variable, so stormwater treatment wetlands are not expected to provide phosphorus control.

In land development situations, wetlands are usually constructed for two main reasons: to replace or mitigate impacts when natural wetlands are filled or impacted by development (mitigation wetlands) and to treat stormwater runoff (stormwater treatment wetlands). Mitigation wetlands may not be used as stormwater treatment facilities, because stormwater treatment functions are not compatible with normal wetland function.

5.8.8.3. Applicability

A stormwater treatment wetland can be applied for meeting different levels of water quality treatment as summarized below. Stormwater treatment wetlands can be combined with detention storage to provide flow control (refer to *Section 5.8.9*).

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Stormwater treatment wetland						✓	✓		TT-A	✓

TT-A = Treatment Train A (must be followed by a Basic Sand Filter or Sand Filter Vault)

5.8.8.4. Site Considerations

Refer to BMP T10.30 – Stormwater Treatment Wetlands in Volume V of the SWMMWW for site considerations. Additional site considerations may apply depending on site conditions and other factors.

Setbacks

The location of a stormwater treatment wetland relative to site constraints (e.g., buildings, property lines, etc.) are the same as for Wet Ponds (*Section 5.8.6.4*). Refer to *Section 5.8.1* for general setback requirements for non-infiltrating facilities.

5.8.8.5. Design Criteria

The following provides a description and requirements for the components of stormwater treatment wetlands. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section or in Volume V of the SWMMWW for the following elements:

Design Element	SWMMWW Design Criteria	Seattle-specific Design Criteria
Inlets and outlets	✓	✓
Geometry	✓	
Lining requirements	✓	
Access	✓	
Planting	✓	

Refer to BMP T10.30 – Stormwater Treatment Wetlands Volume V of the SWMMWW for design criteria. In addition to Ecology's criteria, the City has also developed specific design criteria for inlets and outlets which are summarized below.

Inlets and Outlets

Refer to Wet Ponds (*Section 5.8.6.5*) for inlet and outlet requirements.

The following additional requirements apply to Stormwater Treatment Wetlands installed in Seattle:

- Inlets and outlets must be placed to maximize the flow path through the facility. The ratio of flow path length to width from the inlet to the outlet must be at least 3:1. The flow path length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth can be calculated as follows: width = (average top width + average bottom width)/2.
- To the extent possible create a complex microtopography within the wetland. Design the flow path to maximize sinuous flow between wetland cells.

5.8.8.6. BMP Sizing

Refer to BMP T10.30 – Stormwater Treatment Wetlands in Volume V of the SWMMWW for BMP sizing.

5.8.8.7. Minimum Construction Requirements

Construction requirements are the same as for Wet Ponds (*Section 5.8.6.7*).

5.8.8.8. Operations and Maintenance Requirements

Stormwater treatment wetland O&M requirements are provided in *Appendix G (BMP No. 14)*.

5.8.9. Combined Detention and Wet Pool Facilities

5.8.9.1. Description

Combined detention and water quality wet pool facilities have the appearance of a detention facility but contain a permanent pool of water as well. The following design procedures, requirements, and recommendations cover differences in the design of the stand-alone water quality facility when combined with detention storage. Site considerations, setbacks, and other typical siting and design considerations for combined facilities are the same as specified for each individual facility, unless noted below. The following combined facilities are addressed in this section:

- Detention/wet pond (basic and large)
- Detention/wet vault
- Detention/stormwater wetland.

There are two sizes of the combined wet pond, a basic and a large, but only a basic size for the combined wet vault and combined stormwater wetland. The facility sizes (basic and large) are related to the pollutant removal goals (refer to *Section 3.3.2*).

5.8.9.2. Performance Mechanisms

The intent of a combined detention and wet pool facility is to provide water quality treatment in addition to flow control. The three types of combined facilities provide water quality treatment as follows:

- A combined detention/wet pond provides pollutant removal via settling and biological uptake.
- A combined detention/wet vault provides pollutant removal via settling.
- A combined detention/stormwater wetland provides pollutant removal via settling, biological uptake, filtration, and soil adsorption.

5.8.9.3. Applicability

Combined detention and wet pool facilities can be applied for meeting different levels of flow control and water quality treatment as summarized below.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Combined detention and wet pond			✓	✓	✓	✓	TT-B		TT-A	✓
Combined detention and wet vault			✓[a]	✓[b]	✓[c]	✓	TT-B		TT-A	✓
Combined detention and stormwater wetland			✓	✓	✓	✓	TT-B		TT-A	✓

Flow control standards can be achieved in Seattle using a 0.5-inch diameter bottom orifice with a 3-foot live storage depth in the following scenarios:

[a] Pre-developed Forest Standard can be achieved when the contributing impervious area is greater than approximately 35,000 square feet.

