City of Tumwater
Drainage Design and Erosion Control Manual

Volume V -
Stormwater BMPs

Revised July 2022

Prepared for
City of Tumwater

Table of Contents

Tables

Figures

Chapter 1 – Introduction

1.1 What Is the Purpose of this Volume?

Best management practices (BMPs) are schedules of activities, prohibitions of practices, maintenance procedures, managerial practices, or structural features that prevent or reduce adverse impacts to waters of Washington State. As described in Volume I of this manual, BMPs for long-term management of stormwater at developed sites can be divided into three main categories:

- BMPs addressing the volume and timing of stormwater flows
- BMPs addressing prevention of pollution from potential sources
- BMPs addressing treatment of runoff to remove sediment and other pollutants.

This volume of the manual focuses on the first and third categories. It details the approved methods and requirements for runoff control and flow control treatment to prevent impacts to downstream properties or natural resources to the maximum extent practical. The City of Tumwater recognizes that it is not always possible to fully prevent any impacts downstream; in these extreme cases, the project applicant may be required to provide off-site mitigation as determined by the Administrator.

The manual presents BMPs with respect to controlling stormwater flows and control of pollutant sources in Volumes III and IV, respectively.

1.2 Content and Organization of this Volume

Volume V of the stormwater design manual contains 29 chapters and 9 appendices.

- Chapter 1 serves as an introduction and summarizes available options for flow control and treatment of stormwater.
- Chapter 2 outlines a step-by-step process for selecting and designing infiltration facilities.
- Chapter 3 presents low impact development (LID) site design BMPs.
- Chapter 4 discusses general requirements for pretreatment facilities.
- Chapters 5 through 27 provide detailed information regarding specific BMPs.
- Chapter 28 discusses special considerations for emerging technologies for stormwater treatment.
- Appendix A provides methods for determining design infiltration rates.

- Appendix B summarizes on-site stormwater management BMP infeasibility criteria that can be used to justify not using various on-site stormwater management BMPs for consideration in the List #1 or List #2 option of Minimum Requirement #5 in Volume I.

- Appendix C provides geotextile specifications for stormwater facilities.

- Appendix D provides specifications for control structures, bypass structures and diversion structures.

- Appendix E discusses facility liners.

- Appendix F provides additional guidance on planning and landscaping.

1.3 How To Use this Volume

The reader should consult this volume for design requirements for runoff treatment and flow control BMPs. See Volume I for project minimum requirements, BMP selection requirements, and Stormwater Site Plan requirements. After you have identified the minimum requirements and appropriate BMPs from Volume I, you can use this volume to identify site assessment requirements and to guide design and construction of those facilities. See Volume III for general hydrologic analysis requirements.

1.4 Additional References

These regulations and criteria are based on fundamental principles of drainage; hydraulics; hydrology; environmental considerations; and publications, manuals, and texts accepted by the professional engineering community. The engineer is responsible for being knowledgeable and proficient with the necessary design methodologies identified within the manual. A partial listing of publications, which may be useful as reference documents, follows:

- Washington State Department of Ecology (Ecology) 2019 Stormwater Management Manual for Western Washington or any Ecology-approved stormwater management manual

- *Low Impact Development: Technical Guidance Manual for Puget Sound* by Washington State University Extension and Puget Sound Partnership WSU and PSP 2012)

- *Applied Handbook of Hydrology*, Second Edition (Singh 2016)

- *Handbook of Hydraulics* (Brater and King 1996)

- The following references published by the Washington State Department of Transportation (WSDOT):

  - Hydraulics Manual
  - Highway Runoff Manual
  - *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT Standard Specifications)
  - Standard Plans

- *Soil Survey of Thurston County, Washington* published by the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS 1990). (Also refer to the Natural Resources Conservation Service [NRCS] Web Soil Survey at <http://websoilsurvey.sc.egov.usda.gov>).
- City of Tumwater *Development Guide*, most recent amendment
- Other information sources acceptable to the city and based on general use by the professional engineering community.

The most current edition of all publications shall be used.

Chapter 2 – Infiltration Facilities

Unless otherwise specified within a specific subsection, **the information outlined in Chapter 2 applies to infiltration basins, trenches, and galleries**. Information and procedures specific to other infiltration facilities (e.g., bioretention areas, permeable pavement surfaces, rain gardens, and downspout infiltration systems) are included in Chapters 6 through 17.

2.1 Purpose

The purpose of this section is to describe the steps required to evaluate the suitability of a site for infiltration facilities, establish a design infiltration rate, and design facilities for infiltration.

Infiltration is the percolation of surface water into the ground. While other flow control facilities, such as detention ponds, reduce peak flow rates associated with developed areas, infiltration facilities also reduce surface water runoff volumes. When properly sited and designed, infiltration facilities can help to decrease runoff, recharge groundwater, and protect downstream receiving waters.

Infiltration for water quality treatment is permitted within the City of Tumwater. However, the requirements for infiltration for water quality treatment are substantially different from those for flow control and are outlined in Chapter 23. To be used for runoff treatment, soils must include sufficient organic content and sorption capacity to remove pollutants. Examples of suitable soils are silty and sandy loams. Coarser soils, such as gravelly sands, can provide flow control but are not suitable for providing runoff treatment. The use of coarser soils to provide flow control for runoff from pollution generating surfaces must be preceded by water quality treatment to protect groundwater quality (see Chapters 23 through 28). Thus, there will be instances when soils are suitable for treatment but not flow control, and vice versa.

Also note that although infiltration is one of the preferred methods for disposing of excess stormwater, infiltration is regulated by Ecology and the underground injection control (UIC) program (WAC 173-218). Additional information and requirements on UIC and how it applies to infiltration and stormwater management is included in Chapter 5.

This section also highlights design criteria that are applicable to infiltration facilities serving a treatment function.

2.2 Procedures

The following procedures must be followed when considering and designing an infiltration basin or trench. Each step is outlined in more detail in the subsequent sections. All pertinent information must be reported in the Soils Report portion of the Drainage Control Plan (see Volume I, Section 3.3.3).

Step 1 – Conduct general site reconnaissance, and review survey and other information to identify existing drinking water wells, wellhead protection areas, or critical aquifer recharge areas; existing and proposed buildings; steep slopes; or septic systems in the vicinity of the proposed facility.

Step 2 – Evaluate minimum requirements for infiltration facilities to determine whether infiltration is feasible for the site.

Step 3 – Determine whether the simple or detailed method of analysis is required. Consultation with the City of Tumwater is required at this stage to obtain approval for the proposed method of analysis (simple or detailed).

Step 4 – Complete the simple analysis.

Step 5 – Complete detailed analysis, if necessary.

Step 6 – Construct the facility and verify performance.

2.2.1 Step 1: General Site Characterization

The first step in designing an infiltration facility is to select a location, and assess the site suitability. The information to be reviewed as part of this initial site characterization will vary from site to site, but may include:

- Topography within 500 feet of the proposed facility
- Anticipated site use (street/highway, residential, commercial, high-use site)
- Location of water supply wells within 500 feet of proposed facility
- Location of wellhead protection areas are available on the city web site or from the Administrator upon request.
- Location of steep slope, erosion hazard, or landslide hazard areas
- Location of septic systems in the vicinity of the proposed facility
- A description of local site geology, including soil or rock units likely to be encountered, the groundwater regime, and geologic history of the site.

This information, along with additional geotechnical information necessary to design the facility, shall be summarized in the Soils Report prepared under Step 4, Section 2.2.4.

2.2.2 Step 2: Minimum Requirements for Infiltration Facilities

Infiltration is not permissible unless all of the following criteria are met. Note: not all sites that meet the following criteria will be suitable for infiltration—these are ***minimum*** *requirements only:*

- **Setbacks and Site Constraints:**
  - Refer to Setbacks in Section 2.3 for setbacks that apply to all infiltration ponds/basins, trenches, and galleries. Refer to Chapters 12 through 14 for additional setbacks for these BMPs. Refer to Chapters 6 through 17 for setbacks that apply to other infiltration BMPs (i.e., bioretention areas, permeable pavement surfaces, rain gardens, and downspout infiltration systems).
  - If the depth of the infiltration facility being considered meets one of the following criteria, it is considered an injection well and is subject to the requirements of the UIC Program, Chapter 173-218 WAC **and must be registered with Ecology.** See also Chapter 5:
    - A bored, drilled or driven shaft, or dug hole whose depth is greater that the largest surface dimension
    - An improved sink hole
    - A subsurface fluid distribution system
- **Groundwater Protection Areas:** The applicant must check the wellhead protection area maps and high groundwater maps (available on the city web site or from the Administrator upon request) to determine if the project lies within a wellhead protection area, critical aquifer recharge area or regulated high ground water area. A site is not suitable if the infiltration facility will cause a violation of groundwater quality standards. At a minimum, projects proposing to infiltrate runoff from pollution generating areas must refer to the General Requirements in Volume I, Chapter 4. Those requirements can affect the design and placement of facilities on your site. In addition, all infiltration basins or trenches located within the 1-year capture zone of any drinking water well must be preceded by a water quality treatment facility (including for runoff from roofs any other non-pollution generating surfaces). Note that the setbacks referred to in the previous bullet item may also include setbacks related to groundwater resources for most infiltration facilities. The project Soils Report must be updated to demonstrate and document that the above criteria are met and to address potential impacts to water supply wells or springs.
- **Depth to Bedrock, Water Table, or Impermeable Layer:** The base of all infiltration basins, trenches, or galleries shall be a minimum of 6 feet above seasonal high groundwater levels, bedrock (or hardpan), or other low permeability layer or known high ground water levels in regulated high ground water areas. A separation down to 3 feet may be considered if the groundwater mounding analysis, volumetric receptor capacity, and the design of the overflow and/or bypass structures are judged by the site professional to be adequate to prevent overtopping and meet criteria specified in this section. Infiltration basins may not be constructed within a floodplain area. Refer to Chapters 9, 10, and 11 for depth

to known or seasonal high groundwater levels, bedrock (or hardpan), or other low permeability layers that apply to other infiltration BMPs (i.e., bioretention areas, permeable pavement surfaces, rain gardens, and downspout infiltration systems).

- The maximum depth of an infiltration facility is 20 feet below the surrounding finished (developed) ground elevation, in order to provide for long-term maintenance access to the facility.

2.2.3 Step 3: Determine Method of Analysis

The City of Tumwater encourages consideration of infiltration facilities for sites where conditions are appropriate. However, some sites may not be appropriate for infiltration due to soil characteristics, groundwater levels, steep slopes, or other constraints. All proposed infiltration basins, trenches, and galleries are required, at a minimum, to perform the simple analyses specified below. For those sites that present a risk of infiltration system failure, a more detailed method of analysis is required in addition to the simple analysis.

The sections below outline the criteria to be considered when determining whether a project is subject to the simplified or the detailed method of analysis. The chosen method of analysis must be submitted for approval by the city. Moreover, the city may require that the detailed method of analysis be conducted based on the results of the simple method. (See Chapter 9, Bioretention Cells, Swales, and Planter Boxes; and Chapter 10, Rain Gardens; for methods specific to bioretention and rain gardens. See Chapter 11, Permeable Paving, for methods specific to permeable pavement.)

Simple Method (Detailed in Step 4 Below)

Projects considering using the simplified method generally will have the following characteristics:

- Small facilities serving short plats or commercial developments with less than 1 acre of contributing area
- High infiltration capacity soils (NRCS [SCS] soil Types A or B)
- Evidence of other infiltration facilities performing successfully at nearby locations
- No septic systems, steep slopes, or other sensitive features within 500 feet
- Low risk of flooding and property damage in the event of clogging or other failure of the infiltration system.

Detailed Method (Detailed in Step 4 and 5 Below)

Where there is not clear evidence that a site is well-suited to infiltration, a more detailed method of analysis will be required. The detailed method of analysis, described below, includes more intensive field testing and soils investigation and analyses than the simplified method. Site conditions that will likely require use of the detailed method may include:

- Low infiltration capacity soils (NRCS [SCS] soil Types C or D)
- History of unsuccessful infiltration facility performance, or no history of successful infiltration performance at nearby locations
- A large contributing drainage area
- High groundwater levels
- High risk of flooding in the event of clogging or other failure.

2.2.4 Step 4: Simple Analysis

The following analyses are required for all proposed infiltration basins, trenches, and galleries. Refer to Chapters 7, 9, 10 and 11 for infiltration testing procedures that apply to other infiltration BMPs (i.e., bioretention areas, permeable pavement surfaces, rain gardens, and downspout infiltration systems).

Conduct Soils Testing

- Test hole or test pit explorations shall be conducted during mid to late in the winter season (December 1 through April 30) to provide accurate groundwater saturation and groundwater information.
- **Continuous sampling:** Collect representative samples from each soil type and/or unit to a depth below the base of the infiltration facility of 2.5 times the maximum design ponded water depth, but not less than 10 feet.
- If proposing to estimate the infiltration rate using the soil grain size analysis method, obtain samples adequate for the purposes of that gradation/classification testing.
- For infiltration basins and galleries, there shall be one test pit or test hole per 5,000 square feet of facility infiltrating surface with a minimum of two per facility, regardless of facility size.
- For infiltration trenches, there shall be one test pit or test hole per 200 feet of trench length with a minimum of two required per trench, regardless of length.
- Prepare detailed logs for each test pit or test hole and a map showing the location of the test pits or test holes. Logs must include the depth, soil descriptions, depth to water, evidence of seasonal high groundwater elevation, existing ground

surface elevation, proposed facility bottom elevation, and presence of stratification that may impact the infiltration design.

If using the soil grain size analysis method for estimating infiltration rates, include laboratory testing as necessary to establish the soil gradation characteristics and other properties to complete the infiltration facility design. At a minimum, conduct one grain size analysis per soil stratum in each test hole to a depth of 10 feet below the proposed base of the infiltration facility. When assessing the hydraulic conductivity characteristics of the site, soil layers at greater depths must be considered if the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, requiring soil gradation/classification testing for layers deeper than indicated above.

- Determine design infiltration rate as described in detail in Appendix V-A. Note that the maximum allowable design infiltration rate is 20 inches per hour.

Prepare Soils Report

A report must be prepared that is stamped by a professional engineer with geotechnical expertise, a licensed geologist, a hydrogeologist, or an engineering geologist registered in the State of Washington that summarizes site characteristics and demonstrates that sufficient permeable soil for infiltration exists at the proposed facility location. Refer to Volume I, Section 3.3.3, for Drainage Control Plan Soils Report content requirements.

Estimate Volume of Stormwater

Use the Western Washington Hydrology Model (WWHM) or other approved continuous runoff model to generate an influent file that will be used to size the infiltration facility. The facility must infiltrate either all of the flow volume as specified by the influent file or a sufficient amount of the flow volume such that any overflow/bypass meets the flow duration standard in Minimum Requirement #7. In addition, the overflow/bypass must meet the LID Performance Standard if it is the option chosen to meet Minimum Requirement #5, or if it is required of the project. Also, if the facility is used for both flow control and water quality, the infiltration volume must meet the water quality requirements described in Volume I and Volume III.

2.2.5 Step 5: Detailed Analysis

In addition to the simple method requirements outlined above, projects subject to the detailed analysis method shall include infiltration receptor characterization, as outlined below.

Infiltration Receptor Characterization

Monitor Groundwater Levels

- A minimum of three groundwater monitoring wells shall be installed per infiltration facility that will establish a three-dimensional relationship for the groundwater table, unless the highest groundwater level is known to be at least 50 feet below the proposed base of the infiltration facility.

- Seasonal groundwater levels must be monitored at the site during at least one winter season (December 1 through April 30).
- Normalize the single winter season observation to historical groundwater records in the region.

Characterize Infiltration Receptors in Soils Report

Address the following:

- Depth to groundwater and to bedrock/impermeable layers.
- Seasonal variation of groundwater table based on well water levels and observed mottling of soils.
- Existing groundwater flow direction and gradient.
- 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 or known high groundwater mark, bedrock, hardpan, or other low permeability layer.
- Horizontal hydraulic conductivity of the saturated zone to assess the aquifer’s ability to laterally transport the infiltrated water.
- Approximation of the lateral extent of infiltration receptor.
- Impact of the infiltration rate and proposed added volume from the project site on local groundwater mounding, flow direction, and water table determined by hydrogeologic methods.
- The city may require a groundwater mounding analysis on projects where an infiltration facility has a drainage area exceeding 1 acre and has less than 10-foot depth to seasonal high groundwater (as measured from the bottom of the infiltration basin or trench) or other low permeability stratum. Groundwater mounding analysis methods are subject to city approval, and may include an analytical groundwater model (such as MODRET) to investigate the effects of the local hydrologic conditions on facility performance.
- State whether location is suitable for infiltration and recommend a design infiltration rate. Note that the maximum allowable design infiltration rate is 20 inches per hour.

2.2.6 Step 6: Construct the Facility and Conduct Performance Testing (Verification of Performance)

The project engineer or designee shall inspect infiltration basins, trenches, and galleries before, during, and after construction as necessary to ensure facilities are built to design specifications, that proper procedures are employed in construction, that the infiltration surface is not compacted, and that protection from sedimentation is in place. Before release of the maintenance bond, the project engineer shall perform a minimum of two performance tests after construction to determine that the facility will operate as designed. For trenches and galleries, the type of performance test will depend on specific facility and site constraints, and therefore shall be determined by the project engineer on a case-by-case basis, and must be submitted for approval by the city prior to testing. For infiltration basins, the project engineer shall perform a sufficient number of modified falling-head percolation tests (a minimum of two). The city must be notified of the scheduled infiltration testing at least 2 working days in advance of the test. See Appendix V-A for infiltration testing requirements. If the tests indicate the facility will not function as designed, this information must be brought to the immediate attention of the city along with any reasons as to why not and how it can be remedied.

In addition, before release of the maintenance bond, the completed facility must be monitored through a minimum of one winter season, December 1 to April 30, to demonstrate that the facility performs as designed. The monitoring must occur after permanent erosion control and site stabilization measures have been installed. If tests indicate that the facility will not function as designed (as per the Maintenance and Source Control Manual developed for the project), this information must be brought to the immediate attention of the city along with reasons and potential remedies.

2.3 General Criteria for Infiltration Basins, Trenches, and Galleries

This section covers design, construction, and maintenance criteria that apply to infiltration basins, trenches, and galleries. Similar information for other infiltration BMPs (i.e., bioretention areas, permeable pavement surfaces, rain gardens, and downspout infiltration systems) is included under the detailed BMP descriptions within the individual BMPs in Chapters 6 through 17.

Design Criteria – Sizing Facilities

- The size of infiltration basins, trenches, and galleries can be determined by routing the influent runoff file generated by the continuous runoff model through the facility. In general, an infiltration facility would have two discharge modes. The primary mode of discharge from an infiltration facility is infiltration into the ground. However, when the infiltration capacity of the facility is reached, additional runoff to the facility will cause the facility to overflow. Overflows from an infiltration basin, trench, or gallery must comply with the Minimum Requirement #7 for flow control.

- Infiltration facilities used for runoff treatment must not overflow more than 9 percent of the influent runoff file.

- In order to determine compliance with the flow control requirements, WWHM or an appropriately calibrated continuous simulation runoff model based on HSPF must be used. When using WWHM for simulating flow through an infiltrating facility, the facility is represented by using a pond element and entering the predetermined infiltration rates. Below are the procedures for sizing a basin to completely infiltrate 100 percent of runoff.

For 100 Percent Infiltration:

- Input dimensions of your infiltration facility.

- Input infiltration rate and safety (rate reduction) factor. See Appendix V-A for methods for determining infiltration rates.

- Input a riser height and diameter (any flow through the riser indicates that you have less than 100 percent infiltration and must increase your infiltration facility dimensions).

- Run the continuous simulation for the developed mitigated scenario. (You do not need to evaluate runoff durations for the 100 percent infiltration evaluation.)

- Go back to your infiltration facility and look at the percentage infiltrated at the bottom right. If less than 100 percent infiltrated, increase facility dimension until you get 100 percent.

Pretreatment

A facility to remove a portion of the influent suspended solids must precede infiltration basins, trenches, and galleries (unless the facility is **only** managing runoff from rooftop areas). Use either an option under the basic treatment facility menu (see Volume I, Section 4.3.6), or a pretreatment option from Chapter 4. The lower the influent suspended solids loading to the infiltration facility, the longer the infiltration facility can infiltrate the desired amount of water or more, and the longer interval between maintenance activities.

Reduction in infiltration capability can have significant maintenance or replacement costs in infiltration basins, trenches, and galleries; therefore, selection of a reliable treatment device with high solids removal capability is preferred. In facilities that allow easier access for maintenance and less costly maintenance activity (e.g., infiltration basins with gentle side slopes), there is a trade-off between using a treatment device with a higher solids removal capability and a device with a lower capability. Generally, treatment options on the basic treatment menu are more capable at solids removal than pretreatment devices listed in Volume I, Section 4.3.6. Though basic treatment options may be higher in initial cost and space demands, the infiltration facility should have lower maintenance costs over time. Note that, if designed as a pretreatment facility and a water quality treatment facility (in compliance with Minimum Requirement #6), the pretreatment facility must be designed to treat runoff from the water quality design storm event, but must also safely convey or bypass the developed 100-year recurrence interval peak flow.

Spill Control Device

In addition to requirements for pretreatment, all infiltration basins, trenches, and galleries must have a spill control device upstream of the facility to capture oil or other floatable contaminants before they enter the infiltration facility. If a "tee" section is used for spill control, the top of the spill control riser must be set above the facility's 100-year overflow elevation to prevent oils from entering the infiltration facility.

100-Year Overflow Conveyance

An overflow route must be identified for stormwater flows that overtop the infiltration facility when infiltration capacity is exceeded or the facility becomes plugged and fails. The overflow route must be able to convey the 100-year recurrence interval developed peak flow to the downstream conveyance system or other acceptable discharge point without posing a health or safety risk or causing property damage.

Access Road

Access roads are needed to the control structure, and at least one access point per cell, and they may be designed and constructed as specified for detention ponds in Chapter 18.

Setbacks

All infiltration basins, trenches, and galleries shall maintain minimum setback distances listed below. All setbacks shall be horizontal unless otherwise specified or modified with written approval by the Thurston County Public Health and Social Services Department for wells and septic systems. To request a variance from setbacks not related to wells and septic systems, the project proponent may submit a request to the Administrator documenting the impracticality or infeasibility of the setback, which may require written recommendations from a geotechnical engineer.

- 1 foot positive vertical clearance from any open water maximum surface elevation to structures, crawl spaces, or below grade basement areas within 25 feet. 5 feet from septic tank, holding tank, containment vessel, pump chamber, and distribution box.

- 20 feet from open water maximum surface elevation or edge of infiltration facility to property lines and on-site structures.

- 10 feet from open water maximum surface elevation or edge of infiltration facility to building sewer.

- 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high. A geotechnical assessment and Soils Report must be prepared to address the potential impact of the facility on the steep slopes, erosion hazard, or landslide hazard areas. See also Title 16.20.045 TMC. The Soils Report may recommend a reduced setback, but in no case shall the setback be less than the vertical height of the slope.

- 300 feet from an erosion hazard or landslide hazard area (as defined by Title 16.20.045 TMC) unless a geotechnical professional has analyzed and mitigated the slope stability impacts of such systems, and appropriate analysis indicates that the impacts are negligible.

- 100 feet from drinking water wells and springs used for public drinking water supplies.

- Infiltration basins, trenches, and galleries with a maximum design flow less than 0.5 cubic feet per second must be at least 30 feet upgradient, or 10 feet downgradient, of the drainfield primary and reserve areas (per WAC 246-272A-0210). Infiltration basins, trenches, and galleries with a maximum design flow of 0.5 cubic feet per second or greater must be at least 100 feet from of the drainfield primary and reserve areas.

- 50 feet horizontal clearance from septic tanks, holding tanks, containment vessels, pump chambers, or distribution boxes.

- 100 feet horizontal clearance from building foundation or basement, where infiltration facilities are located upgradient from building. The project engineer shall perform calculations to ensure that the line of saturation, measured from the design storm elevation in the facility, at a gradient acceptable to the Administrator, falls a minimum of 1 foot below the lowest floor elevation. Setbacks shall be increased as necessary to allow for saturation effects.

- 20 feet horizontal clearance from building foundation or basement, where infiltration facilities are located downgradient from building. The project engineer shall perform calculations to ensure that the line of saturation, measured from the design storm elevation in the facility, at a gradient acceptable to the Administrator, falls a minimum of 1 foot below the lowest floor elevation. Setbacks shall be increased as necessary to allow for saturation effects.

2.3.1 Construction Criteria

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. Most of the construction requirements for small-scale infiltration facilities included in Volume II, Section 3.3, apply to all infiltration facilities. Any additional BMP specific construction requirements are included in the infiltration BMP “Construction Criteria” in Chapters 6 through 17.

2.3.2 Operations and Maintenance Criteria

Adequate access for operation and maintenance must be included in the design of infiltration basins, trenches, and galleries. Provisions must be made for regular and perpetual maintenance of the infiltration facility, including replacement and/or reconstruction of the any media that are relied upon for treatment purposes. A city-approved Maintenance and Source Control Manual shall include information to ensure maintenance of the desired infiltration rate.

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

Chapter 3 – LID Site Design BMPs

3.1 Purpose

Reducing impervious areas and maximizing on-site infiltration reduces the amount of runoff generated by a project site, thereby reducing stormwater management facility costs. The following BMPs are to be implemented to the maximum extent practicable.

- Preserving Native Vegetation (Ecology BMP T5.40) and Restoring Site Vegetation
- Reduce Effective Impervious Areas
- Better Site Design (Ecology BMP T5.41)

3.2 Preserving Native Vegetation (Ecology BMP T5.40) and Restoring Site Vegetation

Native soil and vegetation preservation is the single most effective strategy to reduce stormwater impacts on site, and has the added benefit of enhancing base flow in streams and recharge of aquifers. Preserving native vegetation shall be the first priority wherever feasible. Native vegetation preservation and restoration areas shall be incorporated to the maximum extent feasible and where most effective (i.e., where there is intact native vegetation and soils and/or unconcentrated flows from developed areas).

The following sections present the strategies and practices for meeting the native vegetation preservation requirements. Per Chapter 7, it is preferable that 65 percent or more of the project site be protected for the purposes of retaining or enhancing existing forest cover and preserving wetlands and stream corridors. Additional details on flow dispersion to native vegetation areas are presented in Chapter 7, under Full Dispersion.

3.2.1 Applicability

Preserving Native Vegetation

Native vegetation preservation areas may be required for any of the following conditions:

- Areas reserved for stormwater dispersion for flow control or treatment
- Wetland or other critical area buffers required by the Tumwater Municipal Code
- Riparian areas and buffers and habitat areas
- As required by the Tumwater Municipal Code

New development often takes place on tracts of forested land. Unless sufficient care is taken and planning done, in the interval between buying the property and completing construction much of this resource is likely to be destroyed.

With vegetation preservation, the primary goal is to retain large, connected tracts of native vegetation areas, either through a cluster design or on individual lots, to maintain the natural hydrologic function and provide infiltration areas for overland flows generated in developed portions of the site. Forest and native growth areas allow rainwater to naturally percolate into the soil, recharging groundwater for summer stream flows and reducing surface water runoff that creates erosion and flooding. Conifers can retain up to roughly 50 percent of all rain that falls during a typical storm. Of this rainfall, 20 to 30 percent may never reach the ground but evaporates or is taken up by the tree.

On lots that are 1 acre or greater, preservation of 65 percent or more of the site in native vegetation will allow the use of flow dispersion techniques presented in Chapter 7, under Full Dispersion. Sites that can fully meet the requirements of full dispersion are not required to provide runoff treatment or flow control facilities (as required by Volume I, Section 2.4, Minimum Requirements #5, #6, and #7).

Restoring Site Vegetation

In situations where it is not feasible to preserve existing trees and vegetation of sufficient size and quantity to achieve the target amount of tree cover, additional tree cover shall be provided where feasible through supplemental tree and vegetation plantings. In addition, on those sites where vegetation cover does not exist due to previous removal, vegetation cover shall be reestablished to the maximum extent feasible.

3.2.2 Design Criteria

Preserving Native Vegetation

Vegetation Preservation Standards

The goals for native vegetation preservation/retention on a development site are:

- Low-density residential (0 to 4 dwelling units/acre): 50 percent of the development site
- Low-density residential (3 to 6 dwelling units/acre): 50 percent of the development site
- Moderate density (8 to 16 dwelling units/acre): maximum practical extent
- High density (minimum 12 dwelling units/acre): maximum practical extent.

At a minimum, requirements for native vegetation preservation and/or replacement as set forth in applicable sections of the Tumwater Municipal Code, including critical areas, zoning, and grading, shall be implemented.

Siting

Selection of areas for natural vegetation preservation shall be made in consultation with a landscape architect. Native vegetation and soil protection areas should be prioritized by location and type as follows.

- Large tracts of riparian areas, that connect, create, or maintain contiguous protected riparian areas
- Large tracts of critical and wildlife habitat area, that connect, create, or maintain contiguous protected areas
- Tracts that create common open space areas among or within developed sites
- Protection areas on individual lots
- Protection areas on individual lots that connect to protection areas on adjacent lots

Other minimum standards for siting include:

- The preserved area shall be situated to minimize the clearing of existing forest cover, to maximize the preservation of wetlands, and to buffer stream corridors.
- Where feasible, trees and other native vegetation shall be retained in groups of sufficient size to maintain adequate growing conditions to support natural successional patterns and develop diverse, multi-layer, canopy structure; snags; large woody debris; understory vegetation; and forest duff. Growing conditions include slope, aspect, soil structure and moisture, sun exposure, humidity, wind, co-dependence on or competition among adjacent plants as well as other microclimatic factors.
- The preserved area shall be shown on all property maps and shall be clearly marked during clearing and construction on the site.
- Maximize the amount of preserved area that can be located downslope from the building sites to optimize the use of full dispersion.
- For trees that are adjacent to existing or proposed structures or other impervious surfaces, it is important to also review Chapter 8, Tree Retention and Tree Planting, to identify possible flow control credits that may be achieved through targeted tree retention.

Restoring Site Vegetation

Vegetation Restoration Standards

The following standards shall be used.

- Vegetation restoration and planting methods shall conform to published standards.
- The applicant shall comply with the provisions for tree protection and replacement as set forth in Title 16.08.050 TMC.
- Trees selected for replacement purposes must be free from injury, pests, diseases, and nutritional disorders. Trees must be fully branched and have a healthy root system.
- Coniferous and broad leaf evergreen trees shall be no less than 4 feet in height at time of planting. Deciduous trees shall be a minimum of 8 feet in height or have a minimum caliper size of 1.5 inch at time of planting.

Construction and Operation

Conversion of a developed surface to native vegetation landscape can require the removal of impervious surface and ornamental landscaping; de-compaction of soils; and/or the planting of native trees, shrubs, and ground cover in compost-amended soil according to all of the following specifications.

1. Existing impervious surface and any underlying base course (e.g., crushed rock, gravel) must be completely removed from the conversion area(s).
2. Underlying soils must be broken up to a depth of 18 inches. This can be accomplished by excavation or ripping with either a backhoe equipped with a bucket with teeth, or a ripper towed behind a tractor.
3. At least 4 inches of well-decomposed compost must be tilled into the broken-up soil as deeply as possible. The finished surface should be gently undulating and must be only lightly compacted.
4. At least 4 inches of hog fuel or other suitable mulch must be placed between plants as mulch for weed control. It is also possible to mulch the entire area before planting; however, an 18-inch-diameter circle must be cleared for each plant when it is planted in the underlying amended soil. *Note: plants and their root systems that come in contact with hog fuel or raw bark have a poor chance of survival*.
5. The area of native vegetated landscape must be planted with native species trees, shrubs, and ground cover. Developments shall use native trees for replacement in areas separate from residential lots, or storm drainage areas adjacent to roadway or parking lots. Species must be selected based on the underlying soils, shade, and moisture conditions; as well as the historical, native indigenous plant community type for the site. Vegetation shall be selected in accordance with the following requirements.
    - Trees: a minimum of two species of trees must be planted, one of which is a conifer. Conifer and other tree species must cover the entire landscape area at a spacing recommended by a professional landscaper or in accordance with

city requirements. No individual species of replacement tree shall exceed 50 percent of the total nor shall any individual species be less than 10 percent of the total. Trees selected for replacement purposes must be free from injury, pests, diseases, and nutritional disorders. Trees must be fully branched and have a healthy root system. Coniferous and broad leaf evergreen trees shall be no less than 3 feet in height at time of planting. Deciduous trees shall be a minimum of 5 feet in height or have a minimum caliper size of 1 inch at time of planting.

Note: Avoid the use of a single species of tree for replacement purposes. No individual species of replacement tree should exceed 50 percent of the total, and no individual species should be less than 10 percent of the total.

- Shrubs: a minimum of two species of shrubs shall be planted. Space plants to cover the entire landscape area, excluding points where trees are planted.
- Groundcover: a minimum of two species of ground cover shall be planted. Space plants so as to cover the entire landscape area, excluding points where trees or shrubs are planted.

  Note: for landscape areas larger than 10,000 square feet, planting a greater variety of species than the minimum suggested above is strongly encouraged. For example, an acre could easily accommodate three tree species, three species of shrubs, and two or three species of groundcover.
- Refer to Title 18.47 TMC for additional landscaping requirements.

Conversion of an area that was under cultivation to native vegetation landscape requires a different treatment. Elimination of cultivated plants, grasses, and weeds is required before planting and will be required on an on-going basis until native plants are well-established. In addition:

1. The soil shall be tilled to a depth of 18 inches. A minimum of 8 inches of soil having an organic content of 6 to 12 percent is required, or a 4-inch layer of compost may be placed on the surface before planting, or 4 inches of clean wood chips may be tilled into the soil, as recommended by a landscape architect or forester.

2. After soil preparation is complete, continue with steps 3 through 5 above. Placing 4 inches of compost on the surface may be substituted for the hog fuel or mulch. For large areas where frequent watering is not practical, bare-root stock may be substituted at a variable spacing from 10 to 12 feet on center (with an average of 360 trees per acre) to allow for natural groupings and 4 to 6 feet on center for shrubs. Allowable bare-root stock types are 1-1, 2-1, P-1, and P-2. Live stakes at 4 feet on center may be substituted for willow and red-osier dogwood in wet areas.

3.2.3 Vegetation Protection Maintenance

The following steps must be taken to protect preserved or restored vegetation after construction.

- Mechanisms shall be put in place to ensure long-term protection of vegetation preservation and restoration areas. Mechanisms to protect these areas include setting aside conservation areas into separate tracts, permanent easements, homeowner covenants, maintenance agreements, and education (see Volume I, Chapter 3 for additional detail).

- Maintenance plans and agreements must be in compliance with Volume I, Chapter 3, and must address issues including but not limited to:

    - Pest and disease management practices
    - Pruning requirements
    - Irrigation requirements
    - Fertilization requirements
    - Fire fuel management practices.

- Maintenance shall include intensive site preparation, including weed control and soil amendment. Ongoing maintenance shall include weeding and watering for a minimum of 3 years from installation so as to achieve a minimum 90 percent survival of all planted vegetation. If during the 3-year period survival of planted vegetation falls below 90 percent, additional vegetation shall be installed as necessary to achieve the required survival percentage. Additionally, the likely cause of the high rate of plant mortality shall be determined and corrective actions shall be taken as needed to ensure plant survival. If it is determined that the original plant choices are not well suited to site conditions, these plants shall be replaced with plant species that are better suited to the site.

- Permanent signs shall be installed indicating that removal of trees or vegetation is prohibited within the native vegetation preservation and restoration areas (with the exception of the removal of dangerous and diseased trees).

- Permanent fencing is required around the limits of the vegetation preservation and restoration areas. The type, size, and location of the fencing must be submitted for approval by city review staff and should be made of materials that blend in with the natural surroundings (e.g., wood split-rail, pinned if necessary) and located in such a manner as to not impede the movement of wildlife within the vegetation preservation and restoration areas.

3.2.4 Additional Requirements

In addition to the general requirements outlined above, criteria specified in Chapter 8, Tree Retention and Tree Planting, are pertinent to vegetation retention. In particular, developers should be aware of the specific measures to protect trees during construction.

3.3 Reduce Effective Impervious Areas

Roads, shared accesses, alleys, sidewalks, driveways, and parking areas are a substantial portion of total urban impervious area and often have highly efficient drainage systems. Reducing the effective area of these surfaces (roofs excluded) is a key concept of LID. The following sections contain strategies for reducing the impacts of impervious surfaces associated with transportation and mobility related networks.

3.3.1 Road Design

The objective for an LID roadway system design is to reduce the amount of impervious area associated with the road network. This may be achieved by utilizing permeable pavement, examining alternative street layouts, and determining the best option for increasing the number of residences per unit length of road, as well as aligning roads to maximize opportunities for discharging to adjacent dispersion or bioretention areas. Strategies to be applied (where feasible) for reducing the amount and impact of impervious area associated with the road network include:

- Design the road layout to follow the existing topographic contours to minimize cuts and fills.

- Design the road layout to avoid crossing natural resource protection areas, thereby minimizing the disruption of sheet flow within these areas.

- Natural resource protection areas or bioretention areas shall be located downgradient of roads, alleys, and other impervious surfaces when feasible.

- Minimize effective impervious area and concentrated surface flows on impervious surfaces by eliminating hardened conveyance structures (e.g., pipes, curbs and gutters).

- Infiltrate or slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement. (Note that if using infiltration and/or conveyance under roads and parking areas in a retrofit setting the design must consider the integrity and protection of adjacent infrastructure.)

- Roads should be designed to service clusters of development located within the buildable portions of the site (i.e., cluster housing), thereby reducing the overall length of the roadway network.

- In higher density residential neighborhoods with narrow roads and where no on-street parking is allowed, pullout parking can be used. Pullouts (often designed in clusters of two to four stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface rendered ineffective by sloping the pavement to adjacent bioretention swales or bioretention cells.

Road Layout

One type of road layout cannot be used in all situations, so it is usually necessary for a designer to explore different strategies and decide which ones will work best for the existing site. At a minimum, the following types of layouts must be considered.

- Grid layouts: Grid patterns provide multiple access routes to each parcel and may include alleyways between blocks with garages located at the back of the house. However, the use of alleys may increase the total road network and associated impervious surface, unless permeable pavements are used.

- Cul-de-sacs: In instances where cul-de-sacs are used, techniques must be used to reduce or disconnect the impervious area. This can be accomplished by increasing the diameter of the cul-de-sac, but including a bioretention area in the center where stormwater can be directed.

- Hybrid road layouts: Hybrid layouts integrate the grid layout and cul-de-sac approach to minimize impervious coverage per dwelling unit and improve fire and safety access. The loop road design in Figure 3.1 provides an example of the hybrid layout and includes bioretention installed in the interior of the loop for stormwater management that also offers a visual buffer for residences.

Road Cross-Sections

The objective of modifying road cross-sections is to reduce the roadway width to the minimum amount of impervious surface necessary, while still accommodating emergency vehicle access, and using permeable pavements where feasible. Note: Existing applicable road standards still apply, except as modified below.

Roads

- For projects that trigger Minimum Requirements #1 through #5 or #1 through #9 (Volume I, Chapter 2.4), permeable pavement is one option that must be evaluated for on-site stormwater management for roads with very low traffic volumes and very low truck traffic (see Chapter 11 for additional details). If permeable pavement surfaces are used adjacent to conventional impervious road sections for sidewalks or pullout parking, use design techniques described in Chapter 11 to prevent saturation of the impervious road section and migration of aggregate base material from the impervious to the permeable section.

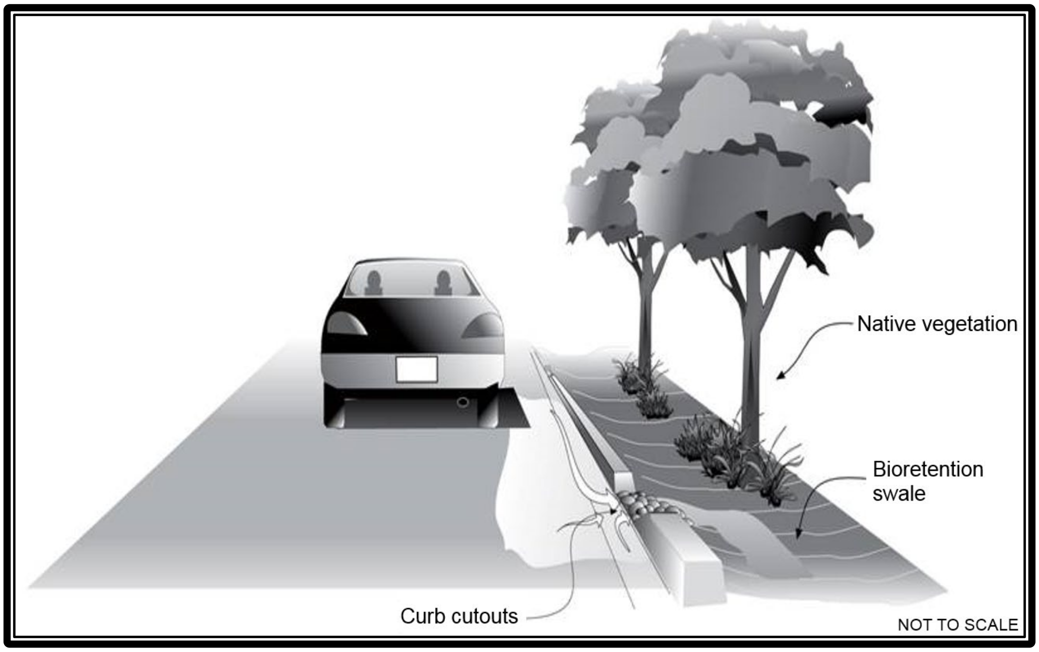
Source: Pierce County

Figure 3.1. Hybrid Road Layout.

- Cement/concrete pavement strips (1-foot-wide strips of concrete that act as a transition between the traveled lane and non-rigid permeable pavement surfaces adjacent to the traveled way) may be used to delineate the traveled lane areas. These delineator strips shall be at least 6 inches thick with expansion joints every 10 feet.

- Curbs and gutters are highly discouraged for use as stormwater collection systems in conjunction with catch basins and pipes. Where there is a legitimate need for constructing a curb and gutter system, the "Curb and Gutter Alternatives" subsection, below, provides guidance for designing curb and gutter alternatives. The following general requirements apply to curb and gutter applications for LID designs.

    - Curbs are allowed when the sidewalk is adjacent and connected to the traveled way, provided: 1) they are used only on one side of the road and the road cross slope is away from the curb, or, 2) if curb cuts are utilized, as shown in Figure 3.2, and drain to a vegetated open channel or bioretention area behind the curb.



Source: Pierce County

Figure 3.2. Curb and Gutter Cutouts.

- Alleys shall be constructed with permeable pavement, provided that the runoff through the material will not be directed towards the subgrade of the traveled lane portion of a roadway (unless the subgrade is designed to handle these flows).

- The use of additional pullout parking spaces is required to compensate for narrower road widths, which restrict roadside parking. An example design is provided in Figure 3.3.

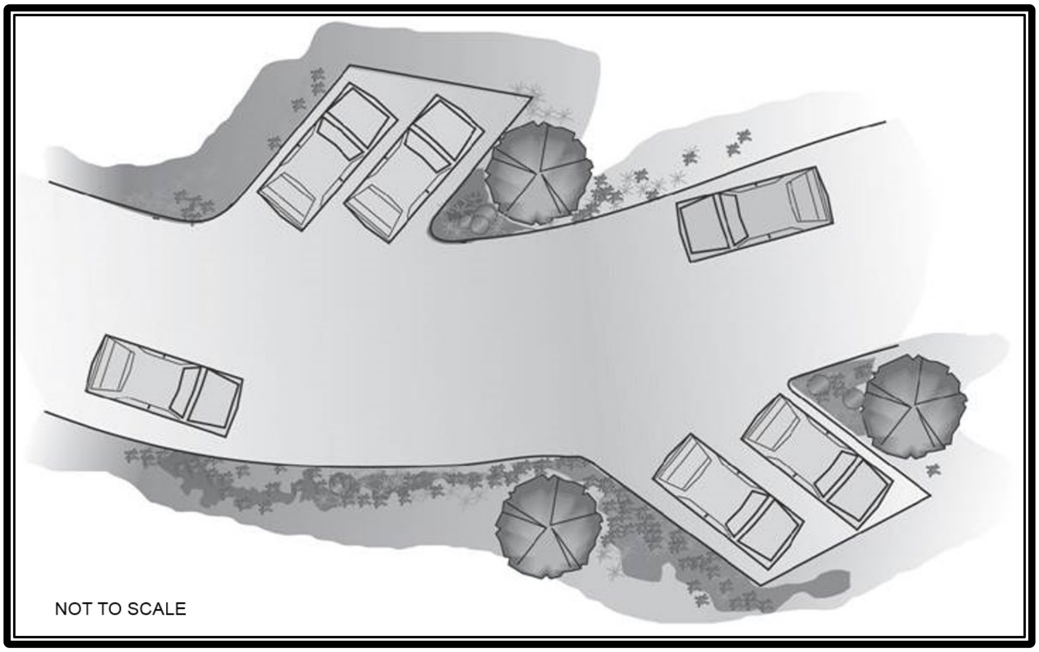
- Bioretention should be incorporated into traffic calming designs associated with retrofit or new streetscapes.

Sidewalks

- Sidewalks and trails must be disconnected from the traveled way portion of the road, to the maximum extent feasible. Every lot shall have pedestrian access to an abutting trail or to a sidewalk located on at least one side of the road. Sidewalks may be separated from the roadway by placement of a vegetated open channel or bioretention area between the sidewalk and the roadway.

- Sidewalks and trails shall be constructed of permeable pavement, provided that the runoff through the material will not be directed towards the subgrade of the traveled lane portion of a roadway (unless the subgrade is designed to handle these flows). Permeable pavement with subsurface engineered soil systems can be particularly beneficial in areas surrounding newly planted trees, as it provides soil volume and sustained root development in a manner compatible with pavement and other subsurface infrastructure. Permeable pavement for sidewalks and trails that abut lots, in lieu of a roadside sidewalk, shall comply with the Americans with Disabilities Act (ADA).

- Where feasible, sidewalks should be "reverse slope" or sloped away from the road and onto adjacent vegetated areas.



Source: Pierce County

Figure 3.3. Alternative Parking.

3.3.1 Parking Lots

The objective of alternative parking lot designs is to eliminate excessive impervious areas dedicated to parking and to minimize the effective impervious area of parking areas, while still providing adequate parking for various land use classifications.

Parking Lot Requirements

- Use the minimum off-street parking requirements for non-residential uses (Refer to Title 18.50 TMC). However, any parking lot space above the required minimum amount shall be constructed of permeable pavement or accommodated in a multi-storied or underground parking structure.

- The designer must incorporate permeable pavement to the maximum extent feasible into the parking lot to promote infiltration of runoff (see also Chapter 11, as well as Volume I, Section 2.4.6, Minimum Requirement #5).

- Bioretention areas shall be used to maximize infiltration and attenuation of surface runoff (see also Chapter 9).

3.3.2 Driveways

Driveways are typically constructed with impervious surfaces and, as such, represent an opportunity to further minimize impervious surfaces and their hydrologic impacts. The following methods shall be used to reduce the amount and hydrologic impact of impervious surfaces associated with driveways.

- Driveways shall be constructed using permeable pavement and shall be graded in such a manner to prevent stormwater runoff from saturating the subgrade of the traveled lane portion of the roadway (if not using permeable pavement for the adjacent road). Surface and subsurface (e.g., discharge from the permeable pavement) stormwater runoff should drain to the adjacent permeable road, vegetated infiltration areas such as soil amended lawns, vegetated open channels, or bioretention areas.

- Runoff from driveways constructed of impervious surfaces shall be directed to vegetated infiltration areas such as soil amended lawns, dispersion areas, or bioretention areas.

- Minimize driveway width to the extent practicable. Minimum driveway width shall be 10 feet.

- Reduce driveway length, where possible

- Design “clusters” of residences with shared driveway

3.3.3 Curb and Gutter Alternatives

The discussion below is intended to give guidance for appropriate LID methods for designing curb and gutter alternatives in situations where there is a need for constructing a curb and gutter system.

Applicability

- Some road types may require use of curb and gutter. Refer to Title 12.12 TMC and the Tumwater Development Guide for curbs and gutter requirements. Variances may be provided for LID facilities upon written request and Administrator approval.

- Where curb and gutters are required in all or part of the road network, alternative curb and gutter designs (discussed below) that will still meet the functional requirements must be considered.

Design Criteria

- Where curb and gutters are required in a community to provide a means of separating pedestrians and motorized traffic, an alternative design using a vegetated channel between the sidewalk and the roadway should be considered. In addition, a visual barrier consisting of a 1-foot-wide concrete strip along the edge of the pavement and at the same surface elevation of the pavement shall be constructed. This concrete strip gives drivers a visual cue of the edge of the driving surface and can help protect the vegetated channel from tire ruts.

- Another alternative is to provide cuts in the curb at 10- to 15-foot spacing to allow runoff to enter adjacent stormwater management areas. See Volume III for additional flow spreading options.

3.4 Better Site Design (Ecology BMP T5.41)

Fundamental hydrological and stormwater management concepts must be applied at the site design phase to help projects better integrate with natural topography.

3.4.1 Design Criteria

Knowing how the site historically processed stormwater is important in determining appropriate strategies for better site design. This information will aid the designer in determining preferred site layout options, and in deciding what appropriate site design BMPs will help either maintain or restore natural, predeveloped, stormwater processes.

Initial delineation, site management, and site design strategies to be considered and implemented as feasible include:

Define Development Envelope and Protected Areas

- Based on the site inventory, delineate the best areas to direct development. Building sites, road layout, and other site infrastructure shall be configured within these development areas to minimize soil and vegetation disturbance and take advantage of a site's natural stormwater processing capabilities.

- Minimize clearing and grading by incorporating natural topographic depressions into the development and, in particular, limiting the amount of cut and fill on portions of the site with permeable soils.

- Delineate natural resource protection areas with appropriate fencing and signage to provide protection from construction activities.

- Eliminate stream crossings with roads and conveyance systems whenever possible.

Minimize Directly Connected Impervious Areas

- Establish limits of disturbance to the minimum area required for roads, utilities, building pads, landscape areas, and the smallest additional area needed to maneuver construction equipment.

- Minimize directly connected impervious areas, that is, any impervious surface that drains directly into a catch basin or other conveyance structure.

Maximize Permeability

- Preserve the existing upper soil horizon to the maximum extent feasible. Where excavation is necessary, excavated topsoil shall be used elsewhere on the site to amend areas with sparse or nutrient deficient topsoil.

- Any portion of the site with permeable soils shall be closely considered for preservation to promote infiltration of stormwater runoff.

- Maximize permeability by minimizing impervious areas, paving with permeable pavements (e.g., porous asphalt pavement, pervious concrete pavement, and pavers for roads, driveways, alleys, parking lots, or other types of drivable or walkable coverage), clustering buildings, and reducing the land coverage of buildings by smaller footprints. Applicable strategies shall be reflected at all levels of a project, from site planning to materials selection.

- Lay out roads, lots, and other proposed site features to follow topographic contours to minimize soil and vegetation disturbance and loss of topsoil or organic duff layer.

Use Drainage as a Design Element

- Maintain predevelopment flowpath lengths in natural drainage patterns whenever possible.

- Where concentrated flow conveyance systems must be used (in lieu of the preferred sheet flow and infiltration approaches), vegetated open channels must be used where feasible instead of piped conveyance systems. Vegetated open channels are most applicable adjacent to roadways where the linear nature of the road can make it difficult to provide enough area within the right-of-way for infiltration or dispersion options.

- Manage stormwater as close to the origin as possible.

- Maximize the use of small, dispersed stormwater management facilities to capture, store, and infiltrate stormwater on site.

Planning

- Meet and walk the property with the owner, engineers, landscape architects, and others directing project design to identify problems and concerns that should be evaluated when implementing the site plan.

- Meet and walk the property with equipment operators prior to clearing and grading to clarify construction boundaries and limits of disturbance. Pay particular attention to subgrade preparation for permeable pavement and bioretention installations and techniques to avoid subgrade compaction.

- Encourage erosion and sediment control training for operators.
- See Volume II, Section 3.3 for additional requirements specific to protection of LID BMPs during construction (in accordance with Volume I Section 2.4.3, Minimum Requirement #2, Element #13).
- Designers should also refer to the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012), specifically Volume I, Chapter 3, for additional guidelines and graphics for better site designs and layouts.

Chapter 4 – Pretreatment

4.1 Purpose

This section presents the methods that may be used to provide pretreatment prior to basic or enhanced runoff treatment facilities. Presettling basins are a typical pretreatment BMP used to remove suspended solids. All of the basic runoff treatment facilities may also be used for pretreatment to reduce suspended solids.

4.2 Applications

Pretreatment must be provided 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). BMPs that require pretreatment include but are not limited to: canister systems, infiltration basins, infiltration trenches, and infiltration galleries that receive runoff from pollution generating surfaces.

A detention pond sized to meet the flow control standard in Volume I, Chapter 2 may also be used to provide pretreatment for suspended solids removal.

4.3 Best Management Practices for Pretreatment

This section has only one BMP for presettling basins. Ecology has approved some emerging technologies for pretreatment through the Technology Assessment Protocol – Ecology (TAPE) process. See Ecology's web site for a list of approved pretreatment technologies: <www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html>. Only those BMPs that have received a General Use Level Designation (GULD) may be used to meet the requirements of this manual. If ownership of the facility is to be taken over by the city or a homeowners' association, the designer must obtain approval from the city before including those facilities in the stormwater design.

4.3.1 Presettling Basin (Ecology BMP T6.10)

A presettling basin provides pretreatment of runoff in order to remove suspended solids, which can impact other runoff treatment BMPs.

Application and Limitations

Runoff treated by a presettling basin may not be discharged directly to a receiving water or to groundwater; it must be further treated by a basic or enhanced runoff treatment BMP.

Presettling Basin Design Criteria

- A presettling basin shall be designed to include a wet pool sedimentation area at least 6 inches deep at the bottom of the facility. The total treatment volume of the presettling basin shall be at least 30 percent of the total water quality treatment design volume.

- Drawdown time of the presettling storage area (excluding wet pool area) must not exceed 48 hours.

- If the runoff in the presettling basin will be in direct contact with the soil (e.g., not within a concrete vault), it must be lined per the liner requirement in Volume V-F.

- The presettling basin shall conform to the following:

    - The length-to-width ratio shall be at least 3:1. Berms or baffles may be used to lengthen the flowpath.

    - The minimum depth shall be 4 feet; the maximum depth shall be 6 feet.

- Inlets and outlets shall be designed to minimize velocity and reduce turbulence. Inlet and outlet structures should be located at extreme ends of the basin in order to maximize particle-settling opportunities.

Site Constraints and Setbacks

All facilities shall be a minimum of 20 feet from any structure, property line, and any vegetative buffer required by the City of Tumwater.

All facilities shall be 100 feet from any septic tank/drainfield (except wet vaults shall be a minimum of 20 feet).

All facilities shall be a minimum of 50 feet from any steep (greater than 15 percent) slope. A geotechnical assessment must address the potential impact of a wet pond on a steep slope.

Embankments that impound water must comply with the Washington State Dam Safety Regulations (Chapter 173-175 WAC). If the impoundment has a storage capacity (including both water and sediment storage volumes) greater than 10 acre-feet (435,600 cubic feet or 3.26 million gallons) above natural ground level, then dam safety design and review are required by Ecology. See Chapters 18 through 20, for more detail.

Chapter 5 – Underground Injection Control

The following information on UIC is excerpted from the 2006 Ecology document titled "Guidance for UIC Wells that Manage Stormwater" (Ecology 2006). This document is available online at: <https://apps.ecology.wa.gov/publications/documents/0510067.pdf>.

The UIC program in the State of Washington is administered by Ecology. In 1984, Ecology adopted Chapter 173-218 WAC – UIC to implement the program. A UIC well is a manmade subsurface fluid distribution system designed to discharge fluids into the ground and consists of an assemblage of perforated pipes, drain tiles, or other similar mechanisms, or a dug hole that is deeper than the largest surface dimension (WAC 173-218-030).

UIC systems include drywells, pipe or French drains, drainfields, and other similar devices that are used to discharge stormwater directly into the ground. Infiltration trenches with perforated pipe used to disperse and inject flows (as opposed to collect and route to surface drainage, as in an underdrain) are considered to be UIC wells. **This type of infiltration trench must be registered with Ecology.**

The following are not UIC wells; therefore, this guidance does not apply to the following.

- Buried pipe and/or tile networks that serve to collect water and discharge that water to a conveyance system or to surface water
- Surface infiltration basins and flow dispersion stormwater infiltration facilities, unless they contain additional infiltration structures at the bottom of the basin/system such as perforated pipe, or additional bored, drilled, or dug shafts meant to inject water further into the subsurface greater than 20 feet deeper than the bottom of the pond (or deeper than the largest surface dimension per above)
- Infiltration trenches designed without perforated pipe or a similar mechanism
- A system receiving roof runoff from a single-family residence.

The two basic requirements of the UIC program are:

- Register UIC wells with Ecology unless the wells are located on tribal land, in which case the wells must be registered with the U.S. Environmental Protection Agency (U.S. EPA).
- Make sure that current and future underground sources of groundwater are not endangered by pollutants in the discharge (non-endangerment standard).

UIC wells must either be rule-authorized or covered by a state waste discharge permit to operate. If a UIC well is rule-authorized, a permit is not required. Rule authorization can be rescinded if a UIC well no longer meets the non-endangerment standard. Ecology can also require corrective action or closure of a UIC well that is not in compliance. If an existing UIC well receives stormwater and was in use before 2/3/2006, the well owner must complete a well assessment with Ecology to determine if the UIC well is a high threat to groundwater. See Chapter 173-218-090 (2) WAC UIC Program, or visit https://apps.ecology.wa.gov/publications/documents/1210012.pdf for more information. Additional information on UIC systems can be found in Chapter I-4 UIC Program in the 2019 Stormwater Management Manual for Western Washington (SWMMWW).

To find adequate infiltration rates, an engineer may propose to excavate through a till layer or low-permeability layer when designing a stormwater facility. Since excavating through a low-permeability layer creates a new condition, more extensive geotechnical assessments, water quality BMPs, and monitoring may be required, including but not limited to groundwater monitoring through a winter season (December 1 through April 30).

Chapter 6 – Postconstruction Soil Quality and Depth (Ecology BMP T5.13)

Most projects require that site soils meet minimum quality and depth requirements 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 *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13* (Stenn et al. 2012), which is available at: < https://www.soilsforsalmon.org/>.

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 can become PGPS themselves 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.

Postconstruction soil quality and depth requirements help to regain greater stormwater functions in the postdevelopment 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).

6.1.1 Applications and Limitations

- When used in combination with other on-site stormwater management BMPs, soil preservation and amendment can help achieve compliance with the Performance Standard option of Minimum Requirement #5.
- On sites underlain by cemented till layers, which are nearly impermeable, the upper soil horizon (native topsoil) processes most of the stormwater on the site. Ensure that the existing depth of the upper soil horizon is either left in place, or

removed and replaced (according to the requirements herein) during the grading process.

- On sites underlain by outwash soils, the existing topsoil is not usually as deep (as with till soils), but must still be preserved or replaced.

- Portions of the site composed of till soils with slopes greater than 33 percent need not implement this BMP.

6.1.2 Modeling and Sizing

Lawn and landscaped areas that meet the requirements of this section 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 postconstruction soil quality and depth BMP requirements are met and used as part of a dispersion design under the conditions described in Chapters 9 through 15.

6.1.3 Postconstruction Soil Quality and Depth Design Criteria

This section describes the implementation options and design requirements for postconstruction soil quality and depth. Typical cross-sections of compost-amended soil in planting bed and turf applications are shown in Figure 6.1. Design criteria are provided in this section for the following elements.

- Implementation options

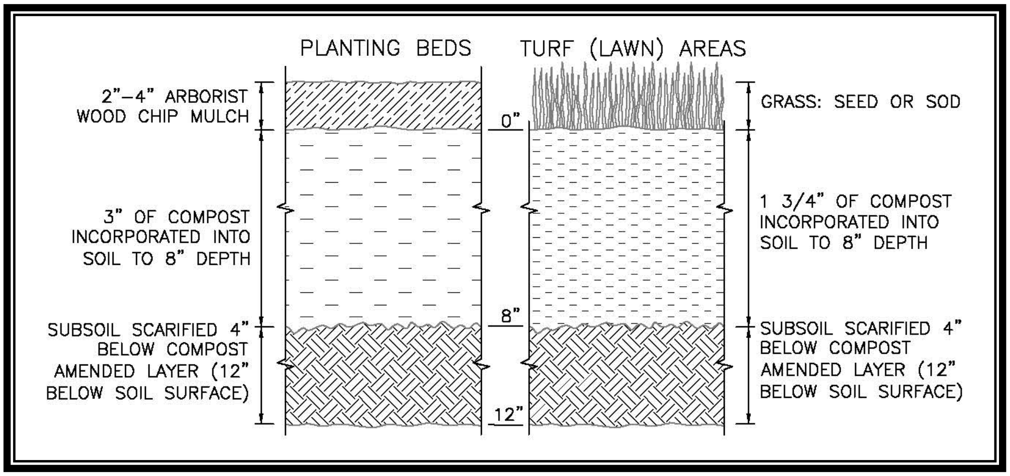
- Soil retention

- Soil amendment

- Soil stockpiling

- Soil importing

- Postconstruction Soil Quality and Depth Plan



Source: Seattle 2016 (reproduced with permission)

Figure 6.1. Cross-Section of Soil Amendment.

Implementation Options

The soil quality design requirements can be met by using one of the four options listed below. Additional details for each option are provided in the subsequent subsections.

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 is disturbed, use option 2, 3, or 4.

2. Amend Soil

   - Soil amendments shall be applied to all areas that are being set aside as non-buildable areas (open space or natural resource protection areas) and are in need of rehabilitation because of past land use disturbances such as clearing and intrusion of invasive species. The purpose is to enhance and accelerate the rehabilitation of the soil structure. The application will be non-destructive to the existing vegetation that is retained by taking care to taper depths of soil amendment near the surface roots.

   - Amend existing site topsoil or subsoil either at default "preapproved" rates, or at custom calculated rates to meet the soil quality guidelines based on engineering tests of the soil and amendment. (Refer to the *Building Soil* manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/> for custom calculation methods.)

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 "preapproved" rate or at a custom calculated rate (refer to the *Building Soil* manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/> for custom calculation method). Scarify subsoil and mulch planting beds, as described under the Soil Amendment heading below.

4. Import Soil

   - Import topsoil mix of sufficient organic content and depth to meet the requirements. Imported soils must not contain excessive clay or silt fines (more than 5 percent passing the U.S. #200 sieve) because that could restrict stormwater infiltration. Use imported topsoil that meets default "preapproved" rates.

   - Scarify subsoil and mulch planting beds, as described under the "Soil Amendment" heading below.

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

Soil Retention

In buildable areas where minimal excavation foundation systems may be applied, existing topsoils shall be left in place to the greatest extent feasible and shaped or feathered only with tracked grading equipment not exceeding 650 pounds per square foot machine loads. Where some re-grading is required, re-compaction of placed materials, which may include topsoils free of vegetated matter, shall be limited to the minimum densities required by the foundation system engineering.

Soil Amendment

If soil retention and protection is not feasible, disturbed soil must be amended. 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 Postconstruction Soil Quality and Depth 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.

Amend existing site topsoil or subsoil either at default "preapproved" soil amendment rates or at custom calculated rates to meet the soil quality guidelines based on engineering tests of the soil and amendment. Both options are described in further detail below.

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:
    - Turf areas: Place 1.75 inches of compost and till-in to an 8-inch depth. Achieve an organic matter content, as measured by the loss-on-ignition test, of a minimum 4 percent (target 5 percent) organic matter content[1].
    - Planting beds: Place 3 inches of compost and till-in to an 8-inch depth. Achieve an organic matter content, as measured by the loss-on-ignition test, of a minimum 8 percent (target 10 percent) dry weight[1].
    - 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 (loosen) 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.
- For turf installations: Water or roll to compact to 85 percent of maximum dry density, rake to level, and remove surface woody debris and rocks larger than 1-inch diameter (*Building Soil* manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/>).
- After planting: Mulch planting beds with 2 to 4 inches of organic material such as arborist wood chips, bark, shredded leaves, compost, etc. Do not use fine bark because it can seal the soil surface.
- Use compost and other materials that meet the following organic content requirements:

    The organic content for "preapproved" amendment rates can only be met using compost meeting the compost specification for bioretention (see Chapter 9), with the exception that the compost may have up to 35 percent biosolids or manure. The compost must have an organic matter content of 40 percent to 65 percent, and a carbon to nitrogen ratio below 25:1. The

---

[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 05.07-A "Loss-On-Ignition Organic Matter Method"

carbon to nitrogen ratio may be as high as 35:1 for plantings composed entirely of plants native to the Puget Sound Lowlands region (*Building Soil* manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/>).

- Within the 1-year capture zone of any drinking water well or wellhead protection area, compost used within the site shall not include biosolids or animal manure components, as these can result in large concentrations of nitrates leaching into groundwater aquifers and are consequently prohibited within the wellhead protection area.

- 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 not exceeding the contaminant limits identified in Table 220-B, Testing Parameters, in WAC 173-350-220 (*Building Soil* manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/ >).

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

Soil Stockpiling

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.

- In buildable areas of the site, where conventional grading is required, the areas requiring cuts shall have the upper native topsoil removed and stockpiled for replacement for areas of the development utilized for stormwater and/or vegetation management (yards, bioretention areas, interflow pathways, vegetated channels, or degraded natural resource protection areas).

- The depth of upper native topsoil required to be stockpiled and replaced shall be the entire depth of the native topsoil horizon up to a maximum of 3 feet.

- Over-excavation of cut sections may be necessary if the cut is in a location that will be used for stormwater management. Cut to a depth that will allow replacement of stockpiled native topsoil to the entire depth that was on the site predevelopment, up to a maximum of 3 feet.

- Cut sections where native topsoil replacement is required shall require ripping of any cemented till layers to a depth of 6 inches. Subsequently, the replacement of stockpiled topsoil shall be thoroughly mixed into the ripped till to provide a gradual transition between the cemented till layer and the topsoil.