[b] Pre-developed Pasture Standard can be achieved when the contributing impervious area is greater than approximately 26,000 square feet.

[c] Peak Control Standard can be achieved when the contributing impervious area is greater than approximately 2,600 square feet.

TT-A = Treatment Train A (must be followed by a Basic Sand Filter or Sand Filter Vault)

TT-B = Treatment Train B (must be followed by a Basic Sand Filter or Sand Filter Vault or Media Filter)

5.8.9.4. Site Considerations

Refer to BMP T10.40 – Combined Detention and Wet Pool Facilities in Volume V of the SWMMWW for site considerations. Additional site considerations may apply depending on site conditions and other factors.

5.8.9.5. Design Criteria

Refer to BMP T10.40 – Combined Detention and Wetpool Facilities in Volume V of the SWMMWW for design criteria.

Combined Detention and Wet Vault

The design criteria for detention vaults and wet vaults must both be met, except the modifications included in BMP T10.40 – Combined Detention and Wetpool Facilities in Volume V of the SWMMWW.

Combined Detention and Stormwater Wetland

The design criteria for detention ponds and stormwater wetlands must both be met, except the modifications included in BMP T10.40 – Combined Detention and Wetpool Facilities in Volume V of the SWMMWW.

5.8.9.6. BMP Sizing

Refer to BMP T10.40 – Combined Detention and Wetpool Facilities in Volume V of the SWMMWW for BMP sizing.

5.8.9.7. Minimum Construction Requirements

Construction requirements are the same as for Wet Ponds (*Section 5.8.6.7*).

5.8.9.8. Operations and Maintenance Requirements

Detention and wet pool O&M requirements are provided in *Appendix G (BMP No. 1, No. 3, No. 12, No. 13. and No. 14)*.

5.8.10. Oil/Water Separators

5.8.10.1. Description

Oil/water separators rely on passive mechanisms that take advantage of oil being lighter than water. Oil rises to the surface and can be periodically removed. The two types of oil/water separators typically used for stormwater treatment described in this section are the baffle type or American Petroleum Institute (API) oil/water separator and the coalescing plate (CP) oil/water separator:

1. **Baffle type separator (API)**: Baffle (API) oil/water separators use vaults that have multiple cells separated by baffles extending down from the top of the vault. The baffles block oil flow out of the vault. Baffles are also commonly installed at the bottom of the vault to trap solids and sludge that accumulate over time. In many situations, simple floating or more sophisticated mechanical oil skimmers are installed to remove the oil once it has separated from the water.

2. **Coalescing plate (CP) separator**: CP separators are typically manufactured units consisting of a baffled vault containing several inclined corrugated plates stacked and bundled together. The plates are equally spaced (typical plate spacing ranges from .25 to 1 inch) and are made of a variety of materials, the most common being fiberglass and polypropylene. Efficient separation results because the plates reduce the vertical distance oil droplets must rise in order to separate from the stormwater. Once they reach the plate, oil droplets form a film on the plate surface. The film builds up over time until it becomes thick enough to migrate upward along the inclined plate. When the film reaches the edge of the plate, oil is released as large droplets which rise rapidly to the surface, where the oil accumulates until the unit is maintained. Because the plate pack increases treatment effectiveness significantly, CP separators can achieve a specified treatment level with a smaller vault size than a simple baffle separator.

5.8.10.2. Performance Mechanisms

Oil/water separators are designed to remove free oil and are not generally effective in removing oil that has become either chemically or mechanically emulsified or dissolved in the stormwater.

5.8.10.3. Applicability

Oil/water separator bays are designed specifically for the removal of oil (refer to applicable categories below). Oil/water separators must be located off-line and bypass the incremental portion of flows that exceed the off-line water quality design flow rate (refer to

Section 4.2.1). If it is not possible to locate the separator off-line (e.g., roadway intersections), try to minimize the size of the area requiring oil control, and use the on-line water quality design flow rate (refer to *Section 4.2.1*).

When an oil/water separator is required (i.e., high use sites), it must be installed upstream of any other stormwater treatment facility. In addition, separators must be located upstream of any pumps to prevent oil present in the stormwater from becoming emulsified. When a separator is required, it must precede other stormwater treatment facilities (except wet vaults). Oil/water separators may be located upstream or downstream of flow control facilities, since there are advantages and disadvantages with either placement.