- Stockpiled topsoil shall be replaced in lifts no greater than 1 foot deep and compacted by rolling to a density that matches existing conditions.

- Amend stockpiled topsoil if needed to meet the organic matter or depth requirements either at the default "preapproved" rate or at a custom calculated rate (refer to the Building Soil manual [Stenn et al. 2012] or web site <https://www.soilsforsalmon.org/> for custom calculation method).

- Ensure stockpiles are stabilized according to Volume III Section 3.1.10, BMP C123 – Plastic Covering or other approved methods.

Importing Soil

The default preapproved 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.

Soil Management Plan

A Soil Management Plan must be included in the project submittal, i.e., the Construction SWPPP, and Drainage Control Plan or Abbreviated Plan. Refer to Volume I, Section 3.3, for Soil Management Plan requirements.

6.1.4 Construction Criteria

Most of the construction requirements for small-scale infiltration and dispersion facilities included in Chapter 6, also apply to postconstruction soil quality and depth. Minimum construction requirements for disturbed areas include:

- Install soil to meet postconstruction soil quality and depth 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.

6.1.5 Operations and Maintenance Criteria

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. However, this BMP should not be implemented within a stormwater treatment, flow control or infiltration facility.

Chapter 7 – Dispersion Facilities

7.1 General Dispersion Facility Design Criteria

General Site Considerations

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

- Dispersion flowpath area: Dispersion BMPs generally require large areas of vegetated ground cover to meet flowpath requirements. They are not feasible in many urban settings and some rural settings.
- Erosion or flooding potential: Dispersion 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 detailed flowpath requirements below).

7.1.1 General Design Criteria

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

- Natural resource protection areas and critical area buffers may count towards flowpath lengths. This does not include steep slopes. However, the natural resource protection area must be permanently protected from modification through a covenant or easement, or a tract dedicated by the proposed project.
- Dispersion facilities shall be placed no closer than 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high, and a vegetated flowpath must be maintained between the outlet of the facility and the slope. A geotechnical assessment and Soils Report must be prepared addressing the potential impact of the facility on the slope. The geotechnical assessment may recommend a reduced setback, but in no case shall the setback be less than the vertical height of the slope.
- The dispersion flowpath is not permitted within 300 feet of an erosion hazard or landslide hazard area (as defined by Title 16.20 TMC) unless a geotechnical professional has analyzed and mitigated the slope stability impacts of the dispersion flowpath, and appropriate analysis indicates that the impacts are negligible.

- For sites with on-site or adjacent septic systems, the discharge point must be at least 30 feet upgradient, or 10 feet downgradient, of the drainfield primary and reserve areas (per WAC 246-272A-0210). In addition, the entire flowpath must be oriented so as to not intersect with the primary or reserve areas. These requirements may be modified by the Thurston County Public Health and Social Services Department if site topography clearly prohibits flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that a shorter setback is feasible.

- The vegetated flowpath must consist of either: 1) undisturbed native landscape or 2) well-established lawn, landscape, and groundcover over soil that meets the postconstruction soil quality and depth BMP requirements outlined in Chapter 6. The groundcover must be dense to help disperse and infiltrate flows and prevent erosion.

- The dispersion flowpath is not permitted over contaminated sites or abandoned landfills.

7.2 Full Dispersion (Ecology BMP T5.30)

This BMP allows projects to disperse runoff from impervious surfaces and cleared areas of development sites that protect at least 65 percent of the site (or a threshold discharge area on the site) in a forest or native condition. Fully dispersed runoff from impervious surfaces means that the area is “ineffective.” Ineffective impervious areas are included in the total impervious area thresholds when determining applicable minimum requirements, but they do not need to be included in the continuous modeling calculations when sizing downstream BMPs for the overall project area. Note that the city may still require water quality treatment for pollution-generating areas that are routed to dispersion facilities (e.g., for groundwater protection).

7.2.1 Applicability

- Projects that retain 65 percent of the site (or a threshold discharge area on the site) in a forested or native condition may use dispersion to avoid triggering the flow control facility requirement (see Volume I, Section 2.4, Minimum Requirements #5 and #7). Areas that are fully dispersed (in accordance with the requirements outlined herein) do not need to perform continuous runoff modeling to demonstrate compliance.

- Preservation of existing vegetation areas must meet the requirements outlined for BMP C101: Preserving Natural Vegetation and Topsoil under Volume II, Section 3.1.

- The preserved area may be a previously cleared area that has been replanted in accordance with Restoring Site Vegetation in Chapter 3.

- The preserved area shall be placed in legally protected areas, such as in a separate tract, or protected through recorded easements for individual lots.
- All trees within the preserved area at the time of permit application shall be retained, aside from the approved timber harvest activities regulated under WAC Title 222, except for Class IV General Forest Practices that are conversions from timberland to other uses, and the removal of dangerous or diseased trees. Removal of dangerous or diseased trees will require approval by the City of Tumwater and may require an arborist to make a written assessment of the trees' condition.
- The preserved area may be used for passive recreation and related facilities, including pedestrian and bicycle trails, nature viewing areas, fishing and camping areas, and other similar activities that do not require permanent structures, provided that cleared areas and areas of compacted soil associated with these areas and facilities do not exceed 8 percent of the preserved area.
- The preserved area may contain utilities and utility easements, but not septic systems. Utilities are defined as potable and wastewater underground piping, underground wiring, and power and telephone poles.

7.2.2 Design Criteria for Residential, Commercial, and Industrial Projects

Developments that preserve 65 percent of a site (or a threshold discharge area of a site) in a forested or native condition can disperse runoff from the developed portion of the site into the native vegetation area as long as the developed areas draining to the native vegetation do not have impervious areas that exceed 10 percent of the entire site.

Where a development has less than 65 percent of a site available to maintain or create into a forested or native condition, that area may still be used for full dispersion of a portion of the developed area. The ratio of the native vegetation area to the impervious area, which is dispersed into the native vegetation, must not be less than 65 to 10. The lawn and landscaping areas associated with the impervious areas may also be dispersed into the native vegetation area. (The lawn and landscaped area must comply with Chapter 6, Postconstruction Soil Quality and Depth). All design requirements listed also must be met.

Additional impervious areas above 10 percent are allowed, but shall not drain to the native vegetation area, and are subject to the thresholds, treatment, and flow control requirements of this manual. The portion of developed area that is not managed through full dispersion can be considered a separate project site. In this case, it must be evaluated against the thresholds in Figures 2.1 and 2.2 of Volume I, Section 2.3, whichever is appropriate, to determine the applicable Minimum Requirements.

Within the context of this dispersion option, the impervious surfaces that are over and above the 10 percent maximum can be routed into an appropriately sized drywell or into an infiltration basin that meets the flow control standard and does not overflow into the forested or native vegetation area.

The flowpath from contributing impervious areas to the dispersion area must meet all of the following criteria:

- A native vegetation flowpath of at least 100 feet in length (25 feet for sheet flow from a nonnative pervious surface) must be available along the flowpath that runoff would follow (upon discharge from an appropriate dispersion device).
- The flowpath must be on site or in an off-site tract or easement area reserved for such dispersion.
- The slope of the flowpath must be no steeper than 15 percent for any 20-foot reach of the flowpath. Slopes up to 33 percent are allowed where level spreaders are located upstream of the dispersion area and at sites where vegetation can be established.
- The flowpaths for adjacent dispersion devices must be sufficiently spaced to prevent overlap of flows in the flowpath areas.
- Runoff from contributing impervious areas must be dispersed into the native vegetation area using the dispersion devices specified below.

Roof Downspouts

Roof surfaces are considered to be “fully dispersed” (i.e., zero percent effective impervious) if they discharge to an area that consists of forested (or native vegetative cover) and is more than 65 percent of the development site area, AND if they either: 1) comply with the requirements of Chapter 15, Downspout Dispersion, but with vegetated flowpaths of 100 feet or more through the native vegetation preserved area; or, 2) disperse driveway runoff along with the road runoff in accordance with the roadway dispersion BMP section below. Roof surfaces that comply with Chapter 15, Downspout Infiltration, are considered to be “fully infiltrated” (i.e., zero percent effective impervious) and do not count against the maximum 10 percent impervious area allowed for full dispersion.

Driveway Dispersion

Driveway surfaces are considered to be “fully dispersed” if they are within a threshold discharge area that is or will be more than 65 percent forested (or native vegetative cover) and less than 10 percent impervious (total), AND if they either: 1) comply with the concentrated flow dispersion BMP section, below, and have flowpaths of 100 feet or more through native vegetation; or, 2) disperse driveway runoff along with the road runoff in accordance with the roadway dispersion BMP section below.

Roadway Dispersion BMPs

Roadway surfaces included as part of residential, commercial, or industrial projects are considered to be “fully dispersed” if they are within a threshold discharge area that is or will be more than 65 percent forested (or native vegetative cover) and less than 10 percent impervious (total), AND if they comply with the following dispersion requirements.

1. The road section shall be designed to minimize collection and concentration of roadway runoff. Sheet flow over roadway fill slopes should be used wherever possible to avoid concentration.

2. When it is necessary to collect and concentrate runoff from the roadway and adjacent upstream areas (e.g., in a ditch on a cut slope), concentrated flows shall be incrementally discharged from the ditch via cross culverts or at the ends of cut sections. These incremental discharges of newly concentrated flows shall not exceed 0.5 cubic feet per second from any single discharge location from a ditch for the 100-year runoff event. Where flows at a particular ditch discharge location were already concentrated under existing site conditions (e.g., in a natural channel that crosses the roadway alignment), the 0.5 cubic feet per second limit would be in addition to the existing concentrated peak flows.

3. Ditch discharge locations with up to 0.2 cubic feet per second discharge for the peak 100-year flow shall use rock pads or dispersion trenches to disperse flows. Ditch discharges with between 0.2 and 0.5 cubic feet per second discharge for the 100-year peak flow shall use only dispersion trenches to disperse flows.

4. Dispersion trenches shall be designed to accept surface flows (free discharge) from a pipe, culvert, or ditch end, shall be aligned perpendicular to the flowpath, and shall be minimum 2 feet by 2 feet in section, 50 feet in length, filled with 0.75-inch to 1.5-inch washed rock, and provided with a level notched grade board. Manifolds may be used to split flows up to 2 cubic feet per second discharge for the 100-year peak flow between up to four trenches. Dispersion trenches shall have a minimum spacing of 50 feet between centerlines.

5. Flowpaths from adjacent discharge points must not intersect within the 100-foot flowpath lengths, and dispersed flow from a discharge point must not be intercepted by another discharge point. To enhance the flow control and water quality effects of dispersion, the flowpath shall not exceed 15 percent slope unless a level spreader is used (see criteria above), and shall be located within a designated open space. *Note: Runoff may be conveyed to an area meeting these flowpath criteria*.

6. Where the city determines there is a potential for significant adverse impacts downstream (e.g., erosive steep slopes or existing downstream drainage problems), dispersion of roadway runoff may not be allowed, or other measures may be required.

Cleared Area Dispersion BMPs

The runoff from cleared areas that comprise bare soil, nonnative landscaping, lawn, and/or pasture of up to 25 feet in flowpath length can be considered to be “fully dispersed” if it is dispersed through at least 25 feet of native vegetation in accordance with the following criteria:

1. The topography of the nonnative pervious surface must be such that runoff will not concentrate prior to discharge to the dispersal area.

2. Slopes within the dispersal area shall be no steeper than 15 percent.

If the flowpath length across the contributing nonnative pervious surface is greater than 25 feet, the downstream native vegetation dispersion area flowpath must be extended 1 foot for every 3 feet of contributing flowpath beyond 25 feet (up to a maximum contributing flowpath of 250 feet).

7.2.3 Design Criteria for Roadway Projects

These dispersion criteria apply to the construction of public and private roads. Note that most roadways in the City of Tumwater will not have the required space to fully meet the design requirements for full dispersion (e.g., dispersion area widths, and legal protection of the dispersion area). In addition, the city may still require water quality treatment for pollution generating areas that are routed to dispersion facilities (e.g., for groundwater protection).

1. <u>Uncollected or natural dispersion into adjacent vegetated areas (i.e., sheet flow into the dispersion area)</u>:

   Full dispersion credit (i.e., no other flow control required) is given to projects that meet the following criteria:

   a. Outwash soils (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated hydraulic conductivity rate of 4 inches per hour or greater. The saturated hydraulic conductivity must be based on a pilot infiltration test (PIT) or soil grain size analysis (for Type A soils only) outlined in Appendix V-A.

      - Up to 20 feet of contributing impervious width (i.e., perpendicular to the direction of roadway travel) requires 10 feet of dispersion area flowpath.

      - Each additional foot of contributing impervious width requires an additional 0.25 foot (3 inches) of dispersion area flowpath.

b. Other soils: (Types C and D and some Type B not meeting the criterion in 1.a, above)

- 6.5 feet of flowpath for every 1 foot of contributing impervious width draining to it. A minimum distance of 100 feet is necessary.

c. Criteria applicable to all soil types:

- Depth to the average annual maximum groundwater elevation must be at least 3 feet.
- The contributing impervious surface flowpath must be less than 75 feet. The contributing pervious flowpath must be less than 150 feet. Pervious flowpaths may include upgradient road side slopes that run onto the road and downgradient road side slopes that precede the dispersion area.
- The lateral slope of contributing impervious drainage area must be less than 8 percent. Road side slopes must be less than 25 percent. Road side slopes do not count as part of the dispersion area unless native vegetation is re-established and slopes are less than 15 percent. Road shoulders that are paved or graveled count as impervious surface.
- The longitudinal slope of road must be less than 5 percent.
- The length of the dispersion area must be equivalent to length of road.
- The average longitudinal (parallel to road) slope of the dispersion area must be less than 15 percent.
- The average lateral slope of the dispersion area must be less than 15 percent.

2. <u>Channelized (collected and re-dispersed) stormwater into areas with: a) native vegetation or b) cleared land in areas outside of urban growth areas that do not have a natural or manmade drainage system</u>:

Full dispersion credit (i.e., no other flow control required) is given to projects that meet the following criteria.

a. Outwash soils (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated hydraulic conductivity rate of 4 inches per hour or greater. The saturated hydraulic conductivity must be based on a PIT or Soil Grain Size Analysis (for Type A soils only) outlined in Appendix V-A.

- The dispersion area flowpath must be at least half the width of the contributing impervious drainage area.

b. *Other soils*: (Types C and D and some Type B not meeting the criterion in 2.a, above)

- The dispersion area must have 6.5 feet of width for every 1-foot width of impervious area draining to it. A minimum distance of 100 feet is necessary.

c. *Other criteria applicable to all soil types*:

- Depth to the average annual maximum groundwater elevation must be at least 3 feet.
- Channelized flow must be re-dispersed to produce the longest possible flowpath.
- Flows must be evenly dispersed across the dispersion area.
- Flows must be dispersed using rock pads and dispersion techniques as specified under roadway dispersion BMPs in Section 7.2.5 of this chapter.
- Approved energy dissipation techniques may be used.
- This option is limited to on-site (associated with the road) flows.
- The length of dispersion area must be equivalent to length of the road.
- The average longitudinal and lateral slopes of the dispersion area must be less than 8 percent.
- The slope of any flowpath segment must be no steeper than 15 percent for any 20-foot reach of the flowpath segment.

3. <u>Engineered dispersion of stormwater runoff into an area with engineered soils</u>:

Full dispersion credit (i.e., no other flow control required) is given to projects that meet the following criteria.

a. Outwash soils (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated hydraulic conductivity rate of 4 inches per hour or greater must be amended with compost in accordance with Chapter 6, Postconstruction Soil Quality and Depth.

- Up to 20 feet of impervious width needs 10 feet of dispersion area flowpath.
- Each additional foot of impervious width needs 0.25 foot (3 inches) of dispersion area flowpath.

b. *Other soils*: (Types C and D and some Type B not meeting the criterion in 3.a, above) must be compost-amended in accordance with Chapter 6, Postconstruction Soil Quality and Depth.

- The dispersion area must meet the 65 to 10 ratio.

c. *Other criteria applicable to all soil types*:

- Stormwater can be dispersed via sheet flow or via collection and re-dispersion in accordance with the techniques specified under roadway dispersion BMPs in Section 7.2.5 of this chapter.
- Depth to the average annual maximum groundwater elevation shall be at least 3 feet.
- Average longitudinal (parallel to road) slope of dispersion area must be less than 15 percent.
- Average lateral slope of dispersion area must be less than 15 percent.
- The dispersion area should be planted with native trees and shrubs.

7.2.4 Calculation of the Total Native Vegetation Retention Achieved

Calculation of native vegetation retention achieved shall exclude water bodies (such as large ponds or lakes 10 acres or greater) and include areas part of a common conservation easement (such as parks, stormwater, open space, wetland buffers, or critical area tracts) or areas incorporated into the individual lot design where conservation easements are placed on that portion of the lot. However, proposed residential subdivisions and planned unit developments (PUDs) shall locate a minimum of 75 percent of the required native vegetation within areas of land separate from residential lots, such as those listed above. When lots or building sites are located contiguous to protective tracts, the preferred location of the native vegetation areas is the area adjacent to the protective tracts.

7.3 Sheet Flow Dispersion (Ecology BMP T5.12)

7.3.1 Description

Sheet flow dispersion is the simplest method of runoff control. This BMP can be used for any impervious or pervious surface that is graded so as to avoid concentrating flows. Because flows are already dispersed as they leave the surface, they need only traverse a narrow band of adjacent vegetation for effective attenuation and treatment.

7.3.2 Applications and Limitations

- Use for flat or moderately sloping (less than 15 percent slope) surfaces such as driveways, sport courts, patios, roofs without gutters, lawns, pastures; or any situation where concentration of flows can be avoided.

- Where the contributing surface is flat to moderately sloped and cross-sloped at a minimum of 2 percent (to convey runoff across the contributing surface), a transition zone may be used to route runoff to a vegetated buffer.

- Where the contributing surface is of variable slope, berms and dispersion trenches may be used to route runoff to the vegetated buffer.

- Modeling credits for sheet flow dispersion (see "Modeling and Sizing," below) can be applied to help meet the flow control standards of Minimum Requirement #7, as well as to help achieve compliance with the Performance Standard option of Minimum Requirement #5.

7.3.3 Modeling and Sizing

Where sheet flow dispersion is used to disperse runoff into an undisturbed native landscape area or an area that meets the requirements of Chapter 6, the impervious area may be modeled as grass/lawn area.

7.3.4 Sheet Flow Dispersion Design Criteria

Refer to the general dispersion design criteria above. Additional design criteria specific to sheet flow dispersion include:

- See Figure 7.1 for required setbacks and flowpath lengths. Figure 7.1 is applicable for non-driveway surfaces.

- <u>Transition Zones</u>:

  - A 2-foot-wide transition zone to discourage channeling must be provided between the edge of the contributing surface (or building eaves) and the downslope vegetation. This transition zone may consist of subgrade material (crushed rock), modular pavement, drain rock, or other material approved by the city.

  - Provide a 10-foot-wide vegetated buffer for up to 20 feet of width of contributing surface. Provide an additional 10 feet of width for each additional 20 feet of contributing area width or fraction thereof. (For example, if a driveway is 30 feet wide and 60 feet long, provide a 15-foot-wide by 60-foot-long vegetated buffer, with a 2-foot by 60-foot transition zone).

- Berms:
    - Berms must be diagonal to surface flow to intercept and convey runoff to dispersion trenches.
    - Dispersion Trenches must be designed in accordance with Chapter 15.
    - Provide a 25-foot vegetated flowpath between the discharge point of the dispersion trench and any property line, structure, steep slope (greater than 20 percent), stream, lake, wetland, or other impervious surface.

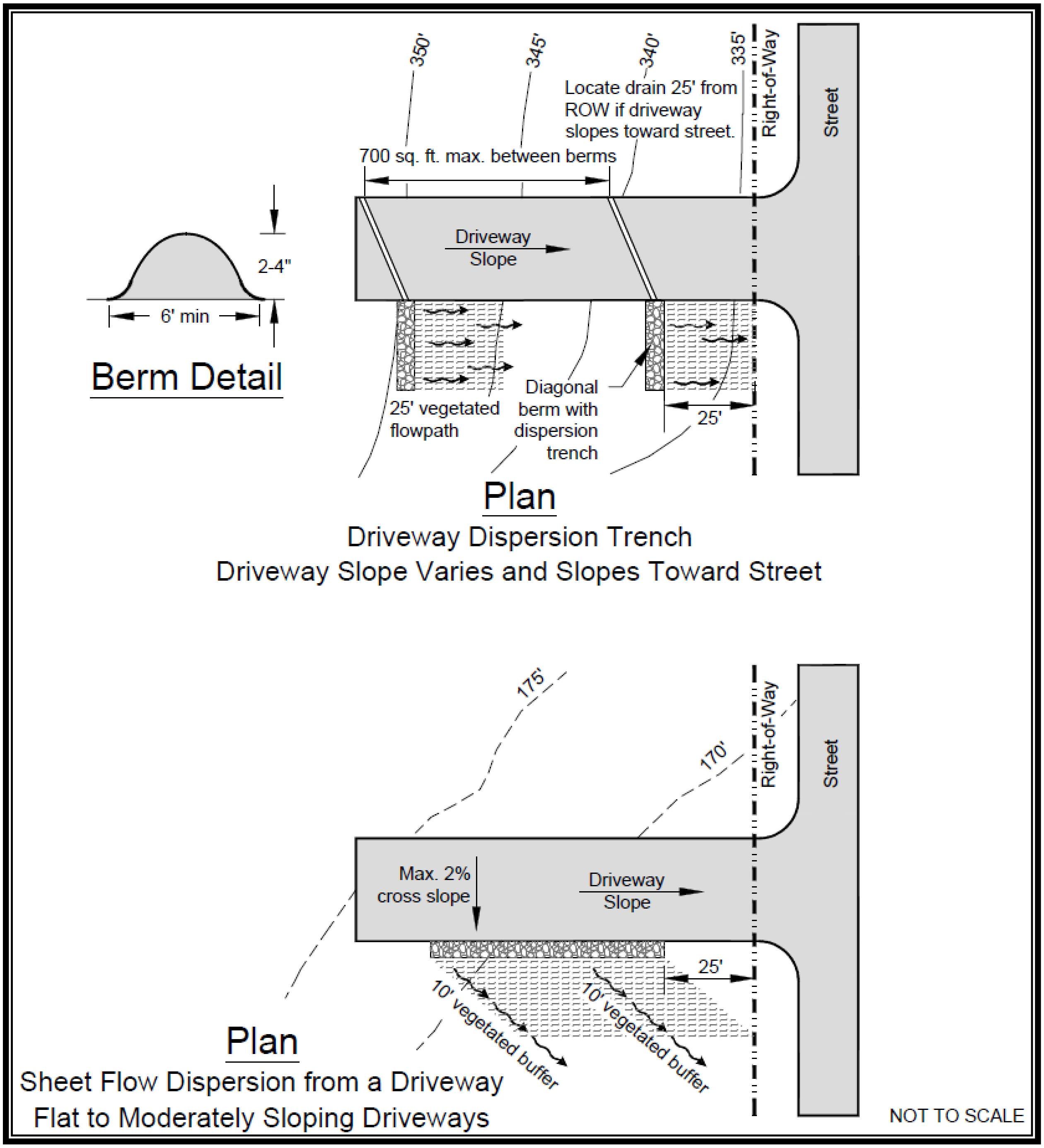


Figure 7.1. Sheet Flow Dispersion for Driveways.

7.3.1 Construction Criteria

Protect the dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area to meet the postconstruction soil quality and depth requirements in Chapter 6 and establish a dense cover of lawn, landscape, or groundcover. See Volume II, Section 3.3, for additional dispersion facility construction requirements.

7.3.2 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

7.4 Concentrated Flow Dispersion (Ecology BMP T5.11)

7.4.1 Description

Dispersion of concentrated flows from driveways or other pavement through a vegetated pervious area attenuates peak flows by slowing entry of the runoff into the conveyance system, allows for some infiltration, and provides some water quality benefits. See Figure 7.2.

7.4.2 Applications and Limitations

- Concentrated flow dispersion can be used in any situation where concentrated flow can be dispersed through vegetation.
- Modeling credits for concentrated flow dispersion (see below) can be applied to help meet the flow control standards of Minimum Requirement #7, as well as to help achieve compliance with the Performance Standard option of Minimum Requirement #5.
- Dispersion for driveways will generally only be effective for single-family residences on large lots and in rural short plats. Lots proposed by short plats in urban areas will generally be too small to provide effective dispersion of driveway runoff.
- Figure 7.2 shows two possible ways of spreading flows from steep driveways.

7.4.3 Modeling and Sizing

Where concentrated flow dispersion is used to disperse runoff into an undisturbed native landscape area or an area that meets the requirements of Chapter 6, and the vegetated flowpath is at least 50 feet, the impervious area may be modeled as grass/lawn area. If the available vegetated flowpath is 25 to 50 feet, use of a dispersion trench allows modeling the impervious area as 50 percent impervious/50 percent landscape.

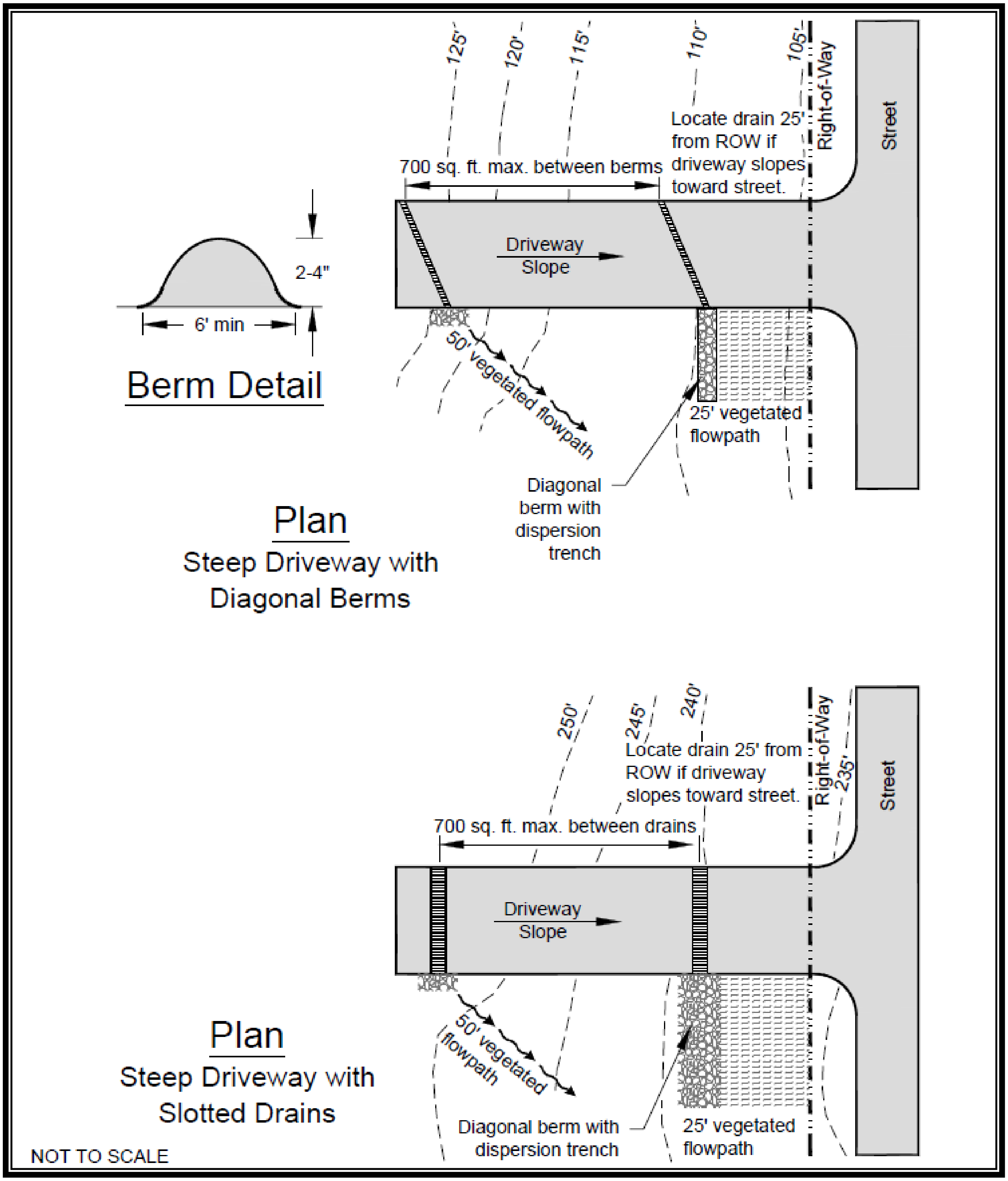


Figure 7.2. Typical Concentrated Flow Dispersion for Steep Driveways.

7.4.4 Concentrated Flow Dispersion Design Criteria

Refer to general dispersion design criteria above. Additional design criteria specific to concentrated flow dispersion include:

- Maintain a vegetated flowpath of at least 50 feet (if using rock pads) or 25 feet (if using dispersion trenches) between the discharge point and any property line, structure, slopes steeper than 20 percent, stream, lake, wetland, or other impervious surface. The flowpath length is measured perpendicular to site contours.

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

- A maximum of 700 square feet of impervious area may drain to each concentrated flow dispersion device.

- Provide a pad of crushed rock (2 feet wide by 3 feet long by 6 inches deep) or dispersion trench (per Chapter 15) at each discharge point.

- No erosion or flooding of downstream properties may result.

- Each 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 minimum required flowpath lengths.

7.4.5 Construction Criteria

Protect the dispersion flowpath from sedimentation and compaction during construction. If the flowpath area is disturbed during construction, restore the area to meet the postconstruction soil quality and depth BMP requirements in Chapter 6 and establish a dense cover of lawn, landscape, or groundcover. See Volume II, Section 3.3, for additional dispersion facility construction requirements.

7.4.6 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Chapter 8 – Tree Planting and Tree Retention (Ecology BMP T5.16)

8.1 Description

Trees provide flow control via interception, transpiration, and increased infiltration. Additional environmental benefits include improved air quality, carbon sequestration, reduced heat island effect, pollutant removal, and habitat preservation or formation.

8.2 Applications and Limitations

- When used in combination with other low impact development techniques, retained and newly planted trees can help achieve compliance with the Minimum Requirement #5.

- When implemented in accordance with the criteria outlined below, retained and newly planted trees receive credits toward meeting the flow control standards of Minimum Requirement #7. The degree of flow control provided by a tree depends on the tree type (i.e., evergreen or deciduous), canopy area, and proximity to hard surfaces. Flow control credits may be applied to project sites of all sizes.

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

8.2.1 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.

8.2.2 Newly Planted Trees

Mature tree height, size, and rooting depth must be considered to ensure that new tree planting locations are appropriate given adjacent above- and below-ground infrastructure. Although setbacks will vary by species, some general recommendations include:

- Minimum 5-foot setback from structures

- Minimum 2-foot setback from edge of any paved surface.

8.3 Modeling and Sizing

Retained Trees

Flow control credits for retained trees are provided in Table 8.1 by tree type. These credits can be applied to reduce hard surface area requiring flow control. Credits are given as a percentage of the existing tree canopy area. The minimum credit for existing trees ranges from 50 to 100 square feet.

Table 8.1. Flow Control Credits for Retained Trees.

Tree Type	Credit
Evergreen	20% of canopy area (minimum of 100 sq. ft./tree)
Deciduous	10% of canopy area (minimum of 50 sq. ft./tree)

Impervious/Hard Surface Area Mitigated = (Σ Evergreen Canopy Area x 0.2) + (Σ Deciduous Canopy Area x 0.1).

Tree credits are not applicable to trees in native vegetation areas used for flow dispersion or other flow control credit. Credits are also not applicable to trees in planter boxes. The total tree credit for retained and newly planted trees shall not exceed 25 percent of hard surface requiring mitigation.

8.3.1 Newly Planted Trees

Flow control credits for newly planted trees are provided in Table 8.2 by tree type. These credits can be applied to reduce the hard surface area requiring flow control. Credits range from 20 to 50 square feet per tree.

Table 8.2. Flow Control Credits for Newly Planted Trees.

Tree Type	Credit
Evergreen	50 ft^2 per tree
Deciduous	20 ft^2 per tree

Impervious/Hard Surface Area Mitigated = Σ Number of Trees x Credit (square feet).

Tree credits are not applicable to trees in native vegetation areas used for flow dispersion or other flow control credit. Credits are also not applicable to trees in planter boxes. The total tree credit for retained and newly planted trees shall not exceed 25 percent of the hard surface requiring mitigation.

8.4 Tree Planting and Tree Retention Design Criteria

8.4.1 Retained Trees

The following design criteria are specific to projects proposing to retain on-site trees for flow control credits.

Tree Species and Condition

- Existing tree species and location must be clearly shown 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 flow control credit, retained trees shall have a minimum 6-inch diameter at breast height (dbh), which 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 below.

Tree Canopy Area

- The retained tree canopy area shall be 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 (see also Figure 8.1). If trees are clustered, overlapping canopies are not double-counted.

Tree Location

- Flow control credit for retained trees depends upon proximity to ground level hard surfaces. To receive a credit, the existing tree must be on the development site and within 20 feet of new and/or replaced ground level hard surfaces (e.g., driveway or patio) on the development site. Distance from hard surfaces is measured from the tree trunk center.