API oil/water separators are not effective in removing low concentrations of oil, and therefore, are not recommended for use on sites with very dilute concentrations of TPH. Other stormwater facilities, such as sand filters, biofiltration swales, and emerging technologies may be more applicable under these conditions. Linear sand filters are also approved for oil control (refer to *Section 5.8.5*). Spill control separators are often used as a source control BMP, but are not permitted as a stormwater treatment oil control BMP. Refer to *Volume 4, Source Control* for additional details on spill prevention and control.

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
API oil/water separator								✓		
CP oil/water separator								✓		

5.8.10.4. Site Considerations

The following considerations can influence the feasibility of API oil/water separators for a particular site:

- Oil/water separators must be installed upstream of facilities and conveyance structures that introduce turbulence that promotes emulsification.
- Oil/water separators must not be used for removal of dissolved or emulsified materials such as coolants, soluble lubricants, glycols (anti-freeze), and alcohols.
- API oil/water separators installed in the City must only be used for sites with catchment areas larger than 2 acres.
- Oil/water separators are best located in areas where the contributing drainage area is nearly all impervious and a fairly high load of TPH is likely to be generated.
- Excluding unpaved areas helps to minimize the amount of sediment entering the vault, which reduces the need for maintenance. Pretreatment should be considered if the

level of TSS in the inlet flow would cause clogging or otherwise impair the long-term efficiency of the separator.

The following considerations can influence the feasibility of CP separators for a particular site:

- CP separators are typically smaller than API separators and are suitable for sites where space is limited. CP separator units are required for sites with catchment areas smaller than 2 acres that are required to provide oil control, where API separators are not allowed.
- CP separator designs may be required to add pretreatment for TSS that could cause clogging of the CP separator, or otherwise impair the long-term effectiveness of the separator.
- Typical applications of CP oil/water separators include inflows from small drainage areas (fueling stations, maintenance shops, etc.) due to space limitations. However, if plugging of the plates is likely, then a new design basis for the baffle type API separator may be considered on an experimental basis.

Additional site considerations may apply depending on site conditions and other factors.

5.8.10.5. Design Criteria

The following provides a description and requirements for the components of oil/water separators. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Design criteria are provided in this section for the following elements:

- Vault geometry
- Vault structure
- Baffles
- Separator plates
- Material requirements
- Inlet and outlet
- Access

Note: The following criteria apply to both API baffle and CP separators, unless otherwise specified.

Vault Geometry

Oil/water separator vaults are typically divided in three compartments: a forebay, an oil separation cell, and an afterbay:

- The forebay is designed primarily to trap and collect sediment and debris, support plug flow conditions, and reduce turbulence.

- The oil separation cell traps and holds oil as it rises from the water column, and it serves as a secondary sediment collection area.
- The afterbay provides a relatively oil-free cell before the outlet and provides a secondary oil separation area.

The following criteria apply specifically to API separator bay vaults (Figure 5.25):

- The length of the forebay must be approximately 0.33 to 0.5 the length of the vault.
- The surface area of the forebay must be at least 20 sf per 10,000 sf of impervious area draining to the separator.
- The design water depth must be no deeper than 8 feet unless approved by the Director. Depths greater than 8 feet may be permitted on a case-by-case basis, taking into consideration the potential for depletion of oxygen in the water during the warm summer months.
- Baffle separator vaults must have a minimum length-to-width ratio of 5:1.
- Baffle separator vaults must have a design water depth-to-width ratio of between 0.3 and 0.5.

The following criteria apply specifically to CP separators (Figure 5.26):

- The length of the forebay must be a minimum of 0.33 the length of the vault (L), but 0.5 L is recommended.
- The surface area of the forebay must be at least 20 sf per 10,000 sf of tributary impervious area draining to the separator. In lieu of an attached forebay, a separate grit chamber, sized to be at least 20 sf per 10,000 sf of tributary impervious area, may precede the oil/water separator.

Vault Structure

The following criteria apply to both API and CP separator bays:

- Separator vaults must be watertight. Pipes entering and exiting a vault below the water quality design water surface, must be sealed using a non-porous, non-shrinking grout.
- Separator vaults must have a shutoff mechanism on the outlet pipe to prevent oil discharges during maintenance and to provide emergency shutoff capability in the event of a spill. A valve box and riser must be provided according to the design criteria for wet vaults (refer to *Section 5.8.7.5*).
- Roughing screens for the forebay or upstream of the separator to remove debris, should be used if needed. Screen openings should be approximately .75 inch.
- A gravity drain for maintenance is recommended if grade allows. The drain invert should be at a depth equal to the depth of the oil retaining baffle. Deeper drains are encouraged where feasible.