- Minimize the installation of any impervious surfaces in critical root zones. An arborist report is required 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 (see also Figure 8.1). If the arborist report concludes that 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, the tree flow control credit may still be approved.

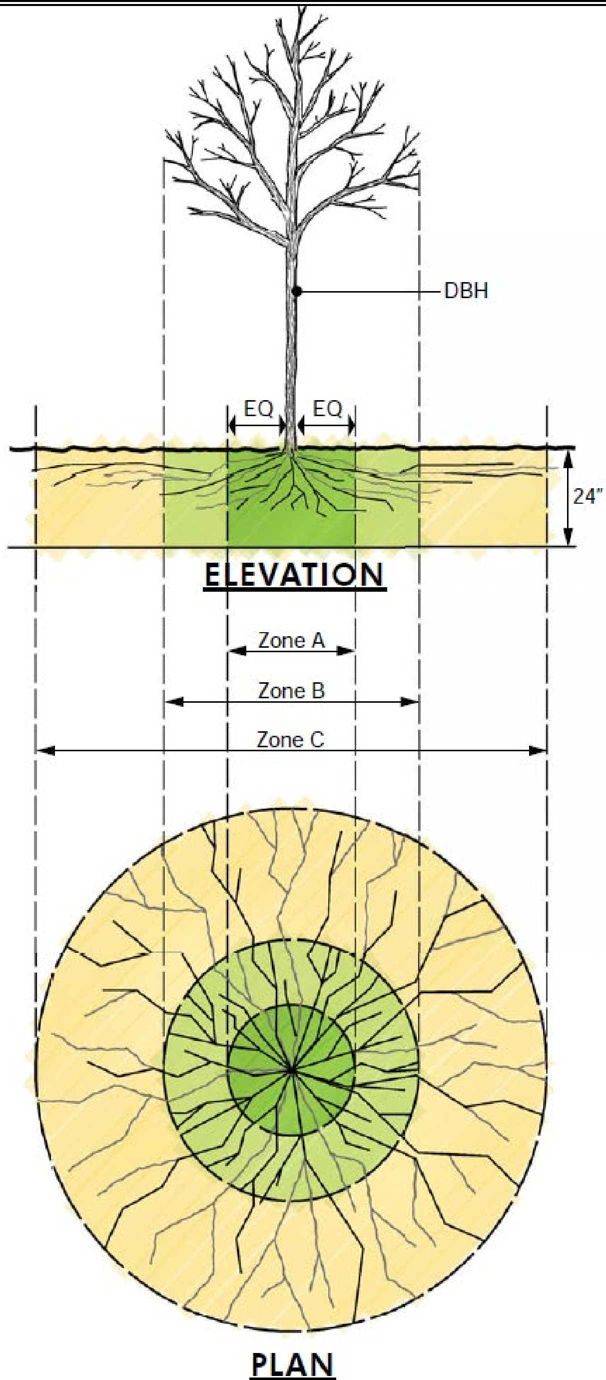
- Where road or sidewalk surfaces are needed under a tree canopy, unmortared permeable pavers or flagstone (rather than concrete or asphalt) or bridging techniques should be used (see Figure 8.2).

8.4.2 Newly Planted Trees

The following design criteria are specific to projects proposing to plant new on-site trees for flow control credits.

Tree Species

It is recommended that a landscape architect or other trained professional guide plant selection for each unique location and/or application. An approved list of tree species is provided on the city web site.



TREE PROTECTION ZONES:

Zone A - *Critical Root Zone*
The area under a tree whose diameter at breast height (DBH) measures 1 foot per 1 inch of DBH from the trunk outwards and twenty-four inches in depth. See table below for examples:

Tree Diameter	CRZ radius	CRZ diameter (including tree trunk)
2 inches	2 feet	4.5 feet
6 inches	6 feet	13 feet
20 inches	20 feet	42 feet
50 inches	50 feet	105 feet

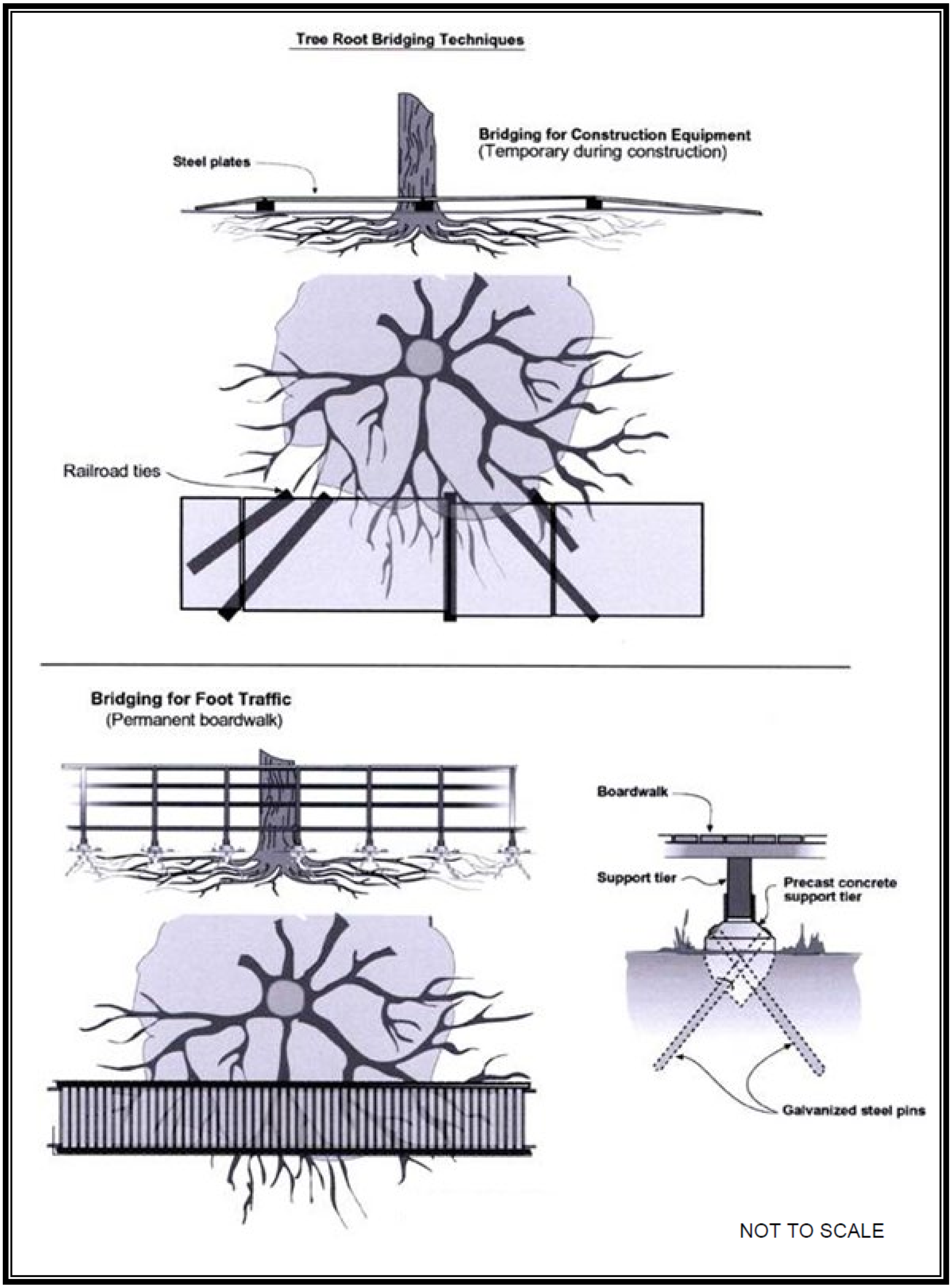
Zone B - *Drip Line*
The area on the ground below the tree in which the boundary is designed by the edge of the tree's crown. For young trees, Zone A and B may be one and the same.

Zone C - *Feeder Root Zone*
The area under a tree whose diameter measures 2 feet per one inch of DBH from the trunk outwards and 24 inches in depth. For example, for a 10 inch DBH tree, the Feeder Root Zone is at least 20 feet in diameter and 24 inches deep.

Tree Protection Zone (TPZ)
"Tree Protection Zone" is an arborist defined area surrounding the trunk intended to protect the roots and soil to ensure future tree health and stability. A TPZ consists of a minimum Zone A or B, whichever is greater, or other area as defined by a project arborist or urban forester.

Source: WSU and PSP 2012

Figure 8.1. Tree Protection Zones.



Source: WSU and PSP 2012

Figure 8.2. Root Bridge.

Tree Size

To receive flow control credit, new deciduous trees at the time of planting shall be at least 1.5 inches in diameter measured 6 inches above the ground. New evergreen trees shall be at least 4 feet tall.

Tree Location

- Similar to retained trees, flow control credit for newly planted trees depends upon proximity to ground level hard surfaces. To receive a credit, the tree must meet tree location requirements listed in retained tree design criteria above. Distance from hard surfaces is measured from the edge of the surface to the center of the tree at ground level.

- Trees shall be sited according to sun, soil, and moisture requirements. Planting locations shall be selected to ensure that sight distances and appropriate setbacks are maintained given mature height, size, and rooting depths.

- To help ensure tree survival and canopy coverage, the minimum tree spacing for newly planted trees shall accommodate mature tree spread. On-site stormwater management and/or flow control credit shall not be given for new trees with on-center spacing of less than 10 feet.

Plant Material and Planting Specifications

- Standard practices for planting materials and methods are provided on the city web site and on the Trees Are Good web site <http://www.treesaregood.com/treeowner/treeownerinformation.aspx>.

8.5 Construction Criteria

Protect trees and tree root systems utilizing the following methods:

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

- Trees that are removed or die shall be replaced with like species during the next planting season (typically in fall). Trees shall be pruned according to industry standards (ANSI A 300 standards).

- Reduce soil compaction during the construction phase by protecting critical tree root zones that usually extend beyond the trees canopy or drip line. The critical tree root zone should be factored using the tree’s diameter at breast height (see Figure 8.1).

- Prohibit any excavation within the critical tree root zone.

- Prohibit the stockpiling or disposal of excavated or construction materials in the tree planting areas to prevent contaminants from damaging vegetation and soils.

- Avoid excavation or changing the grade near trees that have been designated for protection. If the grade level around a tree is to be raised, a dry rock wall or rock well shall be constructed around the tree. The diameter of this wall or well should be at least equal to the diameter of the tree canopy plus 5 feet.

- Prevent wounds to tree trunks and limbs during the construction phase.

- Tree root systems tend to overlap and fuse among adjacent trees. Trees or woody vegetation that will be removed and that are next to preserved trees must be cut rather than pushed over with equipment. Where construction operations unavoidably require temporary access over tree root zones or other soil protection areas, provide protection as follows.

    - For foot access or similar light surface impacts, apply a 6-inch layer of arborist wood chip mulch and water regularly to maintain moisture, control erosion and protect surface roots.

    - For any vehicle or equipment access, apply a minimum 1-inch steel plate or 4-inch-thick timber planking over 2 to 3 inches of arborist wood chip mulch, or a minimum 0.75-inch plywood over 6 to 8 inches of arborist wood chip mulch to protect roots and root zone soil from disturbance or compaction.

- Prep the tree protection zone (See Figure 8.1) to better withstand the stresses of the construction phase by pruning and applying a 1-inch layer of compost covered with a 2-inch layer of mulch around them well in advance of construction activities.

8.6 Operations and Maintenance Criteria

Trees shall be retained, maintained, and protected on site after construction and for the life of the development or until any approved redevelopment occurs in the future. 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 installation to help ensure tree survival.

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

Chapter 9 – Bioretention Cells, Swales, and Planter Boxes (Ecology BMPs T5.14 and T7.30)

9.1 Description

Bioretention areas are shallow stormwater systems with a designed soil mix and plants adapted to the local climate and soil moisture conditions. Bioretention areas are designed to mimic a forested condition by controlling stormwater through detention, infiltration, and evapotranspiration. Bioretention areas also provide water quality treatment through sedimentation, filtration, adsorption, and phytoremediation.

Bioretention areas function by storing stormwater 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.

The terms “bioretention area” and “rain garden” are sometimes used interchangeably. Bioretention areas and rain gardens are applications of the same LID concept and can be highly effective for reducing surface runoff and removing pollutants. However, in the City of Tumwater (in accordance with Ecology’s distinction), the term “bioretention” is used to describe an engineered facility that includes designed soil mixes and perhaps underdrains and control structures. The term “rain garden” is used to describe a shallow landscaped depression on small project sites that only trigger Minimum Requirements #1 through #5. Rain gardens have less restrictive design criteria for the soil mix and do not include underdrains or other control structures. See Chapter 10 for more information on rain garden design.

The term bioretention is used to describe various designs using soil and plant complexes to manage stormwater. The following bioretention-related terminology is used in this manual:

- **Bioretention cells** are shallow depressions with a designed planting soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants. Bioretention cells may or may not have an underdrain and are not designed as a conveyance system. Bioretention cells can be configured as depressed landscape islands, larger basins, planters, or vegetated curb extensions.

- **Bioretention swales** incorporate the same design features as bioretention cells. However, bioretention swales are designed as part of a system that can convey stormwater when maximum ponding depth is exceeded. Bioretention swales have relatively gentle side slopes and ponding depths that are typically 6 to 12 inches.

- **Bioretention planters and planter boxes** incorporate designed soil mix and a variety of plant material including trees, shrubs, grasses, and/or other herbaceous plants within a vertical walled container usually constructed from formed concrete, but could include other materials. Planter boxes are completely impervious and include a bottom (they must include an underdrain). Planters have an open bottom and allow infiltration to the subgrade. These designs are often used in ultra-urban settings.

Note: Ecology has approved use of certain patented treatment systems that use specific, high-rate media for treatment. These systems may be similar to bioretention facilities, but, unless specifically approved by Ecology, they are not considered on-site stormwater management BMPs and are not options for meeting the requirements of Minimum Requirement #5. The Ecology approval (GULDs only) is meant to be used to meet Minimum Requirement #6, where appropriate.

Figure 9.1 shows an example illustration of a bioretention cell. See Figure 9.2 for an example of a bioretention planter.

9.2 Applications and Limitations

Bioretention provides effective removal of many stormwater pollutants by passing stormwater through a soil profile that meets specified characteristics. Bioretention areas that infiltrate stormwater into the ground can also serve a significant flow reduction function.

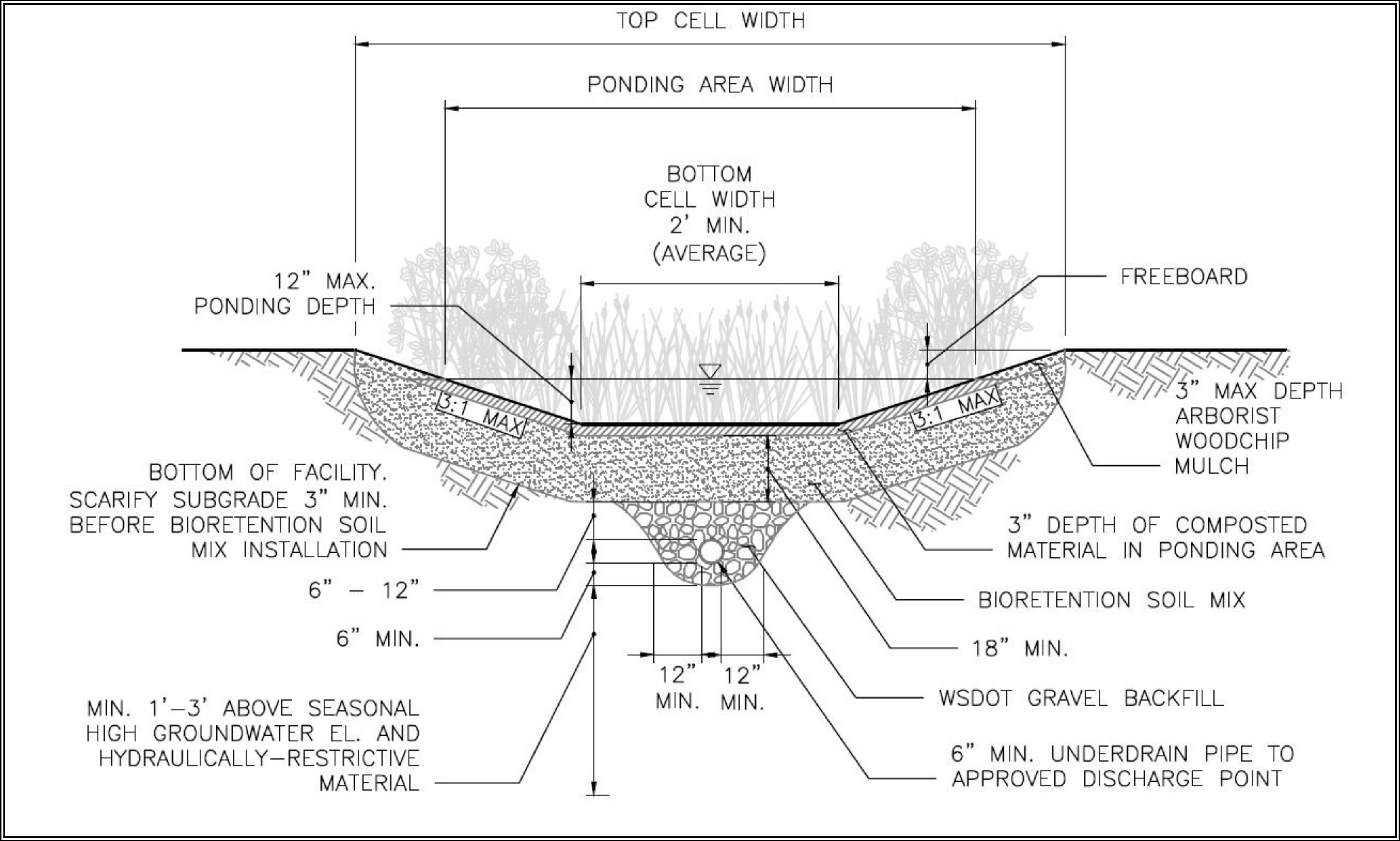
- Bioretention areas are an on-site stormwater management BMP option for: 1) projects that only have to comply with Minimum Requirements #1 through #5, and 2) projects that trigger Minimum Requirements #1 through #9.

- Bioretention can be sized to achieve the Performance Standard option or can be applied from List #1 or List #2 option of Minimum Requirement #5.

- Bioretention areas may meet the Minimum Requirement #6 requirements for basic and enhanced treatment (see Volume I, Section 2.4.7 and Chapter 23) when the bioretention soil meets the requirements described under the "Bioretention Soil Mix" heading, below.

- Bioretention can be designed to fully meet the flow control duration standard of Minimum Requirement #7. However, because they typically do not have an orifice restricting overflow or underflow discharge rates, most designs typically do not fully meet Minimum Requirement #7. Nonetheless, their performance contributes to meeting the standard, and that can result in much smaller flow control facilities on the project site.

- Bioretention areas are particularly effective at flow control in locations where the underlying soil has a high infiltration rate. Where the native soils have low infiltration rates, underdrain systems can be installed and the facility used to filter pollutants and detain flows that exceed infiltration capacity of the surrounding soil. However, designs utilizing underdrains provide less flow control benefits.



Source: Pierce County 2015

Figure 9.1. Bioretention Cell (shown with optional underdrain).

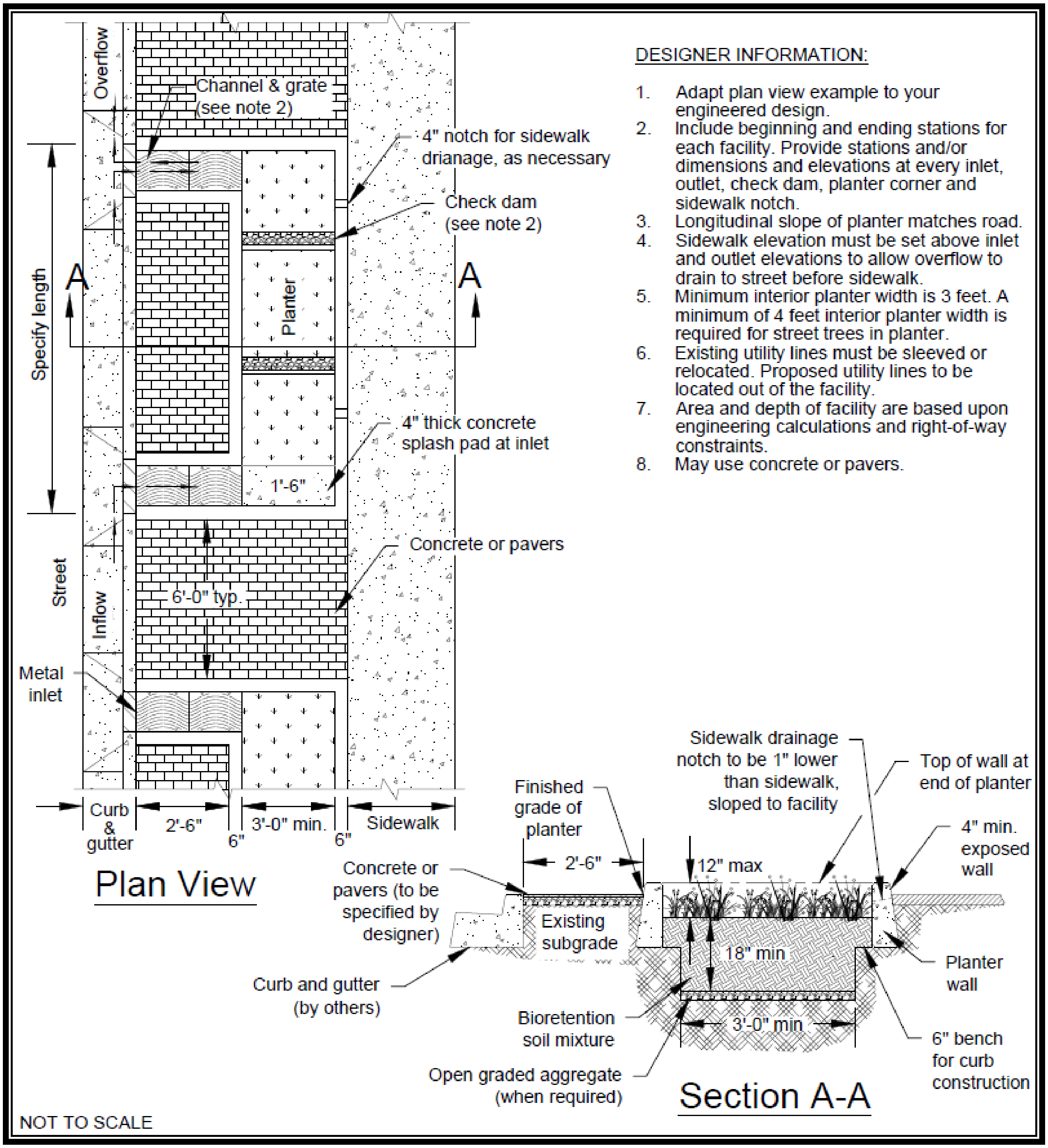


Figure 9.2. Example of a Bioretention Planter.

- Because bioretention areas use an imported soil mix that has a moderate design infiltration rate, they are best applied for small drainage areas and near the source of the stormwater. Cells may be scattered throughout a subdivision, a swale may run alongside an access road, or a series of planter boxes may serve a road.

- Bioretention areas are applicable to new development, redevelopment, and retrofit projects. Typical applications with or without underdrains include:

  - Individual lots for managing rooftop, driveway, and other on-lot impervious surfaces.

  - Shared facilities located in common areas for individual lots.

  - Areas within loop roads or cul-de-sacs.

  - Landscaped parking lot islands, where bioretention can be situated lower than the height of the parking lot surface so that stormwater runoff is directed as sheet flow into the bioretention area. This application, in concert with permeable surfaces in the parking lot, can greatly attenuate stormwater runoff.

  - Within rights-of-way along roads (often linear bioretention swales and cells).

  - Common landscaped areas in apartment complexes or other multifamily housing designs.

  - Planters on building roofs, patios, and as part of streetscapes.

9.3 Infeasibility Criteria

The following criteria describe conditions that make bioretention not required for consideration in the List #1 or List #2 option of Minimum Requirement #5. In addition, other bioretention design criteria and site limitations that make bioretention areas infeasible (e.g., setback requirements) may also be used to demonstrate infeasibility, subject to approval by the city. See also Appendix V-B for a summary of infeasibility criteria for all BMPs. If a project proponent wishes to use a bioretention BMP, but is not required to because of these feasibility criteria, they may propose a functional design to the city.

Note: Criteria with setback distances are as measured from the bottom edge of the bioretention soil mix.

Citation of any of the following infeasibility criteria must be based on an evaluation of site-specific conditions and a written recommendation from an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist).

It is infeasible to locate a bioretention facility:

- Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or downgradient flooding.
- Where the only area available for siting would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, pre-existing structures, or pre-existing road or parking lot surfaces.
- Where the only area available for siting does not allow for a safe overflow pathway to a stormwater drainage system.
- Where there is a lack of usable space for bioretention areas at re-development sites, or where there is insufficient space within the existing public right-of-way on public road projects.
- Where infiltrating water would threaten existing, below-grade basements.
- Where infiltrating water would threaten shoreline structures, such as bulkheads.

The following criteria can be cited as reasons for infeasibility without further justification (though some require professional services to make the observation).

It is infeasible to locate a bioretention facility:

- Within setbacks provided in “Setbacks and Site Constraints” subsection below.
- Where they are not compatible with a surrounding drainage system, as determined by the city (e.g., project drains to an existing stormwater collection system, but the elevation or location of that system precludes connection to a properly functioning bioretention area).
- Where land for bioretention is within an erosion hazard or landslide hazard area (as defined by Title 16.20 TMC).
- Where the site cannot be reasonably designed to locate bioretention areas on slopes less than 8 percent.
- For properties with known soil or groundwater contamination (typically federal Superfund sites or state cleanup sites under the Model Toxics Control Act [MTCA]):
    - Within 100 feet of an area known to have deep soil contamination.
    - Where groundwater modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the groundwater.

  - Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the bioretention area.
  - Any area where these facilities are prohibited by an approved cleanup plan under the MTCA or federal Superfund law, or an environmental covenant under Chapter 64.70 RCW.

- Within 100 feet of a closed or active landfill.

- Within 10 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is 1,100 gallons or less. As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10 percent or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface.

- Within 100 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is greater than 1,100 gallons.

- Where the field testing indicates potential bioretention area site has a measured (a.k.a., initial) native soil saturated hydraulic conductivity less than 0.30 inch per hour. A small-scale PIT or large-scale PIT in accordance with Appendix V-A shall be used to demonstrate infeasibility of bioretention areas. In these slow-draining soils, a bioretention area with an underdrain may be used to treat pollution-generating surfaces to help meet Minimum Requirement #6, Runoff Treatment. If the underdrain is elevated within a base course of gravel, the bioretention facility will also provide some modest flow reduction benefit that will help achieve Minimum Requirement #7.

- Where the minimum vertical separation of 3 feet to the known or seasonal high groundwater elevation or other impermeable layer would not be achieved below bioretention that would serve a drainage area that exceeds the following thresholds:
  - 5,000 square feet of PGIS
  - 10,000 square feet of impervious area
  - 0.75 acre of lawn and landscape

- Where the minimum vertical separation of 1 foot to the known or seasonal high groundwater or other impermeable layer would not be achieved below bioretention that would serve a drainage area less than the above thresholds.

9.3.1 Other Site Suitability Factors

- Utility conflicts: Consult City of Tumwater requirements for horizontal and vertical separation required for publicly-owned utilities, such as sewer lines. Consult the appropriate franchise utility owners for separation requirements from their utilities, which may include communications, water, power, and gas. When separation requirements cannot be met, designs should include appropriate mitigation measures, such as impermeable liners over the utility, sleeving utilities, fixing known leaky joints or cracked conduits, and/or adding an underdrain to the bioretention.

- Transportation safety: The design configuration and selected plant types should provide adequate sight distances, clear zones, and appropriate setbacks for roadway applications in accordance with the city's requirements.

- Ponding depth and surface water draw-down: Flow control needs, as well as location in the development, and mosquito breeding cycles will determine draw-down timing. For example, front yards and entrances to residential or commercial developments may require rapid surface dewatering for aesthetics.

- Impacts of surrounding activities: Human activity influences the location of the facility in the development. For example, locate bioretention areas away from traveled areas on individual lots to prevent soil compaction and damage to vegetation, or provide elevated or bermed pathways in areas where foot traffic is inevitable and provide barriers, such as wheel stops, to restrict vehicle access in roadside applications.

- Visual buffering: Bioretention areas can be used to buffer structures from roads, enhance privacy among residences, and as aesthetic site features.

- Site growing characteristics and plant selection: Appropriate plants should be selected for sun exposure, soil moisture, and adjacent plant communities. Native species or hardy cultivars are recommended and can flourish in the properly designed and placed bioretention soil mix with no nutrient or pesticide inputs and 2 to 3 years' irrigation for establishment. Invasive species control may be necessary.

9.4 Modeling and Sizing

Bioretention areas receiving runoff from roads or a combination of roads and other impervious/pervious surfaces will be larger than rain gardens. For bioretention areas designed to meet Minimum Requirement #5, the bioretention area shall have a horizontally projected surface area below the overflow that is at least 5 percent of the total impervious surface area draining to the bioretention area. If pervious areas will also be draining to the bioretention area, the horizontally projected surface area below the overflow shall be increased by 2 percent of the pervious area. For bioretention areas designed to meet Minimum Requirement #6 or #7, the bioretention area must be sized using an approved continuous simulation model.

When using continuous modeling to size bioretention areas, the assumptions listed in Table 9.1 shall be applied. It is recommended that bioretention cells be modeled as a layer of soil (with specified infiltration rate) with infiltration to underlying soil, ponding, and overflow. The bioretention soil is designed in accordance with the treatment soil requirements outlined in the design criteria below.

Table 9.1. Continuous Modeling Assumptions for Bioretention Cells.

Variable	Assumption
Computational Time Step	15 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 Mix Measured Infiltration Rate	For imported soil, rate is 12 inches per hour before applying the correction factor.
Bioretention Soil Porosity	30 percent
Bioretention Soil Depth	Minimum of 18 inches
Native Soil Infiltration Rate	Measured infiltration rate, including applicable safety factors (see Appendix V-A)
Infiltration Across Wetted Surface Area	Only if side slopes are 3:1 or flatter
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	Overflow elevation set at maximum ponding elevation (excluding freeboard). May be modeled as weir flow over riser edge or riser 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.

To meet Minimum Requirement #6, at least 91 percent of the influent runoff file produced using a continuous simulation model must be infiltrated. Applicable water quality design storm volume drawdown requirements must also be met (see Volume I, Chapter 4).

If 91 percent of the influent runoff file cannot be infiltrated, the percent infiltrated may be subtracted from the 91 percent volume that must be treated, and downstream treatment facilities may be significantly smaller as a result.

To meet Minimum Requirement #7, the tributary areas, cell bottom area, and ponding depth must be iteratively sized until the duration curves and/or peak values meet the applicable flow control requirements (see Volume I, Chapter 2).

At the time of publication of this volume, the professional version of WWHM included a bioretention module that can be used to size the cell with or without an underdrain as a function of tributary area, land use type, native soil infiltration rate, side slopes, etc. It is anticipated that other modeling programs will develop similar modules to represent bioretention cells in the future.

For additional guidance on bioretention modeling and sizing, see the 2019 Ecology Manual, Volume III, Section III-2.

Infiltration rates of the native soil (i.e., the undisturbed soil below the imported and/or amended facility soil) and bioretention soil mix infiltration rate must be used when sizing and modeling bioretention areas. The native infiltration rate shall be determined using the methods outlined above. The method for determining infiltration rate of bioretention soil mix is described in the “Bioretention Soil Mix” subsection below.

9.5 Field and Design Procedures

Geotechnical analysis is an important first step to develop an initial assessment of the variability of site soils, infiltration characteristics, and the necessary frequency and depth of infiltration tests. This section includes infiltration testing requirements and application of appropriate safety factors specific to bioretention areas.

Refer to Appendix V-A for detailed descriptions of methods for infiltration rate testing procedures. However, note that the subgrade safety factors in Appendix V-A may not apply to bioretention (additional details are provided below).

If the bioretention area includes a liner and does not infiltrate into the underlying soils, it is not considered an infiltration facility and is not subject to the infiltration procedures or the setbacks provided in this section. Adhere to setbacks and site constraints for detention vaults included in Chapter 20 for such facilities.

9.5.1 Determining Design Infiltration Rate

Determining the infiltration rate of the site soils is necessary to determine feasibility of designs that intend to infiltrate stormwater on site. Infiltration rates are also necessary to estimate bioretention performance using the WWHM.

9.5.2 Determining Initial Soil Infiltration Rate

Initial (measured) infiltration rates are determined through soil infiltration tests. Infiltration tests must be run at the anticipated elevation of the top of the native soil beneath the bioretention area. Test hole or test pit explorations shall be conducted during mid to late in the winter season (December 1 through April 30) to provide accurate groundwater saturation and groundwater information. The following provides required test procedures for analysis of the soils underlying bioretention areas.

- Projects subject to Minimum Requirements #1 through #5:
  - One small-scale PIT or soil grain size analysis (for sites underlain by Type A soils) outlined in Appendix V-A shall be performed at each potential bioretention site. Tests at more than one site could reveal the advantages of one location over another.

    Note that to demonstrate infeasibility of bioretention areas, a small-scale PIT in accordance with Appendix V-A must be used.
  - Confirm that the site has the required 1-foot minimum clearance to the known or seasonal high groundwater or other impermeable layer (refer to “Setbacks and Site Constraints,” below).
- Projects subject to Minimum Requirements #1 through #9:
  - For small bioretention cells (bioretention areas receiving water from one or two individual lots or <0.25 acre of pavement or other impervious surface), a small-scale PIT or soil grain size analysis (for sites underlain by Type A soils) outlined in Appendix V-A shall be performed at each potential bioretention site. Tests at more than one site could reveal the advantages of one location over another.
  - For large bioretention cells (bioretention areas receiving water from several lots or from 0.25 acre or more of pavement or other impervious surface), a small-scale PIT or soil grain size analysis (for sites underlain by Type A soils) outlined in Appendix V-A, shall be performed every 5,000 square feet. The more test pits/borings used, and the more evidence of consistency in the soils, the less of a safety factor may be used. If soil characteristics across the site are consistent, a geotechnical professional may recommend a reduction in the number of tests.

    If using the PIT method, multiple small-scale or one large-scale PIT can be used. If using the small-scale test, measurements shall be taken at several locations within the area of interest.
  - For bioretention swales or long, narrow bioretention areas (i.e., one following the road right-of-way), a small-scale PIT or soil grain size analysis (for sites underlain by Type A soils) outlined in Appendix V-A shall be performed every 200 linear feet and within each length of road with varying subsurface characteristics (i.e., groundwater elevation, soils type, infiltration rates). However, if the site subsurface characterization, including soil borings across the development site, indicate consistent soil characteristics and depths to

seasonal high groundwater conditions, the number of test locations may be reduced to a frequency recommended by a geotechnical professional.

Note that to demonstrate infeasibility of bioretention areas, a small-scale PIT or large-scale PIT in accordance with Appendix V-A must be used.

- Confirm that the site has the required 1- or 3-foot minimum clearance to the known or seasonal high groundwater or other impermeable layer (refer to "Setbacks and Site Constraints," below).

- If a single bioretention area serves a drainage area exceeding 1 acre, infiltration receptor analysis and performance testing may be necessary. See Section 2.2, Step 5, for specific requirements for infiltration receptor characterization.

- If the general site assessment cannot confirm that the seasonal high groundwater or hydraulic restricting layer will be greater than 1 or 3 feet below the bottom of the bioretention, monitoring wells or excavated pits should be placed strategically to assess depth to groundwater.

9.5.3 Assignment of Appropriate Safety Factor

- If deemed necessary by a qualified professional engineer, a safety factor may be applied to the measured Ksat of the subgrade soils to estimate its design (long-term) infiltration rate. Depending on the size of the facility, the variability of the underlying soils, and the number of infiltration tests performed, a safety factor may be advisable. (Note: This is a separate design issue from the assignment of a safety factor to the overlying, designed bioretention soil mix. See the "Bioretention Soil Mix" subsection below).

- The overlying bioretention soil mix provides excellent protection for the underlying native soil from sedimentation. Accordingly, a safety factor for the native soil (i.e., $F_{plugging}$ used in Appendix V-A) does not have to take into consideration the extent of influent control and clogging over time.

9.5.4 Prepare Soils Report

For projects subject to Minimum Requirements #1 through #5, a Soils Report must be prepared by a professional soil scientist certified by the Soil Science Society of America (or an equivalent national program), a locally licensed on-site sewage designer, or by other suitably trained persons working under the supervision of a professional engineer, geologist, hydrogeologist, or engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.2, for Abbreviated Plan Soils Report requirements.

For projects subject to Minimum Requirements #1 through #9, a Soils Report must be prepared that is stamped by a professional engineer with geotechnical expertise, a licensed geologist, a hydrogeologist, or an engineering geologist registered in the State of

Washington. Refer to Volume I, Section 3.3.3, for Drainage Control Plan Soils Report requirements.

9.5.5 Estimate Volume of Stormwater

If required, use the WWHM or other approved continuous runoff model to generate an influent file that will be used to size the bioretention area. The facility must infiltrate either all of the flow volume as specified by the influent file, or a sufficient amount of the flow volume such that any overflow/bypass meets the flow duration standard in Minimum Requirement #7. In addition, the overflow/bypass must meet the LID Performance Standard if it is the option chosen to meet Minimum Requirement #5, or if it is required of the project.

9.6 Bioretention Design Criteria

The following provides descriptions, recommendations, and requirements related to the components of bioretention. 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. Submittal for facility review must include documentation of the following elements, discussed in detail below.

- Setbacks and site constraints
- Flow entrance/presettling
- Ponding area
- Bottom area and side slopes
- Overflow
- Bioretention soil mix
- Underdrain (if included)
- Check dams and weirs
- Planting
- Mulch layer
- Hydraulic restriction layer.

9.6.1 Setbacks and Site Constraints

For setbacks and site constraints for non-infiltrating bioretention (i.e., lined bioretention cells or planter boxes), refer to the setbacks for detention vaults in Chapter 20. See

Section 9.3, Infeasibility Criteria, for setbacks and site constraints used to evaluate the bioretention option of List #1 and List #2 (Minimum Requirement #5). (See also Appendix V-B for a summary of infeasibility criteria for all BMPs.) The following minimum setbacks and site constraints apply to all infiltrating bioretention areas (i.e., bioretention without a liner or planter box). To request a variance from setbacks not related to wells and septic systems, the project proponent may submit a request to the Administrator documenting the impracticality or infeasibility of the setback, which may require written recommendations from a geotechnical engineer.

- All bioretention areas shall have a minimum of 1 foot positive vertical clearance from any open water maximum surface elevation to structures within 25 feet.
- All bioretention areas shall be a minimum of 10 feet away from any structure or property line. This setback may be reduced by the city for facilities within or adjacent to the right-of-way.
- All bioretention areas shall be set back at least 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high. A reduced setback may be allowed if a geotechnical assessment is done and a Soils Report is prepared that addresses the potential impact of the facility on the slope and recommends a reduced setback. In no case shall the setback be less than the vertical height of the slope.
- All bioretention areas shall be a minimum of 5 feet from septic tanks and distribution boxes.
- For sites with on-site or adjacent septic systems, the edge of the design water surface must be at least 30 feet upgradient, or 10 feet downgradient, of the drainfield primary and reserve areas (per WAC 246-272A-0210). This requirement may be modified by the Thurston County Public Health and Social Services Department if site topography clearly prohibits flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that this is unnecessary.
- Bioretention is prohibited within 300 feet of an erosion hazard or landslide hazard area (as defined by Title 16.20.045 TMC) unless a geotechnical professional has analyzed and mitigated the slope stability impacts of bioretention, and appropriate analysis indicates that the impacts are negligible.
- In no case shall bioretention areas be placed closer than 100 feet from drinking water wells and springs used for drinking water supplies.
    - Where water supply wells are nearby, it is the responsibility of the applicant's engineer to locate such wells, meet any applicable protection standards, and assess possible impacts of the proposed infiltration facility on groundwater quality. If negative impacts on an individual or community water supply are possible, additional runoff treatment must be included in the facility design or relocation of the facility should be considered.

  - The Soils Report must be updated to demonstrate and document that the above criteria are met and to address potential impacts to water supply wells or springs.

- All bioretention areas shall be a minimum of 3 feet from the lowest elevation of the bioretention soil, or any underlying gravel layer, and the known or seasonal high groundwater elevation or other impermeable layer if the area tributary to the facility meets or exceeds any of the following thresholds.

  - 5,000 square feet of PGIS
  - 10,000 square feet of impervious area
  - 0.75 acre of lawn and landscape.

- For bioretention systems with a contributing area less than the above thresholds, a minimum of 1 foot of clearance from the known or seasonal high groundwater or other impermeable layer is acceptable.

- At the time this manual was published, the approved bioretention soil mixes presented in this chapter were known to release elevated levels of nutrients for a period of time after installation. Although recent research has identified methods to mitigate these nutrient export issues, the methods have not yet been formally approved. Therefore, bioretention constructed with imported composted materials is not approved for use within 0.25 mile of any fresh water bodies or conveyance systems tributary to freshwater bodies (including when designed with an underdrain), unless the underlying native soil meets the soil suitability criteria for treatment in Chapter 23. Project proponents should contact the Administrator for the latest information on bioretention soil mix options and requirements in phosphorus control areas.

- In the event that the downstream pathway of infiltration, interflow, and/or the infiltration capacity is insufficient to handle the contributing area flows (e.g., a facility enclosed in a loop roadway system or a landscape island within a parking lot), an underdrain system can be incorporated into the bioretention area. The underdrain system can then be conveyed to a nearby vegetated channel, another stormwater facility, or dispersed into a natural protection area. See the “Underdrain” subsection, below, for additional information.

9.6.2 Flow Entrance/Presettling

The design of flow entrance to a bioretention area will depend upon topography, flow velocities, flow volume, and site constraints. Flows entering a facility should have a velocity of less than 1 foot per second to minimize erosion potential. Vegetated buffer strips are the preferred entrance type because they slow incoming flows and provide initial settling of particulates.

Minimum requirements associated with the flow entrance/presettling design include:

- If concentrated flows are entering the facility, engineered flow dissipation (e.g., rock pad or flow dispersion weir) must be incorporated. Avoid the use of angular rock or quarry spalls at the flow entrance and instead use round (river) rock if needed. Removing sediment from angular rock is difficult.
- A minimum 2-inch grade change between the edge of a contributing impervious surface and the vegetated flow entrance, or 5 percent slope from the outer curb face extending to a minimum of 12 inches beyond the back of curb, is required.
- If the catchment area contains unvegetated exposed soils or steep slopes, a presettling system (e.g., a filter strip, presettling basin, or vault) is required.

Four primary types of flow entrances can be used for bioretention:

1. Dispersed, low velocity flow across a grass or landscape area. This is the preferred method of delivering flows to the facility and can provide initial settling of particulates. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.
2. Dispersed flow across pavement or gravel and past wheel stops for parking areas.
    - Parking lots that incorporate bioretention into landscaped areas should use concrete curb blocks as wheel stops to protect the bioretention area from traffic intrusion while also allowing the parking lot runoff to flow somewhat unobstructed to the bioretention area.
3. Drainage curb cuts for roadside, driveway, or parking lot areas. Curb cuts shall include rock or other erosion protection material in the channel entrance to dissipate energy.
    - The minimum 12-inch drainage curb cut results in a 12-inch opening measured at the curb flow line and will require a 3-foot cut in an existing curb. An 18-inch curb cut is recommended for most applications.
    - Provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell.
    - Curb cuts used for bioretention areas in high-use parking lots or roadways require increased level of maintenance due to high coarse particulates and trash accumulation in the flow entrance and associated bypass of flows. The following are methods recommended for areas where heavy trash and coarse particulates are anticipated:

- Curb cut width: 18 inches
- At a minimum, the flow entrance should drop 2 inches from gutter line into the bioretention area and provide an area for settling and periodic removal of debris.
- Plan for more frequent inspection and maintenance for areas with large impervious areas, high traffic loads and larger debris loads.
- Catch basins or forebays may be necessary at the flow entrance to adequately capture debris and sediment load from large contributing areas and high-use areas. Piped flow entrance in this setting can easily clog, and catch basins with regular maintenance are necessary to capture coarse and fine debris and sediment.

4. Pipe flow entrance. Piped entrances shall include rock or other erosion protection material in the facility entrance to dissipate energy and/or provide flow dispersion.
    - Catch basin: In some locations where road sanding or higher than usual sediment inputs are anticipated, catch basins can be used to settle sediment and release water to the bioretention area through a grate for filtering coarse material.
    - Trench drain. Trench drains can be used to cross sidewalks or driveways where a deeper pipe conveyance creates elevation problems. Trench drains tend to clog and may require additional maintenance.

Woody plants should not be placed directly in the entrance flowpath because they can restrict or concentrate flows and can be damaged by erosion around the root ball.

9.6.3 Ponding Area

Bioretention ponding area may be an earthen depression (for bioretention cells and swales) or a planter box (for bioretention planters or planter boxes). The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the facility. Ponding depth and draw-down rate requirements are to provide surface storage, adequate infiltration capability, and soil moisture conditions that allow for a range of appropriate plant species. Soils must be allowed to dry out periodically in order to: 1) restore hydraulic capacity of system, 2) maintain infiltration rates, 3) maintain adequate soil oxygen levels for healthy soil biota and vegetation, 4) provide proper soil conditions for biodegradation and retention of pollutants, and 5) prevent conditions supportive of mosquito breeding.

Minimum requirements associated with the bioretention ponding area design include the following.

- The ponding depth shall be a maximum of 12 inches.

- The surface pool drawdown time (surface ponding volume) shall be a maximum of 24 hours (drain time is calculated as a function of ponding depth and native soil design infiltration rate or bioretention soil mix infiltration rate, whichever is less).

The minimum freeboard measured from the invert of the overflow pipe or earthen channel to facility overtopping elevation shall be 2 inches for drainage areas less than 1,000 square feet and 6 inches for drainage areas 1,000 square feet or greater.

If berming is used to achieve the minimum top elevation needed to meet ponding depth and freeboard needs, the maximum slope on the berm shall be 3H:1V, and minimum top width of the design berm shall be 1 foot. Soil used for berming shall be imported bioretention soil or amended native soil and shall be compacted to a minimum of 90 percent dry density.

9.6.4 Bottom Area and Side Slopes

Bioretention areas are highly adaptable and can fit various settings such as rural and urban roadsides, ultra-urban streetscapes, and parking lots by adjusting bottom area and side slope configuration. Recommended maximum and minimum dimensions include:

- The maximum planted side slope should be 3H:1V. If steeper side slopes are necessary rockeries, concrete walls, or soil wraps may be effective design options.

- The bottom width should be no less than 2 feet.

Bioretention areas should have a minimum shoulder of 12 inches between the road edge and beginning of the bioretention side slope where flush curbs are used. Compaction effort for the shoulder should be 90 percent proctor.

9.6.5 Overflow

An overflow route must be identified for stormwater flows that overtop the bioretention area when infiltration capacity is exceeded or the facility becomes plugged and fails. The overflow route must be able to convey the 100-year recurrence interval developed peak flow to the downstream conveyance system or other acceptable discharge point without posing a health or safety risk or causing property damage.

Overflow can be provided by a vertical drain pipe installed at the designed maximum ponding elevation (12 inches) and connected to a downstream BMP or an approved discharge point. Overflow can also be provided by a curb cut at the downgradient end of the bioretention area to direct overflows back to the street.

9.6.6 Bioretention Soil Mix

Unlike infiltration basins and trenches, the native soil underlying bioretention areas is not subject to the soil infiltration treatment requirements discussed in Chapter 23 (i.e., soil suitability criteria #1 and #2). Bioretention areas meet the requirements for basic and enhanced treatment when the bioretention soil mix meets the requirements of the bioretention soil mix design criteria (see bioretention soil mix criteria below).

Do not use filter fabrics between the subgrade and the bioretention soil mix. The gradation between existing soils and bioretention soil mix is not great enough to allow significant migration of fines into the bioretention soil mix. Additionally, filter fabrics may clog with downward migration of fines from the bioretention soil mix.

The minimum requirements associated with the bioretention soil mix include the following.

- Minimum depth of treatment soil must be 18 inches.
- Projects can either use a default bioretention soil mix or can create a custom bioretention soil mix.
    - Projects that use the default bioretention soil mix do not have to test bioretention soil mix infiltration rate. They may assume the rates specified in the “Default Bioretention Soil Mix” subsection, below.
    - Projects that create a custom bioretention soil mix rather than using the default requirements must demonstrate compliance with the specific design criteria and must test the bioretention soil mix infiltration rate as described in the “Custom Bioretention Soil Mix” subsection, below.

9.6.7 Default Bioretention Soil Mix

Bioretention soil shall be a well-blended mixture of mineral aggregate and composted material measured on a volume basis. Bioretention soil shall consist of two parts fine compost (approximately 35 to 40 percent) by volume and three parts mineral aggregate (approximately 60 to 65 percent) by volume. The mixture shall be blended well to produce a homogeneous mix.

Mineral Aggregate

- Percent Fines: A range of 2 to 4 percent passing the U.S. #200 sieve is ideal, and fines should not be above 5 percent for a proper functioning specification according to American Society for Testing and Materials (ASTM) D422.

Mineral Aggregate Gradation

- Mineral Aggregate shall be free of wood, waste, coating, or any other deleterious material. The aggregate portion of the bioretention soil mix shall be well-graded. According to ASTM D2487-98 (Classification of Soils for Engineering Purposes

[Unified Soil Classification System]), well-graded sand should have the following gradation coefficients.

- Coefficient of Uniformity (Cu = D60/D10) equal to or greater than 4, and
- Coefficient of Curve (Cc = (D30)2/D60 x D10) greater than or equal to 1 and less than or equal to 3.

Aggregate shall be analyzed by an accredited lab using the U.S. sieve numbers and gradation noted in Table 9.2.

Table 9.2. Aggregate for Bioretention Soil.

U.S. Sieve Number	Percent Passing
0.375 inch	100
4	95 to 100
10	75 to 90
40	24 to 40
100	4 to 10
200	2 to 5

Where existing soils meet the above aggregate gradation, they may be amended rather than importing mineral aggregate.

Compost to Aggregate Ratio, Organic Matter Content, Cation Exchange Capacity

- Compost to aggregate ratio: 60 to 65 percent mineral aggregate, 35 to 40 percent compost.
- Organic matter content: 5 to 8 percent by weight.
- Cation Exchange Capacity (CEC) must be greater than 5 milliequivalents (meq) per 100 grams of dry soil. Note: Soil mixes meeting the above specifications do not have to be tested for CEC. They will readily meet the minimum CEC.

Composted Material

To ensure that the bioretention soil mix will support healthy plant growth and root development, contribute to biofiltration of pollutants, and not restrict infiltration when used in the proportions cited herein, the following compost standards are required.

- Material must meet the definition of "composted material" in WAC 173-350-100 and must comply with testing parameters and other standards in WAC 173-350-220.
- Material must be produced at a composting facility that is permitted by a jurisdictional health authority. Permitted compost facilities in Washington are included on a list available at <www.ecy.wa.gov/programs/swfa/organics/soil.html>.

- The compost product must originate a minimum of 65 percent by volume from recycled plant waste comprising "yard debris," "crop residues," and "bulking agents" as those terms are defined in WAC 173-350-100. A maximum of 35 percent by volume of "postconsumer food waste," as defined in WAC 173-350-100 but not including biosolids, may be substituted for recycled plant waste.

- Moisture content must be such that there is no visible free water or dust produced when handling the material.

- The material shall be tested in accordance with the U.S. Composting Council "Test Method for the Examination of Compost and Composting" (TMECC), as established in the U.S. Composting Council's "Seal of Testing Assurance" (STA) program. Most Washington compost facilities use these tests.

- Composted material shall meet the size gradations established in the U.S. Composting Council's STA program, as follows.

  - Fine compost shall meet the following gradation by dry weight:

	Min.	Max.
Percent passing 2″	100	
Percent passing 1″	99	100
Percent passing 0.625″	90	100
Percent passing 0.25″	75	100

  - The pH shall be between 6.0 and 8.5 (TMECC 04.11-A).

  - "Physical contaminants" (as defined in WAC 173-350-100) content shall be less than 1 percent by weight (TMECC 03.08-A) total, not to exceed 0.25 percent film plastic by dry weight.

  - Minimum organic matter content shall be 40 percent by dry weight basis as determined by TMECC 05.07-A, "Loss-On-Ignition Organic Matter Method."

  - Soluble salt contents shall be less than 4.0 dS/m (mmhos/cm) tested in accordance with TMECC 04.10-A, "1:5 Slurry Method, Mass Basis."

  - Maturity indicators from a cucumber bioassay shall be greater than 80 percent, in accordance with TMECC 05.05-A, "Seedling Emergence and Relative Growth" must be greater than 80 percent for both emergence and vigor.

  - The material must be stable (low oxygen use and low carbon dioxide [CO_2] generation) and mature (capable of supporting plant growth). This is critical to plant success in a bioretention soil mixes. Stability shall be 7 mg CO_2-C/g OM per day or below, in accordance with TMECC 05.08-B, “Carbon Dioxide Evolution Rate.”

- Fine compost shall have a carbon to nitrogen ratio of less than 25:1 as determined using TMECC 05.02 “Carbon to Nitrogen Ratio” and TMECC 04.02-D “Total Nitrogen by Oxidation.” The engineer may specify a carbon:nitrogen ratio up to 35:1 for projects where all of the plants selected are native species of the Puget Sound Lowland, and up to 40:1 for coarse compost to be used as a surface mulch (not in a soil mix).

Compost not conforming to the above requirements or taken from a source other than those tested and accepted shall be immediately removed from the project and replaced.

If using the bioretention soil mix described herein, a default infiltration rate of 12 inches per hour shall be used. Refer to the “Determining Design Bioretention Soil Mix Infiltration Rate” subsection, below.

9.6.8 Custom Bioretention Soil Mixes

Projects that prefer to create a custom bioretention soil mix rather than using the default requirements in Section 9.6.7 must demonstrate compliance with the following criteria using the specified test method:

- CEC ≥5 milliequivalents/100 grams of dry soil; U.S. EPA 9081
- pH between 5.5 and 7.0
- 5 to 8 percent organic matter content before and after the saturated hydraulic conductivity test; ASTM D2974 (Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils)
- 2 to 5 percent fines passing the U.S. #200 sieve; TMECC 04.11-A
- If compost is used in creating the custom mix, it must meet all of the specifications listed in subsection 9.6.7 for compost, except for the gradation specification. An alternative gradation specification must indicate the minimum percent passing for a range of similar particle sizes.
- Measured (initial) saturated hydraulic conductivity of less than 12 inches per hour; ASTM D2434 (Standard Test Method for Permeability of Granular Soils [Constant Head]) at 85 percent compaction per ASTM D1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort). Also, use Appendix 7A, Recommended Modifications to ASTM D2434 When Measuring Hydraulic Conductivity for Bioretention Soil Mixes.
- Design (long-term) saturated hydraulic conductivity greater than 1 inch per hour. Refer to the “Determining Design Bioretention Soil Mix Infiltration Rate” subsection, below.

9.6.9 Determining Design Bioretention Soil Mix Infiltration Rate

A long-term infiltration rate correction factor of 4 shall be used for the bioretention soil if the area tributary to the facility meets or exceeds any of these thresholds:

- 10,000 square feet of impervious area
- 5,000 square feet of PGIS
- 0.75 acre of lawn and landscape.

For bioretention areas with a contributing area less than the above thresholds, a long-term infiltration rate correction factor of 2 for the bioretention soil mix is acceptable.

9.6.10 Underdrain (Optional)

Where the underlying native soils have an estimated initial infiltration rate between 0.3 and 0.6 inch per hour, bioretention areas without an underdrain, or with an elevated underdrain directed to a surface outlet, may be used to satisfy List #2 of Minimum Requirement #5. Underdrained bioretention areas that drain to a retention/detention facility must meet the following criteria if they are used to satisfy List #2 of Minimum Requirement #5.

- The invert of the underdrain must be 6 inches above the bottom of the aggregate bedding layer. A larger distance between the underdrain and bottom of the bedding layer is desirable to create a temporary saturated zone beneath the drain is advised to promote denitrification (conversion of nitrate to nitrogen gas) and to prolong moist soil conditions for plant survival during dry periods.
- The distance between the bottom of the bioretention soil mix and the crown of the underdrain pipe must be not less than 6 or more than 12 inches.
- The aggregate bedding layer must run the full length and the full width of the bottom of the bioretention area.
- The facility must not be underlain by a low permeability liner that prevents infiltration into the native soil.

Underdrain systems 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 volume above an underdrain pipe in a bioretention area provides pollutant filtering and some flow attenuation. However, only the void volume of the aggregate below the underdrain invert and above the bottom of the bioretention area (subgrade) can be used in the WWHM for dead storage volume that provides flow control benefit. Assume a 40 percent void volume for the filter material aggregate specified below.

The minimum requirements associated with the underdrain design include:

- Slotted, thick-walled plastic pipe must be used.
  - Minimum pipe diameter is 6 inches (pipe diameter will depend on hydraulic capacity required). Changes in pipe diameter shall be made using a junction box or other approved structure. Within the public right-of-way, any underdrain shall have a minimum diameter of 8 inches (pipe diameter will depend on hydraulic capacity required).
  - Slotted subsurface drain PVC per WSDOT Standard Specifications Section 9-05.2, Perforated Corrugated Polyethylene Drainage Tubing Underdrain Pipe, or Double-Walled Perforated Corrugated Polyethylene Underdrain Pipe
  - Slots should be cut perpendicular to the long axis of the pipe, be 0.04 to 0.069 inch wide by 1 inch long, and be spaced 0.25 inch apart (spaced longitudinally). Slots should be arranged in four rows spaced on 45-degree centers and cover one-half of the circumference of the pipe.
- 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 shall meet the requirements of WSDOT Standard Specifications Section 9-03.12(4) (gravel backfill for drains).
- A 6-inch, non-perforated cleanout must be connected to the underdrain every 300 feet minimum.
- The underdrain can be connected to a downstream BMP such as another bioretention/rain garden area as part of a connected system, or to an approved discharge point. A geotextile fabric (specifications in Appendix V-C) must be used between the soil layer and underdrain.

9.6.11 Check Dams and Weirs

For sloped bioretention areas, check dams are necessary to provide ponding, reduce flow velocities, and reduce the potential for erosion. Typical check dam materials include concrete, wood, rock, compacted dense soil covered with vegetation, and vegetated hedge rows. Design depends on flow control goals, local regulations for structures within road rights-of-way, and aesthetics. Optimum spacing is determined by performance (modeling) and cost considerations. See the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for typical designs.

9.6.12 Planting

The design intent for bioretention plantings is to replicate, to the extent possible, the hydrologic function of a mature forest including succession plants and groundcover. Plant roots aid in the physical and chemical bonding of soil particles that is necessary to form stable aggregates, improve soil structure, and increase infiltration capacity.

The minimum requirements associated with the vegetation design include:

- 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 Appendix V-F and the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for additional planting guidance, including:

- Guidance and recommendations for plant selection and increasing survival rates

- Planting zone descriptions

- Optimum planting times

- Plant selection for planting zones based on sun exposure

Mulch Layer

Bioretention areas shall be designed with a mulch layer or a dense groundcover. Properly selected mulch material also reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to soil. Mulch shall be:

- Compost in the bottom of the facilities (compost is less likely to float than wood chip mulch and is a better source for organic materials).

- Wood chip mulch composed of shredded or chipped hardwood or softwood on cell slopes above ponding elevation and rim area. Arborist mulch is mostly woody trimmings from trees and shrubs and is a good source of mulch material. Wood chip operations are a good source for mulch material that has more control of size distribution and consistency. Do not use shredded construction wood debris or any shredded wood to which preservatives have been added.

- Free of weed seeds, soil, and roots and other material that is not trunk or branch wood and bark.

- A maximum of 3 inches thick (thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere).

Mulch shall not include: weed seeds, soil, roots and other material that is not from the above-ground components of a tree, grass clippings (decomposing grass clippings are a source of nitrogen and are not recommended for mulch in bioretention areas), or pure bark (bark is essentially sterile and inhibits plant establishment).

In bioretention areas where higher flow velocities are anticipated, an aggregate mulch may be used to dissipate flow energy and to protect underlying bioretention soil mix. Aggregate mulch varies in size and type, but 1- to 1.5-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.

9.6.13 Hydraulic Restriction Layer

For infiltrating bioretention areas adjacent to roads, foundations, or other sensitive infrastructure, it may be necessary to restrict lateral infiltration pathways to prevent excessive hydrologic loading using a restricting layer (for the sides of the bioretention area only). Geomembrane liners are a type of restricting layer that can be incorporated into bioretention designs. Geomembrane liners completely block infiltration. The liner shall have a minimum thickness of 30 mils and be ultraviolet (UV) resistant.

Note: Only the infiltrating (i.e., unlined) bottom area shall be used in sizing calculations or hydrologic modeling.

If it is necessary to prevent infiltration to underlying soils (e.g., contaminated soils or steep slope areas), the facility must include a hydraulic restriction layer across the entire facility. The facility may be composed of a low permeability (e.g., concrete) container with a closed bottom, or it may be lined with a low-permeability material (e.g., geomembrane liner) to prevent infiltration. In such cases, underdrains are required.

9.6.14 Bioretention Construction Criteria

See Volume II, Section 3.3, for infiltration facility construction requirements. The minimum requirements associated with bioretention area construction include:

- Bioretention areas that infiltrate into the underlying soil (i.e., do not include a liner) rely on water movement through the surface soils as infiltration and interflow to underlying soils. Therefore, it is important to always consider the pathway of interflow and ensure that the pathway is maintained in an unobstructed and uncompacted state. This is true during the construction phase as well as postconstruction.

- During construction, it is critical to prevent clogging and over-compaction of the subgrade and bioretention soils.
- Place bioretention soil per the requirements of bioretention soil mix requirements specified in this section.

9.6.15 Verification of Performance

The project engineer or designee shall inspect bioretention areas before, during, and after construction to ensure facilities are built to design specifications, that proper procedures are employed in construction, that the infiltration surface is not compacted, and that protection from sedimentation is in place.

Prior to placement of the bioretention soil mix, the project engineer shall verify that the finished subgrade is scarified and conduct testing to confirm the subgrade meets the design infiltration rate. The type of test will depend on specific facility and site constraints, and therefore shall be determined by the project engineer on a case-by-case basis, and must be submitted for approval by the city prior to testing. The city must be notified of the scheduled infiltration testing at least 2 working days in advance of the test. See Appendix V-A for infiltration testing requirements. If the tests indicate the facility will not function as designed, this information must be brought to the immediate attention of the city along with any reasons as to why not and how it can be remedied.

Before release of the maintenance bond, the project engineer shall perform a minimum of two performance tests after construction to determine if the facility will operate as designed. The type of test will depend on specific facility and site constraints, and therefore shall be determined by the project engineer on a case-by-case basis, and must be submitted for approval by the city prior to testing. The city must be notified of the scheduled infiltration testing at least 2 working days in advance of the test. See Appendix V-A for infiltration testing requirements. If the tests indicate the facility will not function as designed, this information must be brought to the immediate attention of the city along with any reasons as to why not and how it can be remedied.

9.7 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Chapter 10 – Rain Gardens (Ecology BMP T5.14A)

10.1 Description

Rain gardens are shallow stormwater systems with compost-amended soil or imported rain garden or bioretention soil and plants adapted to the local climate and soil moisture conditions. Like bioretention areas, rain gardens are designed to mimic the hydrology of a forested condition by controlling stormwater through detention, infiltration, and evapotranspiration. Rain gardens also provide water quality treatment through sedimentation, filtration, adsorption, and phytoremediation.

Rain gardens function by storing stormwater 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.

The terms “bioretention” and “rain garden” are sometimes used interchangeably. However, in the City of Tumwater (in accordance with Ecology’s distinction), the term “bioretention” is used to describe an engineered facility that includes designed soil mixes and, perhaps, underdrains and control structures. The term “rain garden” is used to describe a landscape feature that serves to capture stormwater on small project sites that trigger only Minimum Requirements #1 through #5.

Rain gardens are similar to bioretention areas (refer to Chapter 9), with the following exceptions:

- Rain gardens may only be used to meet on-site stormwater management requirements (List #1 of Minimum Requirement #5) and must not be used on projects that trigger water quality treatment or flow control requirements (i.e., they are only applicable for projects that trigger only Minimum Requirements #1 through #5).
- Rain gardens shall not have a liner or underdrain.
- The maximum ponding depth is 6 inches.
- A certified landscape architect is not required for vegetation design.
- Private rain gardens must not receive runoff from a public roadway.

10.2 Applications and Limitations

Bioretention areas and rain gardens are applications of the same LID concept and can be highly effective for reducing surface runoff and removing pollutants.

- Rain gardens are an on-site stormwater management BMP option for projects that must comply with Minimum Requirements #1 through #5, but not Minimum Requirements #6 through #9.
- Rain gardens may be used as on-lot stormwater system, even in areas where underlying soils may not be conducive to rapid infiltration (such as underlying glacial till), but where the area has a surface soil cover that allows stormwater to migrate through the upper soil horizon as interflow.
- Underdrains shall not be used for rain gardens. For site sites with poorly draining soils (e.g., 0.3 to 0.6 inches per hour), applicants are encouraged to contact an engineer for other options (e.g., designing a bioretention area for the site).

10.3 Infeasibility Criteria

Infeasibility criteria describe conditions that exempt rain gardens for consideration in the List #1 option of Minimum Requirement #5. Infeasibility criteria for rain gardens are the same as for bioretention. See bioretention area infeasibility criteria in Chapter 9, Section 9.3. In addition, other rain garden design criteria and site limitations that make rain gardens infeasible (e.g., setback requirements) may also be used to demonstrate infeasibility, subject to approval by the city. See also Appendix V-B for a summary of infeasibility criteria for all BMPs.