- If large amounts of oil are likely to be captured, a bleed-off pipe and separate waste oil tank can be located adjacent to the vault to channel separated oils into the tank. This improves the overall effectiveness of the facility, especially if maintenance is only performed annually. It also improves the quality of the waste oil recovered from the facility.
- Absorbents and/or skimmers should be used in the afterbay.

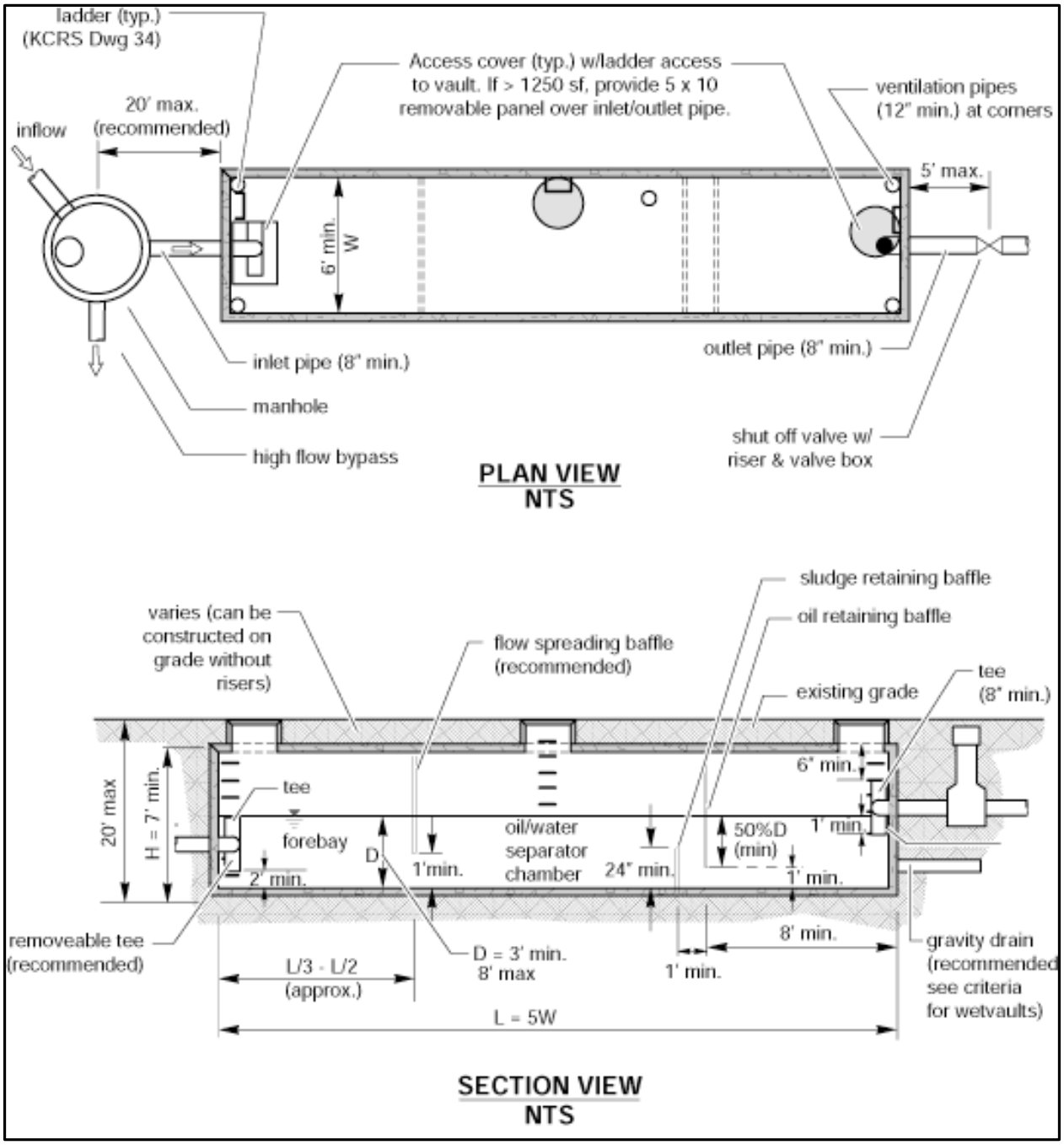


Figure 5.25. Typical API (Baffle Type) Separator.

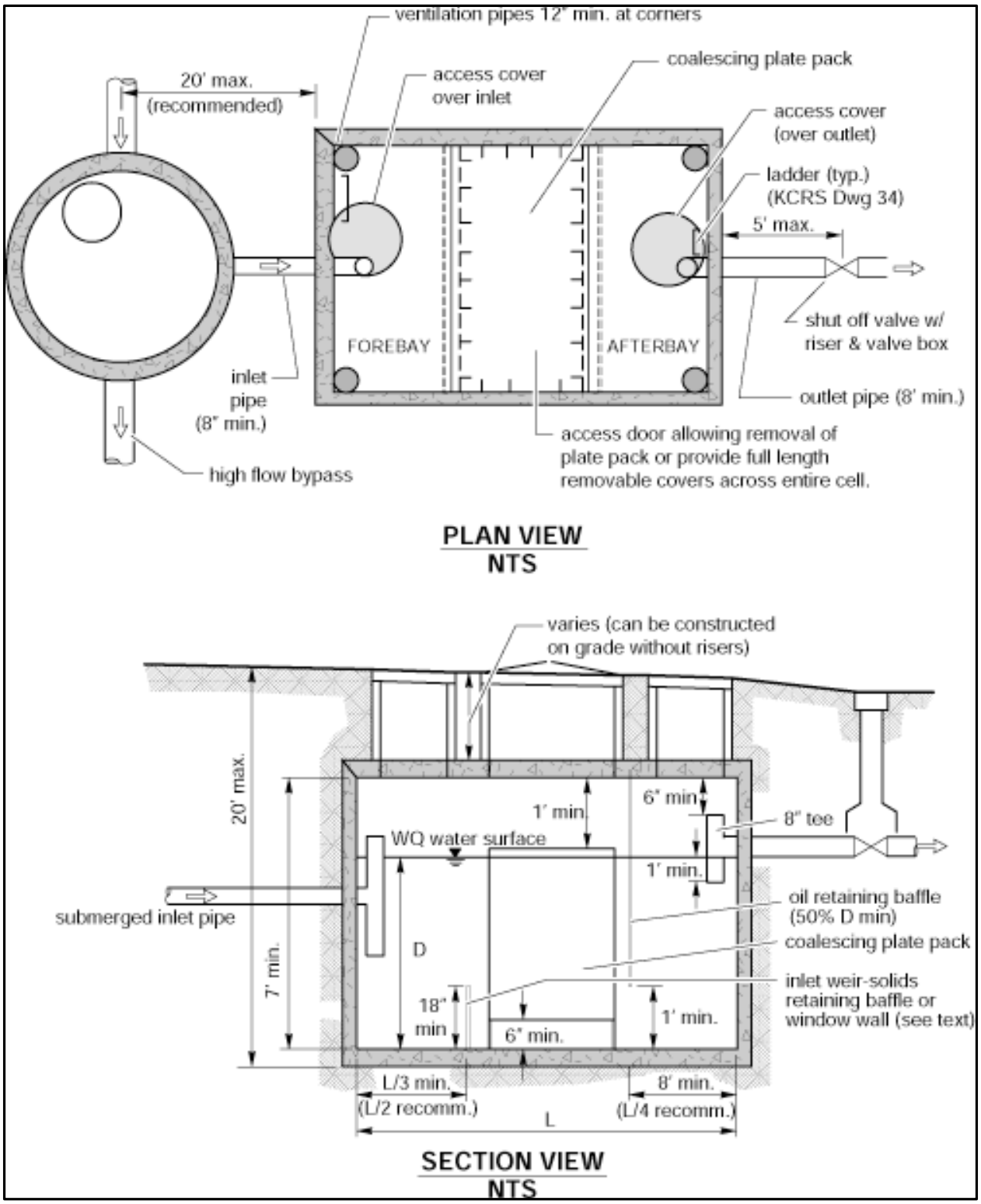


Figure 5.26. Typical Coalescing Plate Separator.

Baffles

The following criteria apply specifically to API separator bay vaults:

- A removable flow-spreading baffle, extending from the surface to a depth of up to half of the vault depth (D) is recommended to spread flows. Design guidelines for level spreaders are provided in *Appendix E*.
- A removable oil retaining baffle must be provided and located approximately one-quarter of the distance from the outlet wall or a minimum of 8 feet, whichever is greater (the 8-foot minimum is for maintenance purposes). The oil-retaining baffle must extend from the elevation of the water surface to a depth of at least 50 percent of the design water depth and at least 1 foot from the separator bottom. Various configurations are possible, but the baffle must be designed to minimize turbulence and entrainment of sediment.
- The removable bottom baffle (sediment-retaining baffle) must be a minimum of 24 inches, and located at least 1 foot from the oil-retaining baffle. A "window wall" baffle may be used, but the area of the window opening must be at least three times greater than the area of the inflow pipe.
- Baffles may be fixed rather than removable if additional entry ports and ladders are provided so that both sides of the baffle are accessible by maintenance crews.
- Baffle height to water depth ratios should be 0.85 for top baffles and 0.15 for bottom baffles.