10.4 Modeling and Sizing

For design on projects subject to Minimum Requirement #5 and choosing to use List #1 of that requirement, rain gardens shall have a horizontally projected surface area below the overflow that is at least 5 percent of the total impervious surface area draining to it. If lawn/landscape area will also be draining to the rain garden, the rain garden’s horizontally projected surface area below the overflow shall be increased by 2 percent of the lawn/landscape area.

The rain garden bottom should not be oversized because vegetation in oversized rain gardens may not receive enough stormwater runoff for irrigation, which would increase operation and maintenance requirements. Stormwater flows from other areas (beyond the area for which the rain garden is sized) should be bypassed around the rain garden to reduce sediment loading and the potential for clogging.

10.5 Field and Design Procedures

Geotechnical analysis is an important first step in developing an initial assessment of the variability of site soils, infiltration characteristics, and the necessary tests for frequency and depth of infiltration. This section describes infiltration testing requirements and application of appropriate safety factors specific to rain gardens.

Refer to Appendix V-A for detailed descriptions of procedures for infiltration rate testing. However, that the subgrade safety factors in Appendix V-A may not apply to rain gardens, as described below.

10.5.1 Determining Design Infiltration Rate

Infiltration rates are determined through soil infiltration tests. Infiltration tests shall be run at the anticipated elevation of the top of the native soil beneath the rain garden area. As outlined in Appendix V-A, a small-scale PIT or, for sites underlain by Type A soils, soil grain size analysis shall be performed at each potential rain garden site. Test hole or test pit explorations shall be conducted between late fall to mid-spring (December 1 through April 30) to provide accurate information on groundwater and saturation. To demonstrate infeasibility for Minimum Requirement #5 (i.e., measured infiltration rate of less than 0.3 inch per hour), the small-scale PIT must be used; a soil grain size analysis cannot be used to demonstrate infeasibility. Confirm that the site has the required 1-foot minimum clearance to the known or seasonal high groundwater or other impermeable layer; methods may include over excavating the pit, or using a soil log or monitoring well). When using the field testing procedures outlined in Appendix V-A, a safety factor is not required for rain gardens.

10.5.2 Prepare Soils Report

A Soils Report must be prepared by a professional soil scientist certified by the Soil Science Society of America (or an equivalent national program), a locally licensed on-site sewage designer, or other suitably trained persons working under the supervision of a professional engineer, geologist, hydrogeologist, or engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.2, for Abbreviated Plan Soils Report requirements.

10.6 Rain Garden Design Criteria

The following provides descriptions, recommendations, and requirements related to the components of a rain garden. 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. Submittal for rain garden review must include documentation of the elements listed below.

Setbacks and Site Constraints

Setbacks and site constraints for rain gardens are the same as those for infiltrating bioretention areas (see Section 9.6.1).

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. See the *Rain Garden Handbook for Western Washington*, page 29, for additional details and information (WSU 2013).

Cell Ponding Area

Design criteria for the cell ponding area of rain gardens are the same as those specified in the *Rain Garden Handbook for Western Washington*, except:

- The ponding depth for rain gardens shall be a maximum of 6 inches.
- The minimum freeboard measured from the invert of the overflow pipe or earthen channel to facility overtopping elevation shall be 6 inches.
- If berming is used to achieve the minimum top elevation needed to meet ponding depth and freeboard needs, the maximum slope on berm shall be 3H:1V, and the minimum top width of design berm shall be 1 foot. Soil used for berming shall be imported bioretention soil, rain garden soil, or amended native soil.

Bottom Area and Side Slopes

Rain gardens are highly adaptable and can fit into various rural and urban settings by adjusting bottom area and side slope configuration. Recommended maximum and minimum dimensions include:

- The planted side slope should be no steeper than 3H:1V. If steeper side slopes are necessary, rockeries, concrete walls, or soil wraps may be effective design options.
- The bottom width should be no less than 2 feet.

Overflow

An overflow route must be identified for stormwater flows that overtop the rain garden area when infiltration capacity is exceeded or the facility becomes plugged and fails. The overflow route must flow to the downstream conveyance system or other acceptable discharge point without posing a health or safety risk or causing property damage.

Rain garden overflow can be provided by a drain pipe installed at the designed maximum ponding elevation and connected to a downstream BMP or an approved discharge point.

See the *Rain Garden Handbook for Western Washington* for additional details and information.

Rain Garden Soil Mix

See the *Rain Garden Handbook for Western Washington* for soil mix information. For amending the native soil within the rain garden, the city recommends use of compost that meets the compost specification for bioretention (see Sections 9.6.7 and 9.6.8). Compost that includes biosolids or manure shall not be used.

Planting

Refer to Appendix V-F and the *Rain Garden Handbook for Western Washington* for guidance on plant selection and recommendations for increasing survival rates. The minimum requirements associated with the vegetation design include:

- 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.
- Plant spacing and plant size must be designed to achieve specified coverage.
- 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.

Mulch Layer

Refer to the *Rain Garden Handbook for Western Washington* for mulch layer requirements. Properly selected mulch material reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to soil. Mulch should consist of compost in the bottom of the rain garden (compost is less likely to float than wood chip mulch and is a better source for organic materials).

10.7 Rain Garden Construction Criteria

During construction, it is critical to prevent clogging and over-compaction of the native soil, rain garden soils, or amended soils. Additionally, excavation, soil placement, or soil amendment must not be allowed during wet or saturated conditions.

Refer to Volume II, Section 3.3, LID BMP Protection During Construction, for additional infiltration facility and bioretention area construction requirements that also apply to rain gardens.

10.8 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Chapter 11 – Permeable Paving (Ecology BMP T5.15)

11.1 Description

Stormwater runoff from vehicular pavement can contain significant levels of solids, heavy metals, and hydrocarbon pollutants. Both pedestrian and vehicular pavements also contribute to increased peak flow durations and associated physical habitat degradation of streams and wetlands. Permeable pavement is designed to accommodate pedestrian, bicycle, and auto traffic while allowing infiltration and storage of stormwater.

Permeable pavement includes porous asphalt, pervious concrete, permeable pavers, aggregate pavers, and grid systems.

- **Porous hot or warm-mix asphalt pavement** is a flexible pavement similar to standard asphalt that uses a bituminous binder to adhere aggregate together. However, the fine material (sand and finer) is reduced or eliminated and, as a result, voids form between the aggregate in the pavement surface and allow water to infiltrate.

- **Pervious portland cement concrete** is a rigid pavement similar to conventional concrete that uses a cementitious material to bind aggregate together. However, the fine aggregate (sand) component is reduced or eliminated in the gradation and, as a result, voids form between the aggregate in the pavement surface and allow water to infiltrate.

- **Permeable concrete pavers** are solid, precast, manufactured modular units. The solid pavers are (impervious) high-strength, portland cement concrete manufactured with specialized production equipment. Pavements constructed with these units have joints that are filled with permeable aggregates and are installed on an open-graded, aggregate bedding course.

- **Aggregate pavers (sometime called pervious pavers)** are a different class of pavers from pervious concrete pavers. They include modular, precast, paving units made with similar-sized aggregates bound together with portland cement concrete with high-strength epoxy or other adhesives. Like permeable concrete pavers, the joints or openings in the units are filled with open-graded aggregate and are placed on an open-graded, aggregate bedding course. Aggregate pavers are intended for pedestrian use only.

- **Grid systems include those made of concrete or plastic**. Concrete units are precast in a manufacturing facility, packaged, and shipped to the site for installation. Plastic grids typically are delivered to the site in rolls or sections. The openings in both grid types are filled with 1) topsoil and grass, or 2) permeable aggregate. Plastic grid sections connect together and are pinned into a densely-graded base, or they are eventually held in place by the grass root structure. Both systems can be installed on an open-graded aggregate base or a densely-graded aggregate base.

11.2 Applications and Limitations

- Permeable pavement is an on-site stormwater management BMP option for: 1) projects that have to comply with only Minimum Requirements #1 through #5, and 2) projects that trigger Minimum Requirements #1 through #9.

- Permeable pavement can achieve compliance with the Performance Standard option or can be applied from List #1 or List #2 option of Minimum Requirement #5.

- Permeable pavement can meet water quality treatment requirements of Minimum Requirement #6 when the underlying soil meets the treatment soil requirements outlined in Chapter 23, or when a water quality treatment course is included.

- Permeable pavement installations can sometimes meet the flow control duration standard of Minimum Requirement #7. The flow control performance is typically 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.

- Appropriate applications for permeable pavement include parking lots, low-volume roads, alleys, access drives, pedestrian and bike trails, and patios. The application of permeable pavement on roads is generally be limited to those roadways that receive very low-traffic volumes (i.e., average daily traffic less than or equal to 400).

- Permeable pavement works well in concert with other on-site stormwater management BMPs such as permeable pavement parking stalls adjacent to bioretention areas, and permeable roadway surfaces bordered by vegetated swales.

- Because permeable pavement can clog with sediment, permeable pavement is 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 erodible areas without presettling.

    - The site has a relatively high risk of concentrated pollutant spills (e.g., gas stations, truck stops, car washes, vehicle maintenance areas, industrial chemical storage sites).

- To reduce the potential of clogging, runoff generated from unstabilized pervious surfaces shall not be directed onto a permeable pavement surface. Absolutely no point discharges shall be directed onto permeable pavement. If runoff comes from minor or incidental pervious areas (including lawns), those areas must be fully stabilized.

- ADA compliance should be requested from the manufacturer and is a consideration in determining where to use permeable pavement.

11.3 Infeasibility Criteria

The conditions described in this section make permeable pavement exempt from consideration in the List #1 or List #2 option of Minimum Requirement #5. If a project proponent wishes to use permeable pavement—though is not required to because of these infeasibility criteria—they may propose a functional design to the city. These criteria also apply to impervious pavements that would employ stormwater collection from the surface of impervious pavement with redistribution below the pavement. In addition, other permeable pavement design criteria and site limitations that make permeable pavement infeasible (e.g., setback requirements) may be used to demonstrate infeasibility, subject to approval by the city. See also Appendix V-B for a summary of infeasibility criteria for all BMPs.

Citation of any of the following infeasibility criteria must be based on an evaluation of site-specific conditions and a written recommendation from an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist).

It is infeasible to install permeable pavement:

- Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or downgradient flooding.

- Where infiltrating and ponded water below new permeable pavement area would compromise adjacent impervious pavements.

- Where infiltrating water below a new permeable pavement area would threaten existing, below-grade basements.

- Where infiltrating water would threaten shoreline structures, such as bulkheads.

- Downslope of steep, erosion-prone areas that are likely to deliver sediment.

- Where fill soils are used that can become unstable when saturated.

- Excessively steep slopes where water within the aggregate base layer or at the subgrade surface cannot be controlled by check dams and may cause erosion and structural failure, or where surface runoff velocities may preclude adequate infiltration at the pavement surface.

- Where permeable pavements cannot provide sufficient strength to support heavy loads at industrial facilities, such as ports.
- Where installation of permeable pavement would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, or pre-existing road subgrades.

The following criteria can be cited as reasons for infeasibility without further justification (though some require professional services to make the observation).

It is infeasible to install permeable pavement:

- Within setbacks provided in “Setbacks and Site Constraints” subsection below.
- For properties with known soil or groundwater contamination (typically federal Superfund sites or state cleanup sites under the MTCA):
    - Within 100 feet of an area known to have deep soil contamination
    - Where groundwater modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the groundwater
    - Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area
    - Any area where these facilities are prohibited by an approved cleanup plan under the state Model Toxics Control Act or Federal Superfund Law, or an environmental covenant under Chapter 64.70 RCW.
- Within 100 feet of a closed or active landfill.
- Within 10 feet of any underground storage tank and connecting underground pipes, regardless of tank size. As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10 percent or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface.
- At multi-level parking garages, and over culverts and bridges.
- Where the site design cannot avoid putting pavement in areas likely to have long-term excessive sediment deposition after construction (e.g., construction and landscaping material yards).
- Where the site cannot reasonably be designed to have a porous asphalt surface at less than 5 percent slope, or a pervious concrete surface at less than 10 percent slope, or a permeable interlocking concrete pavement surface (where appropriate) at less than 12 percent slope. Grid systems upper slope limit can range from 6 to 12 percent; check with manufacturer and local supplier.

- Where the subgrade soils below a pollution-generating permeable pavement (e.g., road or parking lot) do not meet the soil suitability criteria for providing treatment. See soil suitability criteria for treatment in Chapter 23. Note: In these instances, the city may approve installation of a 6-inch sand filter layer meeting city specifications for treatment as a condition of construction.

- Where underlying soils are unsuitable for supporting traffic loads when saturated. Soils meeting a California Bearing Ratio of 5 percent are considered suitable for residential access roads.

- Where appropriate field testing indicates soils have a measured (a.k.a., initial) subgrade soil saturated hydraulic conductivity less than 0.3 inch per hour. A small-scale PIT or large-scale PIT, in accordance with Appendix V-A, shall be used to demonstrate infeasibility of permeable pavement areas. (Note: In these instances, unless other infeasibility restrictions apply, roads and parking lots may be built with an underdrain, preferably elevated within the base course, if flow control benefits are desired.)

- Roads that receive more than very low traffic volumes, and areas having more than very low truck traffic. Roads with a projected average daily traffic volume of 400 vehicles or less are very low volume roads (AASHTO 2001; U.S. Department of Transportation 2013). Areas with very low truck traffic volumes are roads and other areas not subject to through truck traffic but may receive up to weekly use by utility trucks (e.g., garbage, recycling), daily school bus use, and multiple daily use by pickup trucks, mail/parcel delivery trucks, and maintenance vehicles. Note: This infeasibility criterion does not extend to sidewalks and other non-traffic bearing surfaces.

- Where replacing existing impervious surfaces unless the existing surface is a non-pollution-generating surface over an outwash soil with a saturated hydraulic conductivity of 4 inches per hour or greater.

- At sites defined as “high-use sites.” For more information on high-use sites, refer to the Glossary in Appendix I-A; and Volume I, Section 4.2, Step 3.

- In areas with “industrial activity” as defined in the Glossary (located in Appendix I-A).

- Where the risk of concentrated pollutant spills is more likely, such as at gas stations, truck stops, and industrial chemical storage sites.

- Where routine, heavy applications of sand occur in frequent snow zones to maintain traction during weeks of snow and ice accumulation.

- Where the known or seasonal high groundwater or an underlying impermeable/low permeable layer would create saturated conditions within 1 foot of the bottom of the lowest gravel base course.

11.4 Modeling and Sizing

Modeling of runoff from areas of permeable pavement designed in accordance with this volume must conform to requirements of the 2019 Ecology Manual, Volume III, Section III-2; the modeling methods provided in a continuous simulation model approved by Ecology and the City of Tumwater; or subsequent technical documentation approved by Ecology and the City of Tumwater.

11.5 Field and Design Procedures

Geotechnical analysis is an important first step in developing an initial assessment of the variability of site soils, infiltration characteristics, and the necessary tests for frequency and depth of infiltration. This section describes infiltration testing requirements and application of appropriate safety factors specific to permeable pavement surfaces.

Refer to Appendix V-A for detailed descriptions of procedures for infiltration rate testing. The subgrade safety factors in Appendix V-A may not apply to permeable pavement. All test hole or test pit explorations described below shall be conducted between late fall and early spring (December 1 through April 30) to provide accurate information on groundwater and saturation.

11.5.1 Determining Design Infiltration Rate

Confirming the infiltration rate of site soils is necessary to determine which designs are feasible for infiltrating stormwater on site. Infiltration rates are also needed to model permeable pavement performance using WWHM.

Determining Initial Subgrade Infiltration Rates

Perform infiltration testing in the soil profile at the estimated bottom elevation of base materials for the permeable pavement. If no base materials will be used (e.g., a pervious concrete sidewalk), perform the testing at the estimated bottom elevation of the pavement.

- <u>Projects subject to Minimum Requirements #1 through #5</u>:
  - As indicated in Appendix V-A, a small-scale PIT or, for sites underlain by Type A soils, a soil grain size analysis (shall be performed for every 5,000 square feet of permeable pavement, but not less than one test per site. To demonstrate infeasibility of permeable pavement, a small-scale PIT or large-scale PIT in accordance with Appendix V-A must be used; a soil grain size analysis cannot be used to demonstrate infeasibility.
  - Confirm that the site has the required 1-foot minimum clearance from the lowest gravel base course to the known or seasonal high groundwater or other impermeable layer. Methods may include over excavating the pit, or using a soil log or monitoring well). Refer to Section 11.6.1, Setbacks and Site Constraints.

- Projects subject to Minimum Requirements #1 through #9:
  - On commercial property: a small-scale PIT, or other method outlined in Appendix V-A, shall be performed for every 5,000 square feet of permeable pavement, but not less than one test per site.
  - On residential developments: a small-scale PIT, or other method outlined in Appendix V-A, shall be performed at every proposed lot, for at least every 200 feet of roadway and within each length of road with significant differences in subsurface characteristics. However, if the site subsurface characterization—including soil borings across the development site—indicate consistent soil characteristics and depths to seasonal high groundwater conditions, the number of test locations may be reduced to a frequency recommended by a geotechnical professional.

    To demonstrate infeasibility of permeable pavement, a small-scale PIT or large-scale PIT in accordance with Appendix V-A must be used.
  - Confirm that the site has the required 1-foot minimum clearance from the lowest gravel base course to the known or seasonal high groundwater or other impermeable layer. Refer to Section 11.6.1, Setbacks and Site Constraints.
- If the general site assessment cannot confirm that the seasonal high groundwater or hydraulic restricting layer will be greater than 1 foot below the bottom of the lowest gravel base course of permeable pavement (subgrade surface), monitoring wells or excavated pits should be placed strategically to assess depth to groundwater.

Assignment of Appropriate Safety/Correction Factors

- If deemed necessary by a qualified professional engineer, a safety factor may be applied to the measured K_{sat} of the subgrade soils to estimate its design (long-term) infiltration rate. Depending on the size of the facility, the variability of the underlying soils, and the number of infiltration tests performed, a safety factor may be advisable.
- A safety factor for the subgrade (i.e., $F_{plugging}$ used in Appendix V-A) does not have to take into consideration the extent of influent control and clogging over time, unless deemed necessary by a professional engineer.
- The quality of pavement aggregate base material may be compromised if the aggregate base is not clean and washed material, and has more than 1 percent fines passing the U.S. #200 sieve. In such cases, a correction factor ($F_{aggregate}$) may be necessary. $F_{aggregate}$ ranges from 0.9 (not clean or washed aggregate, greater than 1 percent fines passing the U.S. #200 sieve) to 1.0 (aggregate base meets specifications).

11.5.2 Soil Suitability Criteria Confirmation

- Where permeable pavements are used for PGHS (primarily roads, driveways, and parking lots), there must be a determination whether the soil suitability criteria of Chapter 23, are met. This requirement does not apply to projects that trigger only Minimum Requirement #1 through #5.

- Sites not meeting these criteria are considered infeasible for permeable pavements for PGHS, unless a treatment layer is provided.

- The information to make this determination may be obtained from various sources: historical site information, estimated qualities of a general soil type, or laboratory analysis of field samples.

11.5.3 Prepare Soils Report

For projects subject to Minimum Requirements #1 through #5, a Soils Report must be prepared by a professional soil scientist certified by the Soil Science Society of America (or an equivalent national program); a locally licensed on-site sewage designer; or by other suitably trained persons working under the supervision of a professional engineer, geologist, hydrogeologist, or engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.2, for Abbreviated Plan Soils Report requirements.

For projects subject to Minimum Requirements #1 through #9, a Soils Report must be prepared that is stamped by a professional engineer with geotechnical expertise, a licensed geologist, a hydrogeologist, or an engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.3, for Drainage Control Plan Soils Report requirements.

11.5.4 Estimate Volume of Stormwater

Use WWHM or other approved continuous runoff model to generate an influent file that will be used to size the permeable pavement facility. The facility must infiltrate either all of the flow volume as specified by the influent file, or a sufficient amount of the flow volume such that any overflow/bypass meets the flow duration standard in Minimum Requirement #7. In addition, the overflow/bypass must meet the LID Performance Standard if it is the option chosen to meet Minimum Requirement #5, or if it is required of the project.

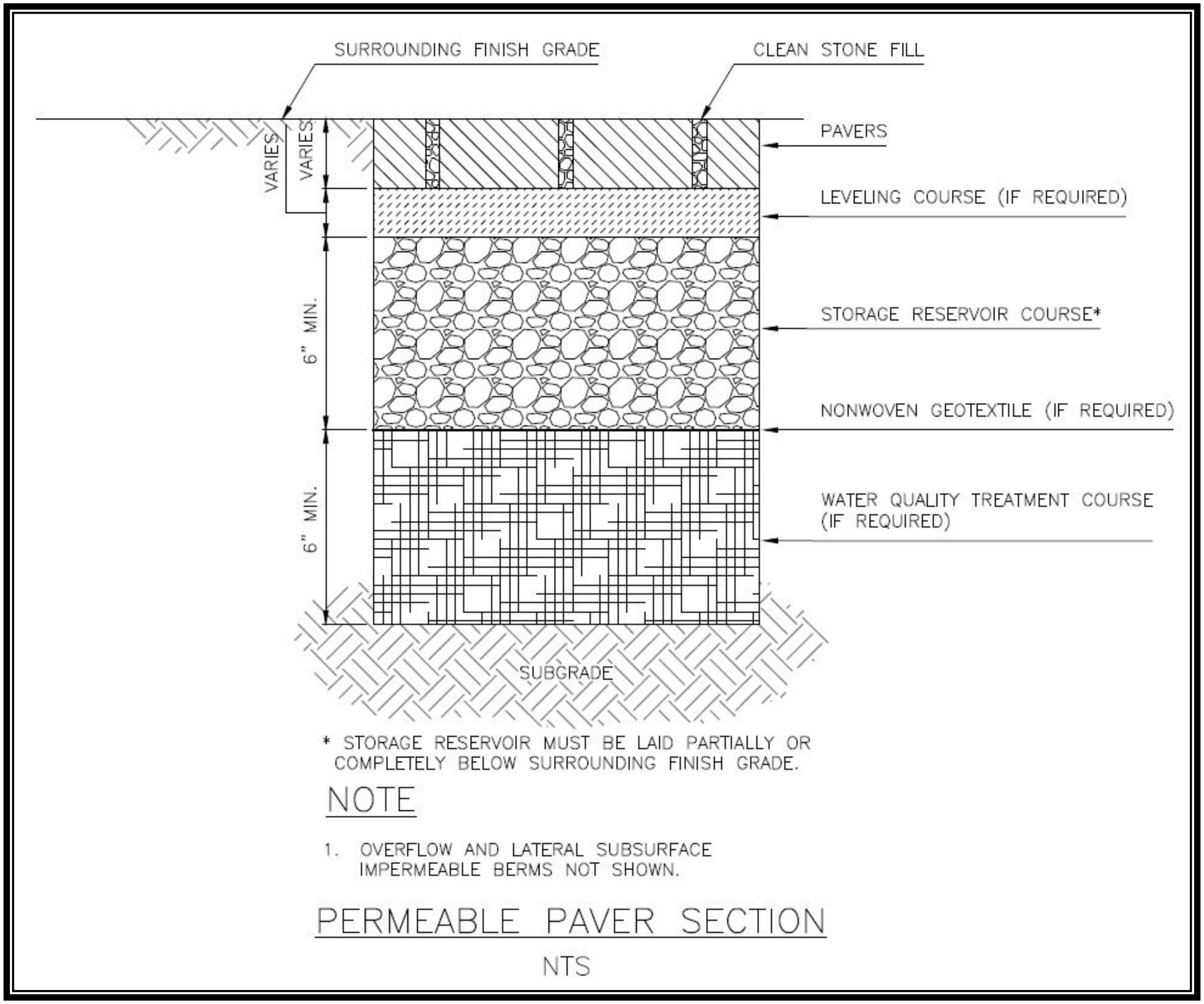
11.6 Paving Surface Design Criteria

This section includes a description, recommendations, and requirements for the components of permeable pavement. 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. Submittal for facility review must include documentation of the following elements, discussed in detail below.

- Setbacks and site constraints
- Permeable wearing course
- Drainage conveyance
- Leveling course
- Aggregate storage reservoir
- Lateral subsurface impermeable barriers
- Nonwoven geotextile (optional)
- Subgrade
- Water quality treatment layer
- Signage

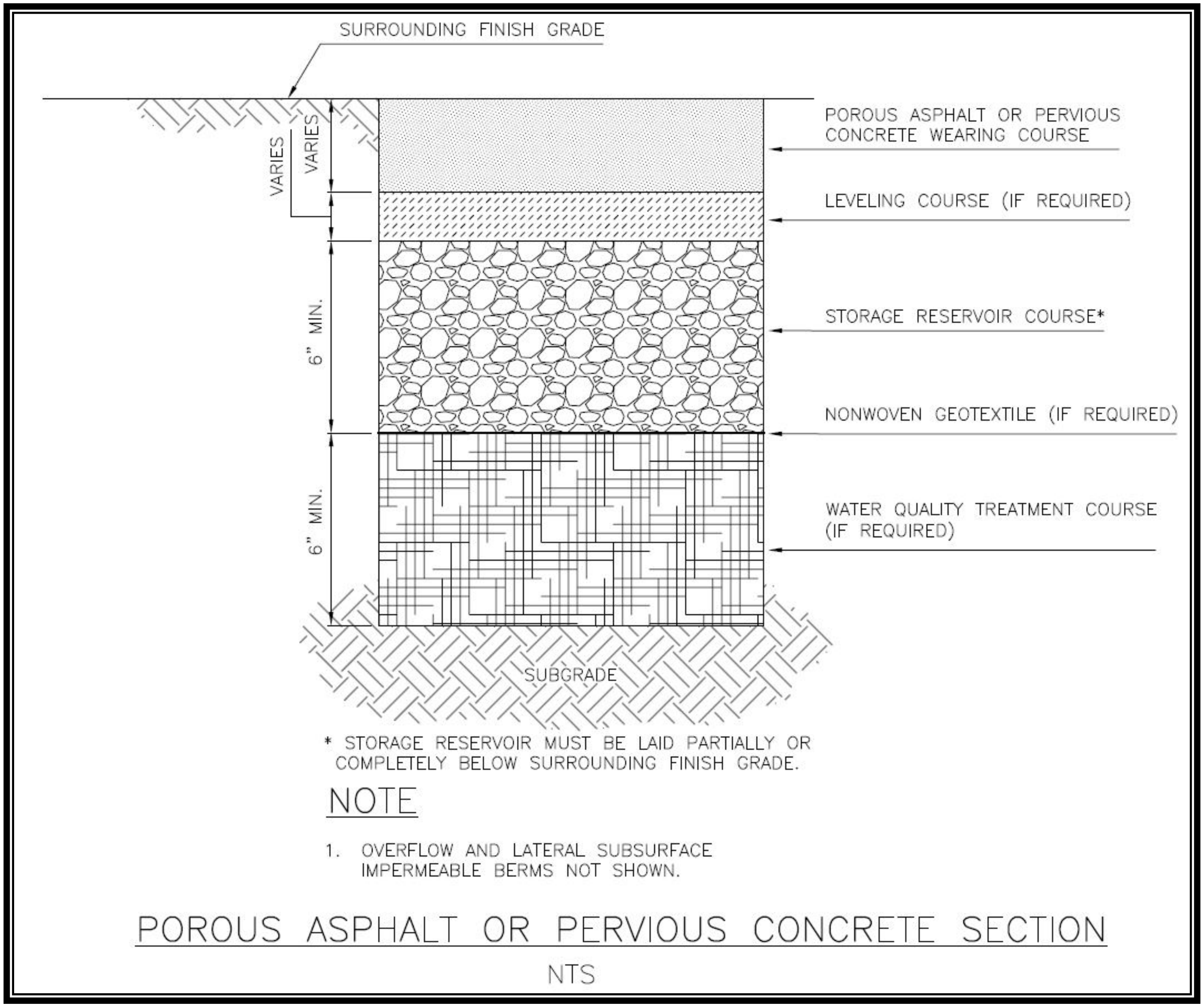
Typical cross-sections of permeable pavement consist of a top layer (pervious wearing course) underlain by a leveling course (if required), aggregate storage reservoir, geotextile fabric (optional), treatment layer (if required), and subgrade. See Figures 11.1 and 11.2 for examples of permeable surface cross-sections.

Manufacturer's or designer's recommendations on design, installation, and maintenance shall be followed for each application.



Source: Pierce County 2015

Figure 11.1. Permeable Paver Section.



Source: Pierce County 2015

Figure 11.2. Porous Asphalt or Pervious Concrete Section.

11.6.1 Setbacks and Site Constraints

See Section 11.3, Infeasibility Criteria, for setbacks and site constraints used to evaluate the permeable pavement option of List #1 and List #2 (Minimum Requirement #5). (See also Appendix V-B for a summary of infeasibility criteria for all BMPs.) The following minimum setbacks and site constraints apply to all permeable pavement areas. To request a variance from setbacks not related to wells and septic systems, the project proponent may submit a request to the Administrator documenting the impracticality or infeasibility of the setback, which may require written recommendations from a geotechnical engineer.

- Permeable pavement shall not be located where known or seasonal high groundwater or an underlying impermeable/low permeable layer would create saturated conditions within 1 foot of the bottom of the lowest gravel base course or treatment layer.

- The base of the lowest gravel course or treatment layer shall be a minimum of 1-foot positive vertical clearance to structures within 25 feet.

- All permeable pavement surfaces shall be set back at least 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high. A geotechnical assessment and Soils Report must be prepared that address the potential impact of the facility on the slope. The geotechnical assessment may recommend a reduced setback, but in no case shall the setback be less than the vertical height of the slope.

- For sites with on-site or adjacent septic systems, the discharge point must be at least 30 feet upgradient or 10 feet downgradient of the drainfield primary and reserve areas (per WAC 246-272A-0210. This requirement may be modified by the Thurston County Public Health and Social Services Department if site topography clearly prohibits flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that this is unnecessary.

- In no case shall permeable pavement surfaces be placed closer than 100 feet from drinking water wells and springs used for drinking water supplies.

  - Where water supply wells are nearby, it is the responsibility of the applicant’s engineer to locate such wells, meet any applicable protection standards, and assess possible impacts of the proposed infiltration facility on groundwater quality. If negative impacts on an individual or community water supply are possible, additional runoff treatment must be included in the facility design or relocation of the facility should be considered.

  - All permeable pavement surfaces located within the 1-year capture zone of any well must be preceded by a water quality treatment facility. (See also

Volume I, Section 4.2 and 4.3.4 for projects proposing to infiltrate runoff from pollution-generating areas.)

- The Soils Report must be updated to demonstrate and document that the above criteria are met and to address potential impacts on water supply wells or springs.

- Permeable pavement surfaces are prohibited within 300 feet of an erosion hazard or landslide hazard area (as defined by Title 16.20 TMC) unless a geotechnical professional has analyzed the slope stability impacts of such surfaces and has proposed mitigation and appropriate analysis indicates that the impacts are negligible.

11.6.2 Permeable Wearing Course

The wearing course or surface layer of the permeable pavement surface may consist of porous asphalt, pervious concrete, interlocking concrete pavers, or open-celled paving grid with vegetation or gravel.

- Recommended maximum wearing course slopes for permeable paving surfaces are: 5 percent (porous asphalt), 10 percent (pervious concrete), 12 percent (interlocking pavers), and 6 to 12 percent (grid and lattice systems; check with manufacturer or local supplier).

- Manufacturer's recommendations on design, installation, and maintenance shall be followed for each application.

- For all surface types, a minimum initial infiltration rate of 20 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, ASTM C1701 shall be used. For grid systems, refer to manufacturer's testing recommendations.

  - Porous Asphalt: Products must have adequate void spaces through which water can infiltrate and must meet performance grade 70-22. See the Low Impact Development Technical Guidance Manual for Puget Sound (WSU and PSP 2012) for additional specifications.

  - Pervious Concrete: Products must have adequate void spaces through which water can infiltrate and must meet the most current version of American Concrete Institute (ACI) 522. See the Low Impact Development Technical Guidance Manual for Puget Sound (WSU and PSP 2012) for additional specifications.

  - Grid/lattice systems filled with gravel, sand, or a soil of finer particles with or without grass: The fill material must be at least a minimum of 2 inches of sand, gravel, or soil. 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.

    - Permeable Interlocking Concrete Pavement and Aggregate Pavers: See the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for specifications and installation procedures published by the Interlocking Concrete Pavement Institute.

- Permeable pavement systems that use pavers need to be confined with a rigid edge system to prevent gradual movement of the paving stones.

- Both gravel and soil with vegetation can be used to fill the openings in paver and rigid grid systems. Manufacturer's recommendations shall be followed to apply the appropriate material for each application.

- Structural designs for permeable pavement shall be per the manufacturer's specifications. If any deviations are made from the manufacturer's recommendations or if the manufacturer's recommendations require engineering judgments to be made, the design shall be stamped by a geotechnical engineer.

11.6.3 Drainage Conveyance

Flow Entrance/Presettling Requirements

- Run-on to permeable pavement must be dispersed as sheet flow or delivered subsurface 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 perforated drain pipe).

- Run-on from upgradient adjacent impervious paved surfaces is not recommended, but it is permissible if the permeable pavement area is at least 50 percent larger than impervious area and the length of sheet flow from the impervious paved surface is no greater than half the length across the permeable pavement section.

Overflow Requirements

Roads should be designed with adequate drainage conveyance facilities, as if the road surface was impermeable. Roads with base courses that extend below the surrounding grade should have a designed drainage flowpath to safely move water away from the road prism and into the roadside drainage facilities.

- In small area applications, the subgrade can be built up with permeable base material and graded to direct runoff through this material to an eventual discharge location, such as bioretention areas. In larger areas, an elevated underdrain system should be installed to collect and convey runoff to bioretention areas or open space. In this manner, stormwater is stored and released slowly, similar to the way the existing topsoil on a site captures and slowly releases runoff. (See Section 11.6.5, Aggregate Storage Reservoir, for additional details on underdrains.)

- An overflow route must be identified for stormwater flows that overtop the permeable pavement surface when infiltration capacity is exceeded or the facility becomes plugged and fails. The overflow route must be able to convey the 100-year recurrence interval, developed peak flow to the downstream conveyance system or other acceptable discharge point without posing a health or safety risk or causing property damage.

- Overflow must be designed to convey excess flow to an approved point of discharge. 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.

11.6.4 Leveling Course

Depending upon the type of permeable pavement installation, a leveling course (also called a bedding or choker course) may be required (per manufacturer or designer recommendations). A leveling course is often required for porous asphalt, open-celled paving grids, and interlocking concrete pavers. The leveling course is a layer of aggregate that provides a uniform surface for laying pavement or pavers, and consists of crushed aggregate that is smaller in size than the underlying aggregate storage reservoir. Course thickness will vary with permeable pavement type.

Leveling course material and thickness shall be included as required per manufacturer's recommendations. Leveling course material must be compatible with material in the underlying aggregate storage reservoir.

11.6.5 Aggregate 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. The aggregate storage reservoir also serves as the pavement's support base and must be sufficiently thick to support the expected loads and be free draining. The aggregate shall meet the following criteria.

- A 6-inch minimum depth of aggregate storage reservoir is recommended under the permeable wearing course and leveling course (if any) for water storage.

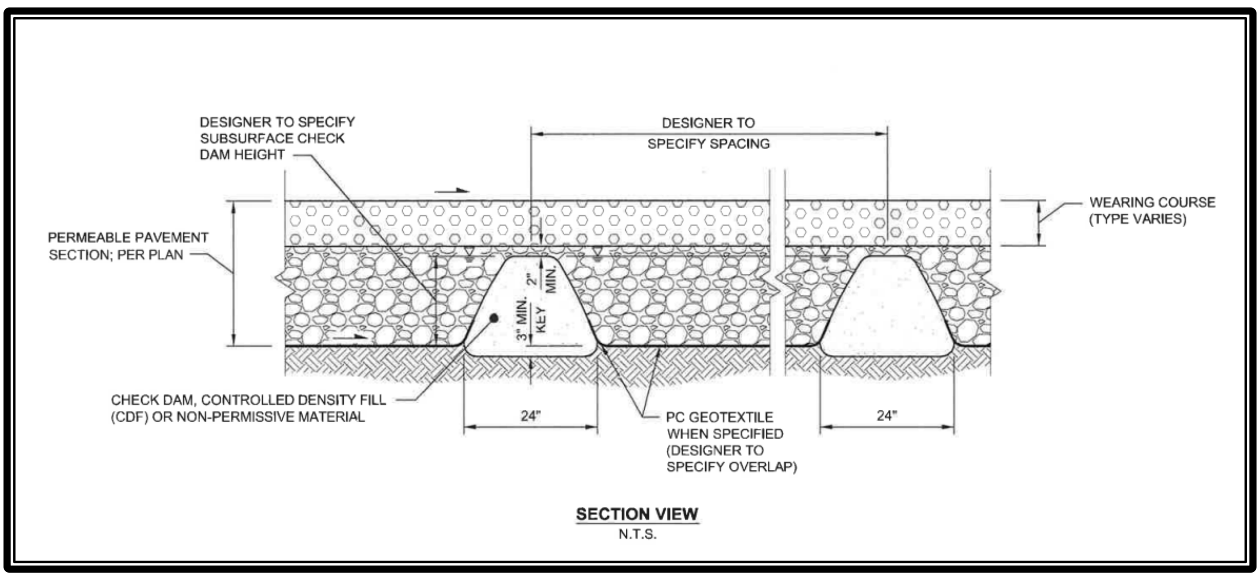
- Aggregate storage reservoir shall consist of larger rock at the bottom and smaller rock directly under the top surface (i.e., a gradient from 2-inch to 5/8 inch).

- Designs using an underdrain that is elevated within the aggregate base course to protect the pavement wearing course from saturation are considered to be LID BMPs and can be used to satisfy Minimum Requirement #5, so long as the underdrain invert is set at or above the maximum design ponding depth.

11.6.6 Lateral, Subsurface, Impermeable Barriers

Sloped permeable pavement surfaces have an increased potential for lateral flows through the aggregate storage reservoir 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.

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 when the slope of the permeable pavement is 3 percent or greater. While the distance between barriers is calculated based on the required subsurface ponding depth and the subgrade slope, typical designs include barriers at every 6 to 12 inches of grade loss. See Figure 11.3 for an example of subsurface permeable pavement check dams.



Source: Pierce County 2015

Figure 11.3. Typical Permeable Pavement Facility with Checkdams.

Minimum requirements associated with lateral, impermeable barriers include:

- Lateral impermeable barriers must be installed at regular intervals, perpendicular to the subgrade slope to provide the average subsurface ponding depth in the aggregate 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 above, or allow overtopping to the next downslope aggregate storage reservoir section without causing flows to express from the pavement surface or out the sides of the base materials that are above grade.

11.6.7 Nonwoven Geotextile (optional)

Generally, geotextiles and geogrids are applied:

- To prevent fines from migrating to more open-graded material and the associated structural instability
- For soil types with poor structural stability to prevent downward movement of the aggregate base into the subgrade

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 deemed necessary. As part of the pavement section design, the designer should review the existing subgrade or subbase characteristics and determine if a nonwoven geotextile is needed for separation of subbase from underlying soils.

11.6.8 Subgrade

- Compact the subgrade to the minimum necessary for structural stability. Two guidelines currently used to specify subgrade compaction are “firm and unyielding” (qualitative), and 90 to 92 percent Standard Proctor (quantitative).
- If the permeable pavement is being designed to provide water quality treatment, underlying soils must meet the requirements for treatment soil provided in Chapter 23 or a water quality treatment layer must be provided.

11.6.9 Water Quality Treatment Layer

If the permeable pavement is being designed to provide water quality treatment, underlying soils must meet the requirements for treatment soil provided in Chapter 23. If the existing subgrade does not meet these requirements, a 6-inch water quality treatment course may be included between the subbase and the aggregate storage reservoir. The course must consist of a media meeting the treatment soil criteria or the sand material specification for sand filters in the 2019 Ecology Manual.

11.6.10 Signage

The City of Tumwater requires that permeable pavement installations include informational signage upon completion of the installation, to help identify the area as a stormwater BMP and to inform maintenance crews and the general public about protecting the facility's function.

11.7 Construction Criteria

Minimum requirements associated with permeable pavement construction include:

- Proper installation is one of the key components to ensure the success of permeable pavement. As with any pavement system, permeable pavement requires careful preparation of the subgrade and aggregate storage reservoir to ensure success in terms of strength and permeability. The compressive strength of a permeable paver system relies on the strength of the underlying soils, particularly in the case of modular or plastic units where the pavement itself lacks rigidity. Design and installation of permeable pavement shall be according to manufacturer recommendations.

- Field infiltration and compaction testing of the optional water quality treatment course shall be conducted prior to placement of overlying courses.

- To prevent compaction when installing the aggregate storage reservoir, the following steps (back-dumping) should be followed.

    - The aggregate storage reservoir is dumped onto the subgrade from the edge of the installation and the aggregate is then pushed out onto the subgrade.

    - Trucks then dump subsequent loads from on top of the aggregate storage reservoir as the installation progresses.

- The various aggregate storage reservoir materials shall be prevented from intermixing with fines and sediment. All contaminated material must be removed and replaced.

- A field infiltration test of the permeable surface shall be conducted after complete pavement section is installed to verify that it meets the minimum initial uncorrected infiltration rate of 20 inches per hour. See Section 11.7.1, Verification of Performance.

- If possible, temporary roads should be used during construction and final construction of the aggregate storage reservoir material, and permeable surfacing should be completed after building construction is complete. This construction method is similar to the installation of leveling courses of asphalt in a subdivision prior to building individual lots and installing the final wearing course upon completion of building construction.

Refer to Volume II, Section 3.3, LID BMP Protection During Construction, for construction considerations specific to infiltration facilities.

11.8 Verification of Performance

The project engineer or designee shall inspect permeable pavement areas before, during, and after construction, as necessary, to ensure facilities are built to design specifications, that proper procedures are employed in construction, that the infiltration surface is not compacted, and that protection from sedimentation is in place.

Prior to placing the aggregate storage reservoir, the project engineer shall verify that the finished subgrade is scarified and conduct one infiltration test per 10,000 square feet to verify the subgrade meets the designed infiltration rate. The type of test will depend on specific facility and site constraints, and therefore shall be determined by the project engineer on a case-by-case basis, and must be submitted for approval by the city prior to testing. The city must be notified of the scheduled infiltration testing at least 2 working days in advance of the test. See Appendix V-A for infiltration testing requirements. If the tests indicate the facility will not function as designed, this information must be brought to the immediate attention of the city along with any reasons as to why not and how it can be remedied.

The project engineer shall verify that the aggregate storage reservoir has been adequately installed and protected (e.g., from compaction and sedimentation) per the design specifications, prior to paving.

Prior to accepting the installation of the permeable pavement, and also before release of the maintenance bond, the project engineer shall perform a sufficient number of ASTM C1701 tests (a minimum of two) after construction to determine whether the facility will operate as designed. The city must be notified of the scheduled infiltration testing at least 2 working days in advance of the test. If the tests indicate the facility will not function as designed, this information must be brought to the immediate attention of the city, along with any reasons as to why not and how it can be remedied.

11.9 Operations and Maintenance Criteria

- See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

- Where run-on flows onto permeable pavement, these areas shall be identified in the Maintenance and Source Control Manual as requiring more frequent cleaning and inspection to ensure that the overall facility is performing.

- Clogging is the primary mechanism that degrades infiltration rates. However, as discussed above, the surface design can have a significant influence on clogging of void space.

- Studies have indicated that infiltration rates on moderately degraded porous asphalts and pervious concrete can be partially restored by suctioning and sweeping of the surface. Highly degraded porous asphalts and concrete require high-pressure washing with suction.

- Maintenance frequencies of suctioning and sweeping shall be specified in the Maintenance and Source Control Manual, or as specified in the Stormwater Facility Maintenance Standards on the city web site, whichever is more stringent.

- Permeable pavement systems designed with pavers have advantages of ease of disassembly when repair or utility work is necessary. However, it is important to note that the paver removal area should be no greater than the area that can be replaced at the end of the day. If an area of pavers is removed, leaving remaining edges unconfined, it is likely that loading in nearby areas will create movement of the remaining pavers, thereby unraveling significantly more area than intended.

Chapter 12 – Infiltration Trenches (Ecology BMP T7.20)

12.1 Description

Infiltration trenches are generally at least 24 inches wide and are backfilled with a coarse stone aggregate, allowing for temporary storage of stormwater runoff in the voids of the aggregate material. Stored runoff then gradually infiltrates into the surrounding soil. The surface of the trench can consist of stone, gabion, sand, or a grassed covered area with a surface inlet. Perforated rigid pipe of at least 8 inches in diameter can also be used to distribute the stormwater in a stone trench. Note that an infiltration trench with a perforated pipe is considered a UIC well and is required to be registered with Ecology, unless the infiltration trench is located at a single-family residence and receives only residential roof runoff or is used to control basement flooding (per WAC 173-218-070 (1)(e). See also Chapter 5 for more information on registration of UIC wells.

See Figures 12.1 and 12.2 for examples of infiltration trench facilities in various configurations and site settings, including infiltration trenches with a grass buffer and parking lot perimeter infiltration trenches. For trenches associated specifically with roof downspout infiltration, see Chapter 15.

12.2 Applications and Limitations

- Infiltration trenches can be used to meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, infiltration trenches can also help achieve compliance with the Performance Standard option of Minimum Requirement #5.
- Infiltration trenches can be used to meet some of the water quality treatment requirements of Minimum Requirement #6 if the underlying soil meets the requirements provided in Chapter 23.

12.3 Modeling and Sizing

See Section 2.3 for guidance on modeling and sizing of infiltration facilities.

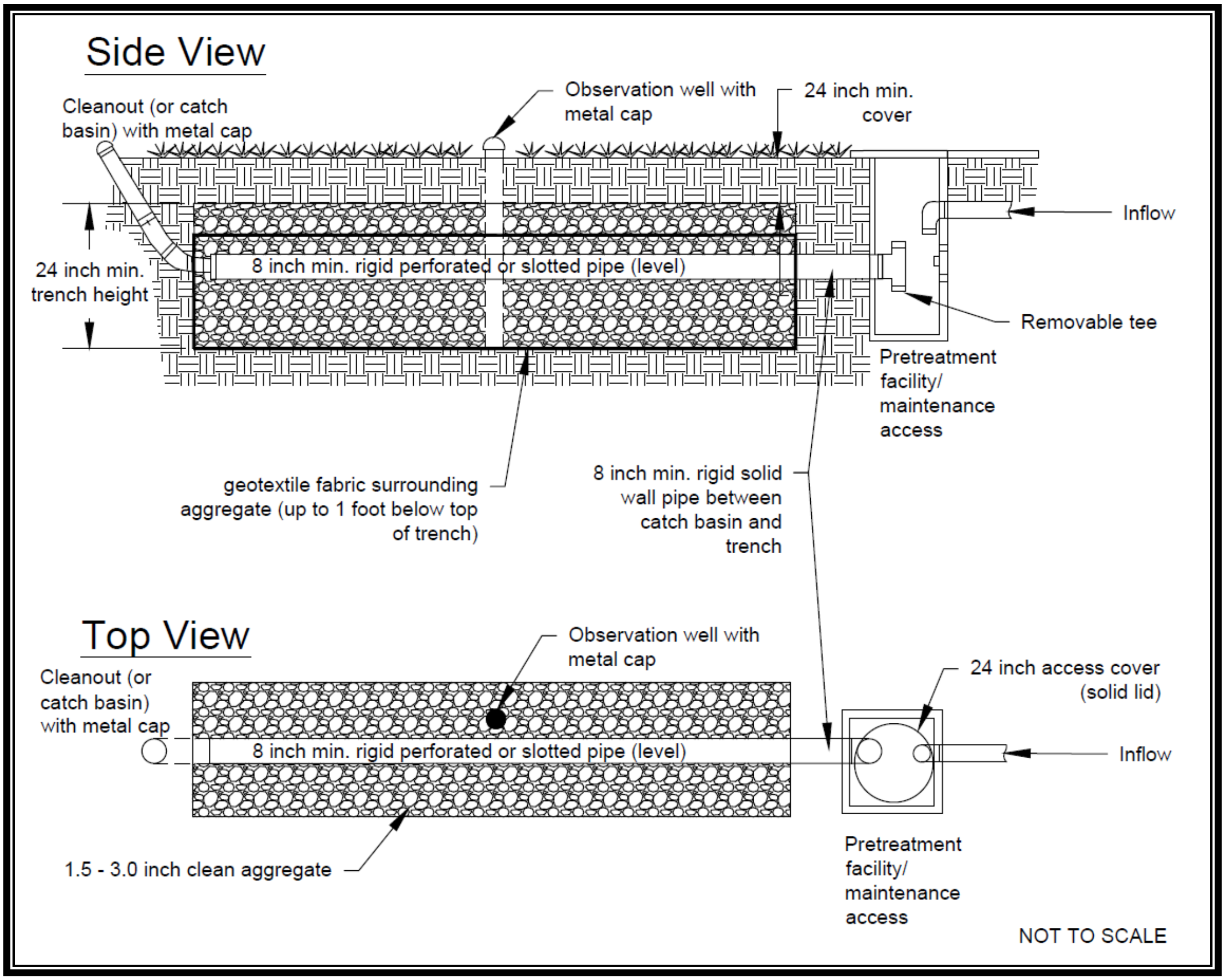


Figure 12.1. Infiltration Trench Design.

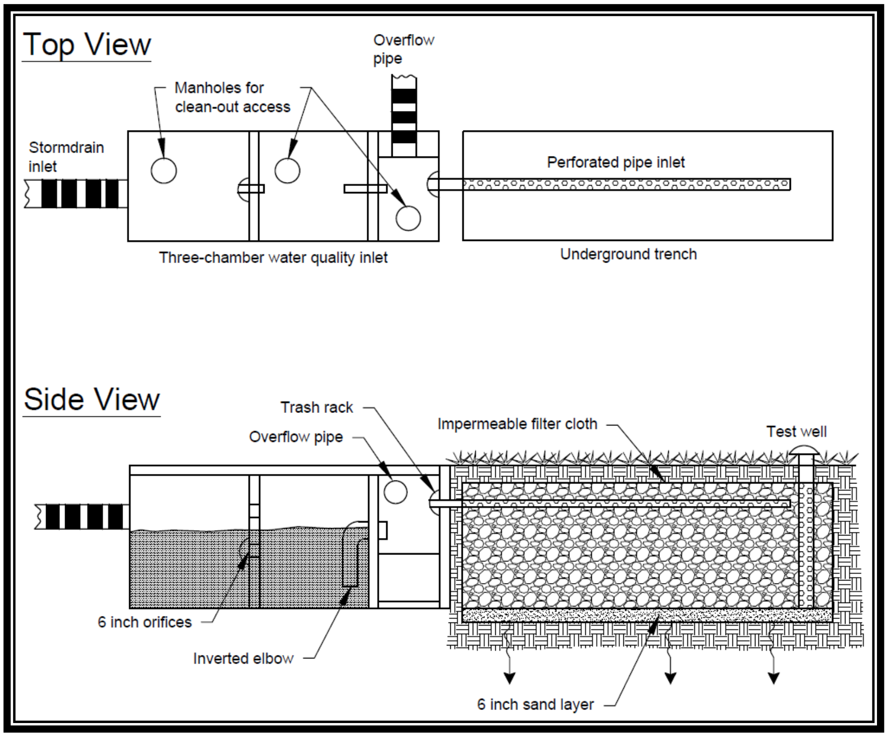


Figure 12.2. Underground Infiltration Trench with Oil/Grit Chamber.

12.4 Infiltration Trench Design Criteria

Refer to Section 2.3 for general procedures and design criteria applicable to infiltration basins, trenches, and galleries. This section provides additional design criteria specific to infiltration trench layout, access, bedding and geotextile, and overflow.

12.4.1 Trench Layout

- Surface cover: A stone-filled trench can be placed under a porous or impervious surface cover to conserve space. If located under pavement, the following are required.
    - Observation wells must be placed no further than 100 feet apart.
    - The plans, details, and Maintenance and Source Control Manual must all clearly state that the pavement may have to be removed for trench maintenance.
    - No infiltration trenches shall be allowed under any private or public streets.
- Flows must be evenly distributed across the trench to ensure it will function as designed. Include appropriate measures to distribute flows (e.g., manifold system, level spreader).

12.4.2 Access

- A catch basin is required at the inlet of the infiltration trench for access.
- An access port, cleanout, or catch basin is required at the outlet for accessibility to conduct inspections and maintenance.
- An observation well must be installed at the lower end of the infiltration trench to check water levels, drawdown time, and sediment accumulation, and to conduct water quality monitoring. See Figure 12.3 for an example observation well detail. It should consist of a perforated PVC pipe that is 4 to 6 inches in diameter, and it should be constructed flush with the ground elevation. For larger trenches, a 12- to 36-inch-diameter well can be installed to facilitate maintenance operations such as pumping out the sediment. The top of the well must be equipped with a secure well cap to discourage vandalism and tampering.

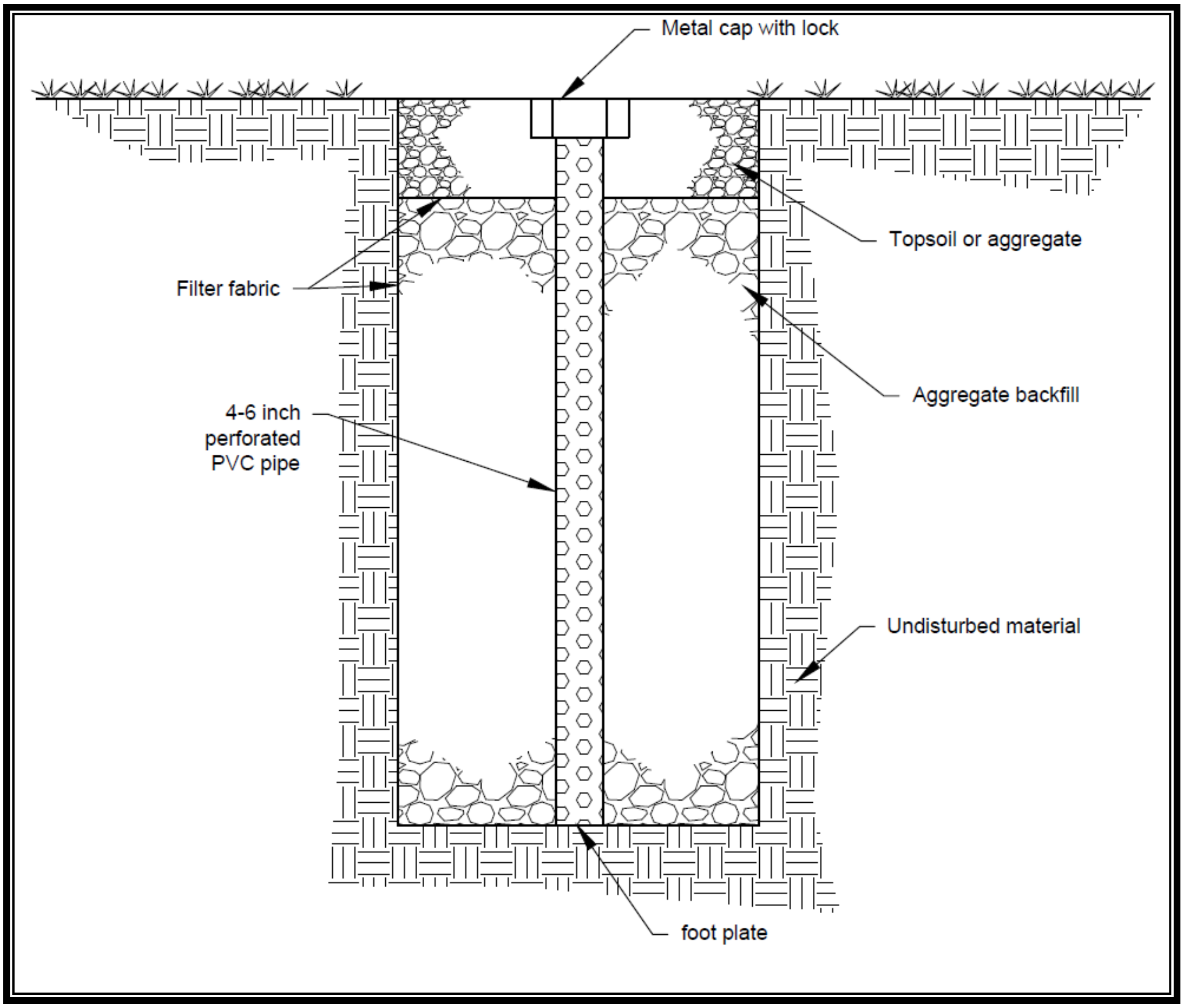


Figure 12.3. Observation Well Details.

12.4.1 Trench Bedding and Geotextile

- Backfill material: The aggregate material for the infiltration trench must consist of a clean aggregate, meeting WSDOT Standard Specification 9-03.12(5), that nominally ranges from 0.75-inch to 1.5-inch diameter. A maximum diameter of 3 inches and a minimum diameter of 1.5 inches may be approved if void space is maintained. Void space for these aggregates must be in the range of 30 to 40 percent.

- Geotextile fabric liner: The aggregate fill material may be completely encased in an engineering geotextile material. If used, geotextile must surround all of the aggregate fill material except for the top 1 foot, which is placed over the geotextile. Carefully select geotextile fabric with acceptable properties to avoid plugging (see Appendix V-C).

- Instead of geotextile, a 6-inch-minimum layer of sand may be used as a filter media at the bottom of the trench.

- The bottom sand or geotextile fabric should be placed as shown in Figures 12.1 and 12.2.

  Refer to the Federal Highway Administration Manual *Geosynthetic Design and Construction Guidelines*, Publication No. FHWA HI-95-038, (FHWA 1995), for design guidance on geotextiles in drainage applications. Refer to the NCHRP Report 367, *Long-Term Performance of Geosynthetics in Drainage Applications*, 1994, (Koerner and Koerner 1994) for long-term performance data and background on the potential for geotextiles to clog, blind, or to allow piping to occur and how to design for these issues.

12.4.2 Overflow

- Because an infiltration trench is generally used for small drainage areas, an emergency spillway is not necessary. However, a nonerosive overflow channel leading to a stabilized watercourse must be provided.

12.5 Construction Criteria for Trenches

Most of the construction requirements for small-scale infiltration facilities included in Volume II, Section 3.3 apply to all infiltration facilities. Additional specific construction criteria for infiltration trenches are listed below. Criteria for residential roof downspout infiltration trenches are provided in Chapter 15.

- Trench preparation: Excavated materials must be placed away from the trench sides to enhance trench wall stability. Take care to keep this material away from slopes, neighboring property, sidewalks, and streets. It is recommended that this material be covered with plastic (see Erosion and Sediment Control Criteria in Volume II, Section 3.1.10, BMP C123 – Plastic Covering).

- Stone aggregate placement and compaction: Place the stone aggregate in lifts and compact it using plate compactors. In general, a maximum loose lift thickness of 12 inches is recommended. The compaction process ensures geotextile conformity to the excavation sides, thereby reducing potential piping and geotextile clogging, and settlement problems.

- Potential contamination: Prevent natural or fill soils from intermixing with the stone aggregate. Remove all contaminated stone aggregate and replace with uncontaminated stone aggregate.

- Overlapping and covering: Following the stone aggregate placement, the geotextile must be folded over the stone aggregate to form a 12-inch-minimum, longitudinal overlap. When overlaps are required between rolls, the upstream roll must overlap a minimum of 2 feet over the downstream roll to provide a shingled effect.

- Voids behind geotextile: Voids between the geotextile and excavation sides must be avoided. Removing boulders or other obstacles from the trench walls is one source of such voids. Place natural soils in voids at the most convenient time during construction to ensure geotextile conformity to the excavation sides. This remedial process helps to avoid soil piping, geotextile clogging, and possible surface subsidence.

- Unstable excavation sites: Vertically excavated walls may be difficult to maintain in areas where the soil moisture is high or where soft or cohesionless soils predominate. Trench boxes or trapezoidal, rather than rectangular, cross-sections may be needed.

12.6 Verification of Performance

To demonstrate that the infiltration trench performs as designed, the constructed facility shall be tested and monitored per the Verification of Performance requirements in Section 2.2.

12.7 Operations and Maintenance Criteria for Trenches

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Chapter 13 – Infiltration Galleries

13.1 Description

The term “infiltration galleries” refers to manufactured detention structures, commonly referred to as “infiltration chambers,” within a broad gravel trench. Infiltration chambers are buried structures, typically arch-shaped, within which collected stormwater is temporarily stored and then infiltrated into the underlying soil. Infiltration chambers create an underground cavity that can provide a greater void volume than infiltration trenches and often require a smaller footprint. Infiltration galleries may be allowed on a case-by-case basis, and must be sized per the manufacturer’s guidance.

13.2 Applications and Limitations

- Infiltration galleries can be used to meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, infiltration galleries can also help achieve compliance with the Performance Standard option of Minimum Requirement #5.
- Infiltration galleries can be used to help meet the water quality treatment requirements of Minimum Requirement #6 if the underlying soil meets the requirements provided in Chapter 23.

13.3 Modeling and Sizing

See Section 2.3 for guidance on modeling and sizing of infiltration facilities.

13.4 Infiltration Gallery Design Criteria

Refer to Chapter 2 for general procedures and design criteria applicable to infiltration basins, trenches, and galleries. Refer to Figure 13.1 for a schematic of a typical infiltration chamber. This section provides additional design criteria specific to infiltration trenches for:

- Gallery layout
- Access
- Gallery bedding
- Subgrade
- Overflow

13.4.1 Gallery Layout

- Infiltration chambers can be constructed of a variety of different materials (e.g., plastic, concrete, aluminum, steel) and shapes (i.e., arch, box).
- Chamber spacing and depth of cover shall be per the manufacturer's requirements, unless otherwise directed by the city.
- Surface cover: An infiltration chamber be placed under a porous or impervious surface cover to conserve space. If located under pavement, the following are required.
    - Observation wells must be placed no more than 100 feet apart.
    - The plans, details, and the Maintenance and Source Control Manual must all clearly state that the pavement may have to be removed for gallery maintenance.
    - No infiltration galleries shall be allowed under any private or public streets.

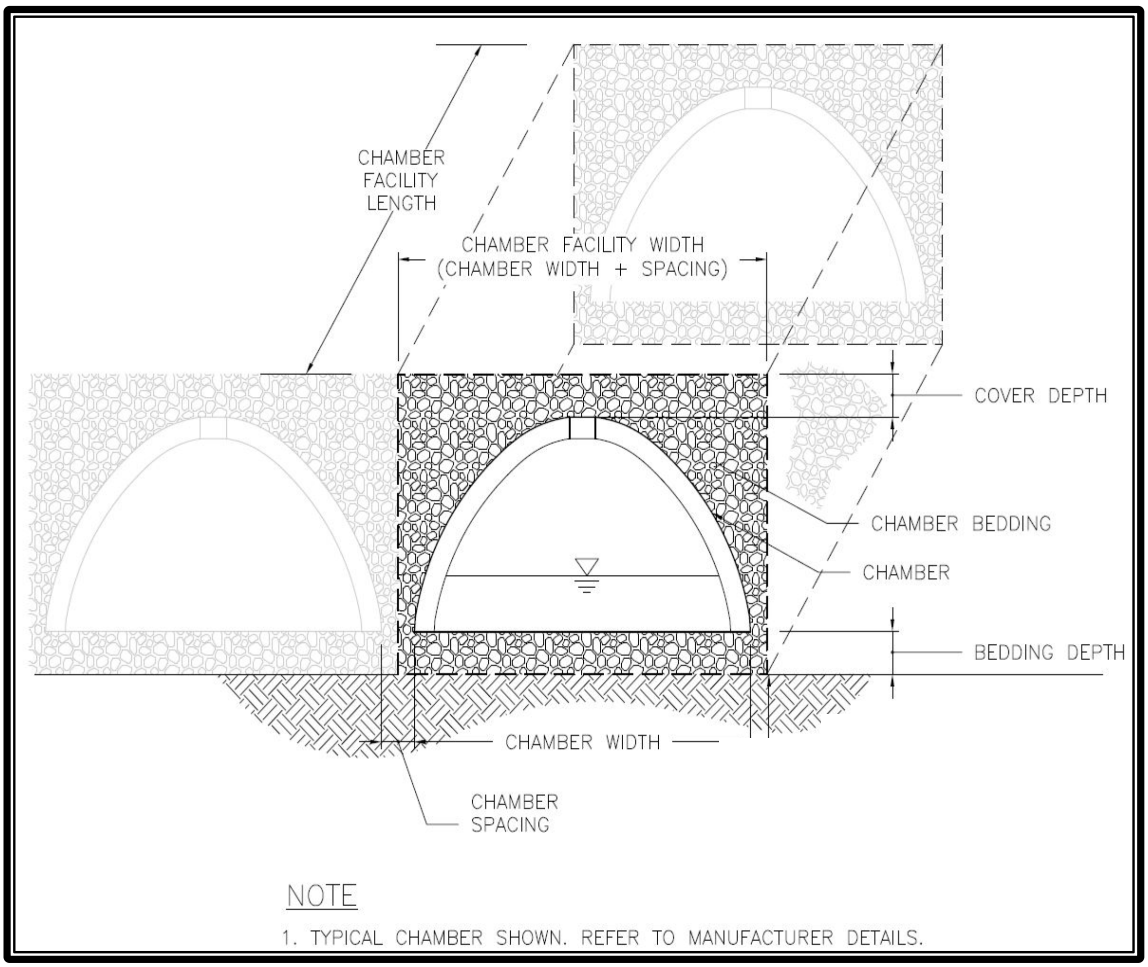


Figure 13.1. Typical Infiltration Chamber.

13.4.1 Access

- A catch basin is required at the inlet of each chamber of the infiltration gallery for access.
- An access port, cleanout, or catch basin is required at the distal end for accessibility to conduct inspections and maintenance.
- An observation well must be installed at the lower end of each chamber to check water levels, drawdown time, and sediment accumulation, and to conduct water quality monitoring. See Figure 12.3 for an example observation well detail. The observation well should consist of a perforated PVC pipe that is 4 to 6 inches in diameter, and it should be constructed flush with the ground elevation. For larger infiltration galleries, a 12- to 36-inch-diameter well can be installed to facilitate maintenance operations such as pumping out the sediment. The top of the well must be equipped with a secure well cap to discourage vandalism and tampering.