The following criteria apply specifically to CP separators:

- An oil-retaining baffle must be provided. For large units, a baffle position of one-quarter of the distance from the outlet wall is recommended. The oil-retaining baffle must extend from the water surface to a depth of at least 50 percent of the design water depth and at least 1 foot from the separator bottom. Various configurations are possible, but the baffle must be designed to minimize turbulence and entrainment of sediment.
- A bottom sediment-retaining baffle must be provided upstream of the plate pack. The minimum height of the sludge-retaining baffle must be 18 inches. Window walls may be used, but the window opening must be a minimum of three times greater than the area of the inflow pipe.

Separator Plates

The following criteria apply specifically to CP separator plates:

- Plates must be inclined at 45 to 60 degrees from the horizontal. This range of angles exceeds the angle of repose of many solids, and therefore, provides more effective droplet separation while minimizing the accumulation of solids on the individual plates.
- Plates must have a minimum spacing of 0.5-inch and have corrugations.

- Plates must be securely bundled in a plate pack for ease of removal and cleaning (with high-pressure rinse or equivalent).
- The plate pack must be a minimum of 6 inches from the vault bottom for sediment storage.
- There should be 1 foot of head space between the top of the plate pack and the bottom of the vault cover.

Material Requirements

The following guidelines apply when selecting oil/water separator materials:

- Vault baffles must be concrete, stainless steel, fiberglass reinforced plastic, or another acceptable material, and must be securely fastened to the vault.
- Gate valves, if used, must be designed for seating and unseating heads appropriate for the design conditions.

The following criteria applies specifically to CP separators:

- Plate packs must be made of fiberglass, stainless steel, or polypropylene, unless otherwise recommended by the manufacturer and approved by the Director.
- The entire space between the sides of the plate pack and the vault wall must be filled with a solid but light-weight removable material such as a plastic or polyethylene foam to reduce short-circuiting around the plate pack. Rubber flaps are not effective for this purpose.

Inlet and Outlet

The following inlet and outlet criteria apply to both types of oil/water separators:

- The separator inlet must be submerged. A tee section may be used to submerge the incoming flow and must be at least 2 feet from the bottom of the tank and extend above the water quality design water surface.

  The submerged inlet is to dissipate energy of the incoming flow. The distance from the bottom is to minimize resuspension of settled sediments. Extending the tee to the surface allows air to escape the flow, thus, reducing turbulence. Alternative inlet designs that accomplish these objectives are acceptable.

- The vault outlet pipe must be sized to pass the water quality design flow before overflow. The vault outlet pipe must be back-sloped or have a tee extending 1 foot above and below the water quality design water surface to provide for secondary trapping of oils and floatables in the wet vault. Note: The invert of the outlet pipe sets the water quality design water surface elevation.

Access Requirements

Access requirements are the same as for wet vaults (*Section 5.8.7.5*).

The following access requirements also apply for CP separators:

- Access to the compartment containing the plate pack must be a removable panel or other access able to be opened wide enough to remove the entire coalescing plate bundle from the cell for cleaning or replacement. Doors or panels must have stainless steel lifting eyes, and panels must weigh no more than 5 tons per panel.
- A parking area or access pad (25-foot by 15-foot minimum) must be provided near the coalescing plate bundles to allow for their removal from the vault by a truck-mounted crane or backhoe, and to allow for extracting accumulated solids and oils from the vault using a vactor truck.

5.8.10.6. BMP Sizing

For off-line separators, the high flow bypass must be designed so that all flows up to and including the water quality design flow rate are directed to the separator. Design guidelines for flow splitters are provided in *Appendix E*. The water quality design flow rate is calculated by multiplying the design flow rate determined using an approved continuous simulation model by the off-line ratio of 3.0. For on-line separators, the water quality design flow rate is calculated by multiplying the flow rate determined using an approved continuous simulation model by the on-line ratio of 1.65. Separators must be designed as off-line facilities wherever possible.

The API and CP sizing method is based on the horizontal velocity of the bulk fluid (Vh), the oil rise rate (Vt), the residence time (tm), width, depth, and length considerations as follows:

1. Determine the oil rise rate, Vt, in cm/sec, using Stokes' Law (Water Pollution Control Federation 1985) or empirical determination. Stokes Law assumes that flow is laminar and that oil droplets are spherical shaped. Stokes Law equation for rise rate, Vt (ft/min):

$$Vt = 1.97g(\sigma_w - \sigma_o)D^2 / 18\eta_w)$$

Where:

1.97	=	conversion factor (cm/sec to ft/min)
g	=	gravitational constant (981 cm/sec^2)
D	=	diameter of the oil particle (cm)
σ_w	=	water density in grams per cubic centimeter (gm/cc) at 32°F
σ_o	=	oil density
η_w	=	dynamic viscosity of water (gm/cm-sec) at water temperature of 32°F, (Refer to American Petroleum Institute 1990)

Use:

g	=	981 cm/sec^2
D	=	60 microns (0.006 cm)
σw	=	0.999 gm/cc at 32°F

σo = Select conservatively high oil density. For example, if diesel oil @ σo=0.85 gm/cc and motor oil @ σo = 0.90 gm/cc can be present then use σo=0.90 gm/cc
ηw = 0.017921 gm/cm-sec

2. Determine Q:

   Q = the 15-minute Water Quality design flow rate in ft^3/min multiplied by the off-line facility ratio of 3.0. Note that some continuous hydrologic models give the water quality design flow rate in ft^3/sec. Multiply this flow rate by 60 to obtain the flow rate in ft^3/min.

3. Calculate horizontal velocity of the bulk fluid, Vh (in ft/min) and water depth in separator (d) in feet.

   $V_h = 15Vt$
   $d = (Q/2V_h)^{1/2}$

   Note: Separator water depth (d) must be: $3 \leq d \leq 8$ feet to minimize turbulence (American Petroleum Institute 1990; US Army Corps of Engineers 1994). If the calculated depth is less than 3 feet, an API separator is not appropriate for the site. If the calculated depth exceeds 8 feet, consider using two separators.

4. Calculate the minimum residence time (tm), in minutes, of the separator at depth d:

   $t_m = d/V_t$

5. Calculate the minimum length of the separator section, l(s):

   $l(s) = FQt_m/wd = F(V_h/V_t)d$

   Where:

   F = 1.65
   Use depth/width (d/w) ratio of 0.5 (American Petroleum Institute 1990)

   For other dimensions, including the length of the forebay, the length of the afterbay, and the overall length, L; refer to Figure 5.26.

6. Calculate V = l(s)wd = FQtm, and Ah = wl(s)

   V = minimum hydraulic design volume, in cubic feet
   A_h = minimum horizontal area of the separator, in square feet.

CP separators follow the same sizing method as API separators. Calculate the projected (horizontal) surface area of plates needed using the following equation:

$$A_p = Q/V_t = Q/0.00386(\sigma_w - \sigma_o/\eta_w)$$

$$A_p = A_a(\text{cosine } b)$$

Where:

A_p = projected surface area of the plate in ft^2; .00386 is unit conversion constant

Q = the on-line (1.65) or off-line (3.0) adjustment factor x the 15-minute water quality design flow rate, ft^3/min

V_t = Rise rate of 0.033 ft/min, or empirical determination, or Stokes Law based

σ_w = density of water at 32°F

σ_o = density of oil at 32°F

A_a = actual plate area in ft^2 (one side only)

b = angle of the plates with the horizontal in degrees (usually varies from 45 to 60 degrees)

ηw = viscosity of water at 32°F.

5.8.10.7. Minimum Construction Requirements

The following are construction requirements associated with the construction of an oil/water separator:

- Follow the manufacturer's recommended construction procedures and installation instructions, as well as any applicable City requirements.
- Where flooding or high groundwater presents a risk of vault floatation, properly anchor the vault in accordance with the manufacturer's or the design engineer's recommendations.
- Upon completion of installation, thoroughly clean and flush the oil/water separator prior to operation.
- Specify appropriate performance tests after installation and shakedown, and/or provide certification by a licensed engineer that the separator is functioning in accordance with design objectives.

5.8.10.8. Operations and Maintenance Requirements

Oil/water separator O&M requirements are provided in *Appendix G (BMP No. 18 and 19)*.

5.8.11. Proprietary and Emerging Water Quality Treatment Technologies

This section describes how the City will evaluate the use of proprietary and emerging stormwater treatment technologies.

5.8.11.1. Ecology's Evaluation of Emerging Technologies

To receive Ecology approval for use in stormwater applications in Washington, new technologies must be evaluated following Ecology's technology assessment protocols (TAPE and CTAPE), which establish guidelines for evaluating the performance of stormwater technologies. The evaluation process requires manufacturers to field test the performance of new stormwater treatment technologies. After the successful completion of field testing, the vendor submits a technology evaluation report (TER) to Ecology for review and approval. Information about Ecology's evaluation process can be found at the following website (http://ecy.wa.gov/programs/wq/stormwater/newtech/index.html).

Under the technology assessment process, Ecology assigns "Use Level Designations" to emerging technologies based on the results of the TAPE and CTAPE evaluation. These designations are described below:

- **GULD – General Use Level Designation** – A General Use Level Designation (GULD) is assigned to technologies for which the performance monitoring demonstrates with a sufficient degree of confidence, that the technology is expected to achieve Ecology's performance goals. Use is subject to conditions documented in a use level designation letter prepared by Ecology.
- **CULD – Conditional Use Level Designation** – A Conditional Use Level Designation (CULD) is assigned to technologies that have considerable performance data not collected per the TAPE protocol. Ecology will allow the use of technologies that receive a CULD for a specified time, during which performance monitoring must be conducted and a TER submitted to Ecology. Units that are in place do not have to be removed after the specified time period. Use is subject to conditions documented in a use level designation letter prepared by Ecology.
- **PULD – Pilot Use Level Designation** – A Pilot Use Level Designation (PULD) is assigned to new technologies that have limited performance monitoring data or that only have laboratory performance data. The PULD allows limited use of the technology to allow performance monitoring to be conducted. PULD technologies may be installed provided that the vendor and/or developer agree to conduct performance monitoring per the TAPE protocol at all installations. Use is subject to conditions documented in a use level designation letter prepared by Ecology.

5.8.11.2. Applicability and Restrictions

The City will rely on the results of Ecology's technology assessment process to identify technologies that can be used on new and redevelopment projects in Seattle. The Director will accept technologies approved by Ecology as described below:

- GULD technologies for use on parcels will be accepted subject to the conditions of use established by in the use level designation letter prepared by Ecology. Use in the right-of-way is subject to approval by SPU and early consultation is encouraged. Not all GULD approved BMPs will be acceptable.
- CULD technologies will be accepted provided that the project owner signs a maintenance agreement with the City stating that the owner will maintain the technology in accordance with manufacturer's and/or Ecology's guidelines at all times, and that the owner will modify/upgrade the system in accordance with any conditions that Ecology may require as part of the final GULD designation following performance monitoring. The owner must also file annual reports as outlined by the City.
- PULD technologies will be accepted on a limited basis to enable manufacturers to obtain data to help fulfill the requirements of the TAPE protocol. These projects must be approved in advance by the Director of SPU, have an approved monitoring plan reviewed by the Board of External Reviewers (BER) and Ecology, and provide a financial bond to provide clean-up and replacement in the event of failure.

Proprietary filtration BMPs must be sized per the manufacturer's approved methodology or mass loading methodology, whichever is most stringent. SPU approval is required for use of any proprietary BMP in the right-of-way. Early consultation is advised.

The use of leaf compost in media filtration systems is not permitted when the drainage water is discharged to within 1/4 mile of a nutrient-critical receiving water.

5.8.11.3. Technologies with General Use Level Designations

The following technologies have received GULD approval from Ecology at the time of publication and is provided as a reference. This list is subject to change. Refer to Ecology's website for a list of approved stormwater technologies and technologies currently under review (http://www.ecy.wa.gov/programs/WQ/stormwater/newtech/technologies.html).

BMP	On-site		Flow Control			Water Quality				Conveyance
	List	Standard	Forest	Pasture	Peak	Basic	Enhanced	Oil Control	Phosphorus	
Bay Filter						✓				
ecoStorm plus						✓				
Filterra						✓	✓	✓	✓	
FloGard Perk Filter						✓			✓	
Media Filtration System						✓				
StormFilter (ZPG Media)						✓				

5.8.11.4. Operations and Maintenance Requirements

Refer to Ecology's website and the manufacturer's website for facility-specific maintenance requirements (http://www.ecy.wa.gov/programs/WQ/stormwater/newtech/technologies.html).

O&M requirements for cartridge type filtration systems (example: StormFilter) and bioretention planters for water quality treatment (example: Filterra) are included in *Appendix G (BMP No. 17 and 21)*.

CHAPTER 6 – REFERENCES

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