13.4.2 Gallery Bedding

- Minimum bedding shall be from 6 inches below the infiltration chamber to an elevation one-half the outside height of the chamber.
- Infiltration gallery bedding is specified by the manufacturer. The aggregate material for the infiltration gallery must consist of a clean aggregate meeting WSDOT Standard Specification 9-03.12(5) that nominally ranges from 0.75-inch to 1.5-inch diameter. A maximum diameter of 3 inches and a minimum diameter of 1.5 inches may be approved if void space is maintained. Void space for these aggregates must be in the range of 30 to 40 percent.

13.4.3 Subgrade

The minimum underlying native soil initial infiltration rate for infiltration galleries is 0.6 inch per hour.

During construction, the subgrade soil surface can become smeared and sealed by excavation equipment. The design shall require project to maintain 1 foot of separation from final elevation until site is fully stabilized. After stabilization, contractor can complete excavation to final grade. Scarification or raking of the side walls and bottom of the facility excavation to a minimum depth of 4 inches after excavation to restore infiltration rate can also be undertaken following final stabilization of site, provided that the risk of compaction due to soil type is minimized or avoided.

13.4.4 Freeboard

A minimum of 1 foot of freeboard is required when establishing the design chamber depth. Freeboard is measured from the rim of the chamber to the maximum ponding level, or from the rim down to the overflow point if overflow or a spillway is included.

13.5 Construction Criteria

During construction, it is critical to prevent clogging and over-compaction of the subgrade. Refer to the minimum construction requirements for infiltration trenches in Section 12.5.

13.6 Verification of Performance

To demonstrate that the facility performs as designed, the constructed facility shall be tested and monitored per the Verification of Performance requirements in Section 2.2.

13.7 Operations and Maintenance Requirements

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements. Manufacturers of specific infiltration chambers may have additional operation and maintenance recommendations.

Chapter 14 – Infiltration Basins (Ecology BMP T7.10)

14.1 Description

Infiltration basins (sometimes referred-to as "dry ponds") are earthen impoundments used for the collection, temporary storage, and infiltration of stormwater runoff. (See schematic in Figure 14.1.)

14.2 Applications and Limitations

Infiltration basins can be used to meet the flow control standards of Minimum Requirement #7. They can also meet some of the water quality treatment requirements of Minimum Requirement #6 if the underlying soil meets the requirements provided in Chapter 23.

14.3 Modeling and Sizing

See Section 2.3 for guidance on modeling and sizing of infiltration facilities.

14.4 Infiltration Basin Design Criteria

Refer to Section 2.2 for general procedures and design criteria applicable to infiltration basins, trenches, and galleries. Additional design criteria specific to infiltration basins include:

- Access must be provided for vehicles to easily maintain the forebay (presettling basin) area while not disturbing vegetation or re-suspending sediment any more than is absolutely necessary.

- Fencing shall be provided where required based on slope or presence of walls (see Chapter 18) and designed according to the requirements for detention ponds (see Chapter 18).

- The slope of the basin bottom shall not exceed 3 percent in any direction. Side slopes, facility depth, and vertical walls, if proposed, shall comply with Chapter 18.

- A minimum of 1 foot of freeboard is required when establishing the design ponded water depth. Freeboard is measured from the rim of the infiltration facility to the maximum ponding level, or from the rim down to the overflow point if overflow or a spillway is included.

- Vegetation: The embankment, emergency spillways, spoil and borrow areas, and other disturbed areas shall be stabilized and planted, preferably with grass, in accordance with the Stormwater Site Plan (see Volume I, Section 2.4.2, Minimum Requirement #1). Without healthy vegetation, the surface soil pores would quickly plug. Infiltration basins designed to provide water quality treatment must have sufficient vegetation established on the basin floor and side slopes to prevent erosion and sloughing and to provide additional pollutant removal. Select suitable vegetative materials for the basin floor and side slopes. Refer to detention pond guidance in Chapter 18 for recommended vegetation. Use the seed mixtures recommended in Table 18.2 in Chapter 18, Detention Ponds.

- Lining material: Basins can be open or covered with a 6- to 12-inch layer of filter material, such as coarse sand, or a suitable filter fabric to help prevent the buildup of impervious deposits on the soil surface. Select a nonwoven geotextile that will function sufficiently without plugging (see geotextile specifications in Appendix V-C). Replace or clean the filter layer when/if it becomes clogged.

- Signage: See the signage requirements in Section 18.11 for detention pond sign requirements that apply to infiltration basins.

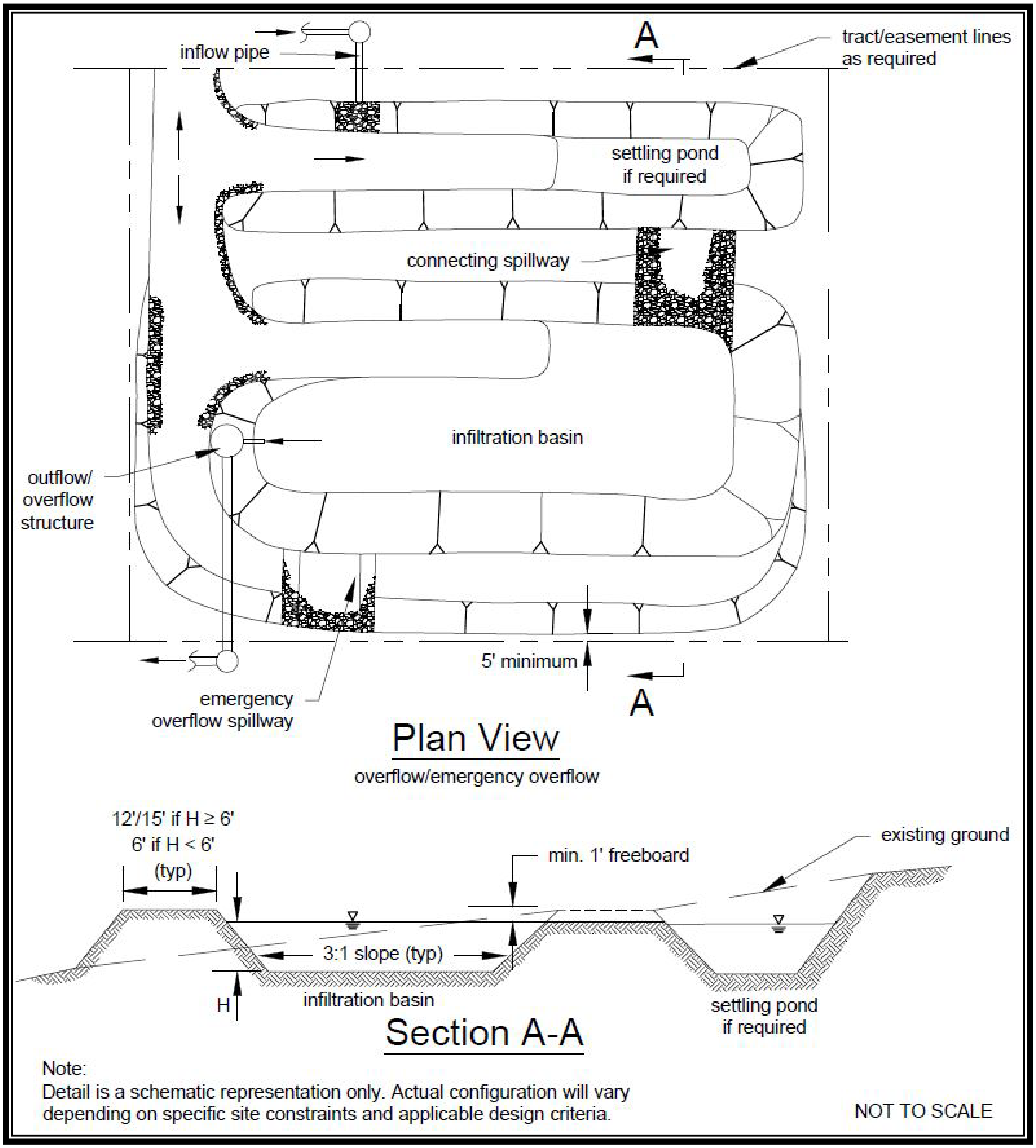


Figure 14.1. Typical Infiltration Basin.

14.5 Construction Criteria

Most of the construction requirements for small-scale infiltration facilities included in Volume II, Section 3.3, apply to all infiltration facilities. Specific construction criteria for infiltration basins are:

- Initial basin excavation must be conducted to within 2 feet of the final elevation of the basin floor. Excavate infiltration basins to final grade only after all disturbed areas in the upgradient project drainage area have been permanently stabilized. The final phase of excavation must remove all accumulation of silt in the infiltration basin before putting it in service.

- Generally, it is preferable to avoid using infiltration basins as temporary sediment traps during construction. If an infiltration basin is to be used as a sediment trap, do not excavate to final grade until after stabilizing the upgradient drainage area. Remove any accumulation of silt in the basin before putting it in service.

14.6 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Additional maintenance considerations for infiltration basins are provided below.

- Maintain basin floor and side slopes to promote dense turf with extensive root growth. This enhances infiltration, prevents erosion and consequent sedimentation of the basin floor, and prevents invasive weed growth.

- The use of slow-growing, stoloniferous grasses will permit long intervals between mowing. Mowing twice a year is generally satisfactory. Apply fertilizers only as necessary and in limited amounts to avoid contributing to groundwater pollution. Consult the local agricultural or gardening resources, such as Washington State University Extension, for appropriate fertilizer type, including slow-release fertilizers, and application rates.

14.7 Verification of Performance

To demonstrate that the facility performs as designed, the constructed facility shall be tested and monitored per the Verification of Performance requirements in Section 2.2.

Chapter 15 – Roof Downspout Controls

15.1 Description

Roof downspout controls are simple, pre-engineered designs for infiltrating and/or dispersing runoff from roof areas. Large lots in rural areas typically have enough area to infiltrate or disperse roof runoff. Lots in urban areas are typically smaller and have a limited amount of area in which to incorporate infiltration or dispersion trenches.

This section presents an overview of the types and applications of roof downspout controls.

15.2 Application to Minimum Requirements

The feasibility and applicability of roof downspout controls must be evaluated for all projects subject to Minimum Requirement #5 (see Volume I, Section 4.2.6). Projects must provide for individual downspout infiltration, bioretention, rain garden, dispersion systems, or perforated stub-out connection systems where feasible. Where roof downspout controls are required or planned, the following four types must be considered in order of preference, per Minimum Requirement #5 (note that some of the following BMPs are discussed in other chapters).

1. Full dispersion (Chapter 7) or downspout infiltration systems (see Section 15.3, Downspout Infiltration Systems)

2. Bioretention cells, swales, and planter boxes (Chapter 9); or rain gardens (Chapter 10)

3. Downspout dispersion systems (see Section 15.4, Downspout Dispersion – Trenches and Splashblocks)

4. Perforated stub-out connections (see Section 15.5, Perforated Stub-Out Connections)

15.3 Downspout Infiltration Systems (Ecology BMP T5.10A)

15.3.1 Description

Downspout infiltration systems are trench or drywell designs intended only for use in infiltrating runoff from roof downspout drains. They are not designed to directly infiltrate runoff from PGIS. See Section 23.3, for requirements related to infiltration designed for water quality treatment.

15.3.2 Applications and Limitations

- Downspout infiltration can be used to help meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, downspout infiltration can also help achieve compliance with Minimum Requirement #5.

15.3.3 Modeling and Sizing

- If roof runoff is infiltrated according to the requirements of this section, the roof area may be discounted from the project area used for sizing stormwater facilities.
- The standardized table (Table 15.1) can be used to facilitate sizing of infiltration trenches and drywells for smaller site applications. Standardized tables may be used under the following conditions.
  - If the project triggers Minimum Requirements #1 through #5, but not Minimum Requirements #1 through #9
  - If the infiltration trench or drywell is designed and constructed in accordance with the design requirements.
- If the design or construction of the downspout infiltration system deviates from the design criteria or the standardized tables, the individual downspout infiltration must be designed by a professional engineer in accordance with the requirements presented in this section.
- All designers have the option to do their own engineered design in lieu of using Table 15.1 (in accordance with the design requirements presented below), subject to approval by the city.

Table 15.1. Sizing Table for Downspout Infiltration Trenches and Drywells.

Trench Gravel Thickness[a] (feet)	Square Feet of Trench Bottom per 1,000 Square Feet of Roof Area for Various Soil Types and Infiltration Rates				
	Type A Soils (60 in/hr)	Type A Soils (12 in/hr)	Type A Soils (4 in/hr)	Type B Soils (2 in/hr)	Type C Soils (1 in/hr)
2.0	24	58	101	144	206
2.5	21	52	90	129	184
3.0	19	46	80	114	163
3.5	18	43	75	107	153
4.0	17	41	71	102	146
4.5	16	38	66	94	134
5.0	15	36	63	90	129

In/hr = inches per hour

[a] The “thickness” is the vertical thickness of the gravel and does not include cover depth over the trench.

15.3.4 Procedure for Evaluating Feasibility

Downspout infiltration is considered feasible on lots or sites that meet all of the following.

- Site-specific tests must indicate that soils are not silty clay loam, clay loam, clay, or any other soil having a percolation rate slower than 1 inch per hour.
- Site-specific tests must indicate 12 inches or more of permeable soil from the proposed bottom (final grade) of the infiltration system to the known or seasonal high groundwater table, or from another impermeable layer to the known or seasonal high groundwater table or other impermeable layer. (Refer to the soil investigation requirements below.)
- The downspout infiltration system can be designed to meet the minimum design criteria specified below.

Prepare Soils Report

For projects subject to Minimum Requirements #1 through #5, a Soils Report must be prepared by a professional soil scientist certified by the Soil Science Society of America (or an equivalent national program); a locally licensed on-site sewage designer; or other suitably trained persons working under the supervision of a professional engineer, geologist, hydrogeologist, or engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.2, for Abbreviated Plan Soils Report requirements.

For projects subject to Minimum Requirements #1 through #9, a Soils Report must be prepared that is stamped by a professional engineer with geotechnical expertise, a licensed geologist, a hydrogeologist, or an engineering geologist registered in the State of Washington. Refer to Volume I, Section 3.3.3, for Drainage Control Plan Soils Report requirements.

For downspout infiltration in particular, the soils investigation and Soils Report must address:

1. Individual lot or site tests must consist of at least one soils log at the location of the infiltration system, a minimum of 4 feet in depth from proposed final grade, identifying the NRCS (formerly SCS) soil series and the USDA textural class of the soil horizon through the depth of the log, and noting any evidence of high groundwater level, such as mottling.
2. Document that soils in the location of the proposed downspout infiltration system are not silty clay loam, clay loam, clay, or any other soil having a percolation rate slower than 1 inch per hour.
3. For sites that do not use the sizing tables presented in Table 15.1, the site infiltration rates must be determined using the procedures outlined in Appendix V-A.

15.3.5 Downspout Infiltration Systems Design Criteria

Design criteria for infiltration trenches and drywells include:

- For sites with on-site or adjacent septic systems, the discharge point must be at least 30 feet upgradient or 10 feet downgradient of the drainfield primary and reserve areas (per WAC 246-272A-0210. This requirement may be modified by the Thurston County Public Health and Social Services Department if site topography clearly prohibits flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that this is unnecessary.

- Systems shall be set back at least 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high. A geotechnical assessment and Soils Report must be prepared addressing the potential impact of the facility on the slope. The geotechnical assessment may recommend a reduced setback, but in no case shall the setback be less than the vertical height of the slope.

- All systems shall be a minimum of 10 feet away from any structure or property line.

- All systems located within the 1-year capture zone of any drinking water well must be preceded by a water quality treatment facility.

- In no case shall infiltration systems be placed closer than 100 feet from drinking water wells and springs used for drinking water supplies.

- If the design or construction of the downspout infiltration system deviates from the design criteria or the standardized tables, the individual downspout infiltration must be designed by a professional engineer in accordance with the requirements presented in this chapter.

Downspout Infiltration Trench System Design Criteria

The trench system is to be constructed according to the standard design shown in Figures 15.1 and 15.2. The following design requirements apply to downspout infiltration trenches.

- Maximum length of trench must not exceed 100 feet from the inlet sump.

- Minimum spacing between distribution pipe centerlines must be 6 feet.

- The aggregate material for the infiltration trench shall consist of 0.75-inch to 1.5-inch-diameter, washed, round rock that meets WSDOT Standard Specification 9-03.12(5).

- Filter fabric shall be placed over the drain rock as shown on Figure 15.1 prior to backfilling. Do not place fabric on trench bottom.

- Infiltration trenches may be placed in fill material if the fill is placed and compacted under the direct supervision of a geotechnical engineer or professional civil engineer with geotechnical expertise, and if the measured infiltration rate is at least 8 inches per hour. Trench length in fill must be 60 linear feet per 1,000 square feet of roof area. Infiltration rates can be tested using the methods described in Appendix V-A.

- A structure with a sump shall be located upstream of the trench and shall provide a minimum of 12 inches of depth below the outlet riser. The outlet riser pipe bottom shall be designed so as to be submerged at all times, and a screening material shall be installed on the pipe outlet.

- Trenches may be located under pavement if designed by a professional engineer. Trenches located under pavement must include a small yard drain or catch basin with grate cover such that the overflow would occur out of the catch basin at least 1 foot below the pavement, and in a location that can accommodate the overflow without creating a significant adverse impact to downhill properties or drainage systems. This is intended to prevent saturation of the pavement in the event of system failure. The trench depth must be measured from the overflow elevation, not the ground surface elevation.

If the above design criteria are met, Table 15.1 may be used to size a downspout infiltration trench or drywell system. Table 15.1 presents trench footprint areas per 1,000 square feet of roof area, based on various depths and infiltration rates. The required trench footprint area may be determined based on the information and rate (square foot of trench required per 1,000 square feet of roof area) in the table. However, for infiltration rates that fall between the rates represented in the table, the designer must use the more conservative (i.e., lower) infiltration rate in their design. As noted previously, all designers have the option to do their own engineered design for infiltration trenches in lieu of using Table 15.1, subject to approval by the city.

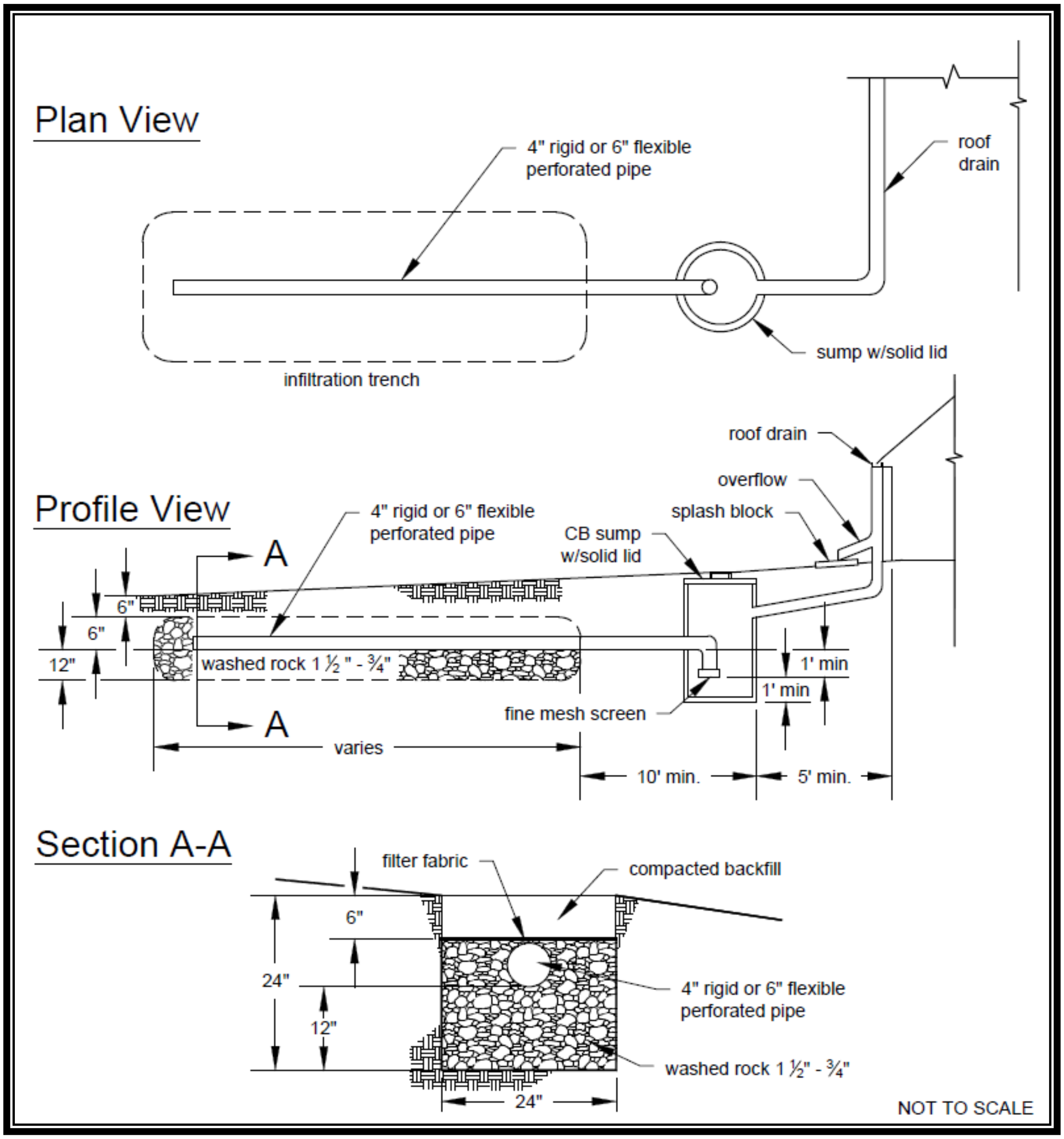


Figure 15.1. Typical Downspout Infiltration Trench.

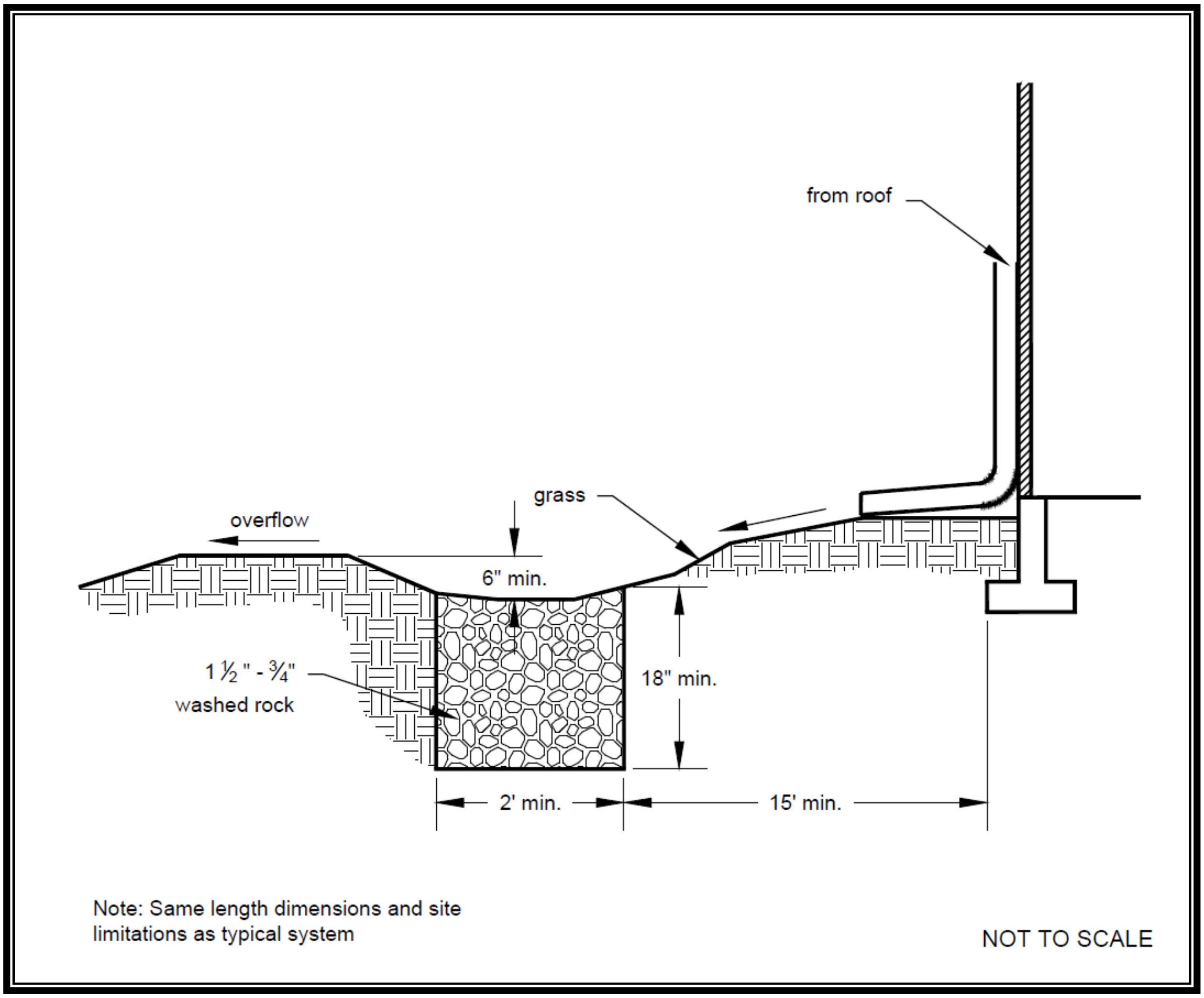


Figure 15.2. Alternative Downspout Infiltration Trench System for Coarse Sand and Gravel.

Downspout Infiltration Drywell System Design Criteria

- The drywell system is to be constructed according to the standard design shown in Figure 15.3.
- The drywell shall include a settling chamber, or its equivalent, for particulate removal. If non-roof runoff is also draining to the drywell system, the contributing flows must also pass through a catch basin structure with a sump.
- Drywells must be 48 inches in diameter (minimum) and deep enough to contain the gravel amounts specified above for the soil type and impervious surface served.
- Geotextile filter fabric shall be wrapped entirely around trench drain rock prior to backfilling.
- Spacing between drywells must be a minimum of 10 feet.

15.3.6 Construction Criteria

See Volume II, Section 3.3 for infiltration facility construction requirements.

15.3.7 Verification of Performance

The project proponent shall inspect and document infiltration systems before, during, and after construction, as necessary, to ensure facilities are built to design specifications, that proper procedures are employed in construction, that the infiltration surface is not compacted, and that protection from sedimentation is in place. The city may require additional verification, as needed, to document performance following construction.

When downspout infiltration facilities have a tributary area of over 2,000 square feet of roof area and contribute to satisfying Minimum Requirement #7 Flow Control, the constructed facility shall be tested and monitored per the Verification of Performance requirements in Section 2.2

15.3.8 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

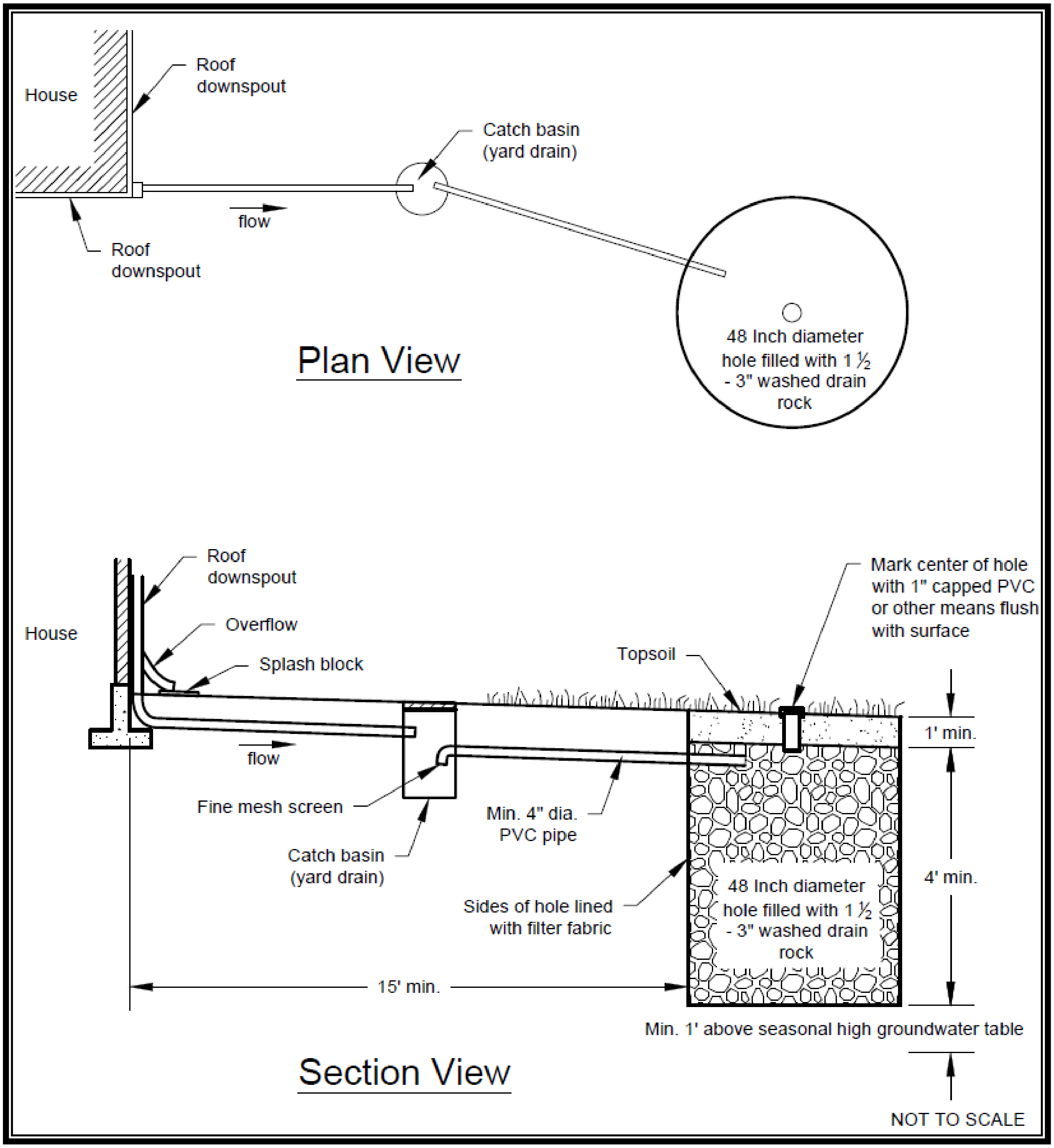


Figure 15.3. Typical Infiltration Drywell.

15.4 Downspout Dispersion—Trenches and Splashblocks (Ecology BMP T5.10B)

15.4.1 Description

Downspout dispersion systems are gravel-filled trenches or splashblocks, which serve to spread roof runoff over vegetated areas. Dispersion attenuates peak flows by slowing runoff entering into the conveyance system, allowing some infiltration, and providing some water quality benefits.

15.4.2 Applications and Limitations

- Downspout dispersion can be used to help meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, downspout dispersion can also help achieve compliance with Minimum Requirement #5.
- The layout of the natural resource protection areas adjacent to and downgradient of individual lots can provide opportunities to disperse runoff into the natural resource protection area.

15.4.3 Modeling and Sizing

If roof runoff is dispersed according to the requirements of this section over a vegetative flowpath that is 50 feet or longer (for splashblocks) through undisturbed native landscape or lawn/landscape area that meets the soils criteria outlined in Chapter 6, the roof area may be modeled as grass/lawn surface. If the available vegetated flowpath is 25 to 50 feet, use of a dispersion trench allows modeling the roof as 50 percent impervious/50 percent landscape.

15.4.4 Downspout Dispersion Design Criteria

General Downspout Dispersion Design Criteria

Refer to Chapter 7 for general dispersion design criteria. This section provides design criteria for both dispersion trenches and splashblocks:

- Each downspout dispersion trench shall have a separate flowpath.
- For the purpose of maintaining adequate separation of flows discharged from adjacent dispersion trenches, vegetated flowpaths shall be at least 20 feet apart at the upslope end and must not overlap with other flowpaths at any point along the flowpath lengths.
- See additional applicable dispersion area setbacks and design criteria in Chapter 7.

Dispersion Trench Design Criteria

This section provides additional design criteria specific to dispersion trenches.

- Dispersion trenches shall be designed as shown in Figures 15.4 through 15.6.
- A vegetated flowpath of at least 25 feet in length must be maintained between the outlet of a trench and any property line, structure, critical area (i.e., stream, wetland), or impervious surface.
- Trenches serving up to 700 square feet of roof area may be simple 10-foot-long by 2-foot-wide gravel filled trenches as shown in Figures 15.3 and 15.5. For roof areas larger than 700 square feet, a dispersion trench with notched grade board as shown in Figure 15.6 may be used subject to approval by the City of Tumwater. It is acceptable to have multiple downspouts routed to a dispersion trench. The total length of this design must not exceed 50 feet and must provide at least 10 feet of trench per 700 square feet of roof area. In both systems, it is important to include a cleanout structure prior to discharge into the dispersal area. Although Figures 15.4 and 15.6 refer at times to a Type 1 catch basin being used, it is also acceptable to utilize an equivalent type structure that includes a lid, 1-foot minimum sump, and T-type outlet with screen.

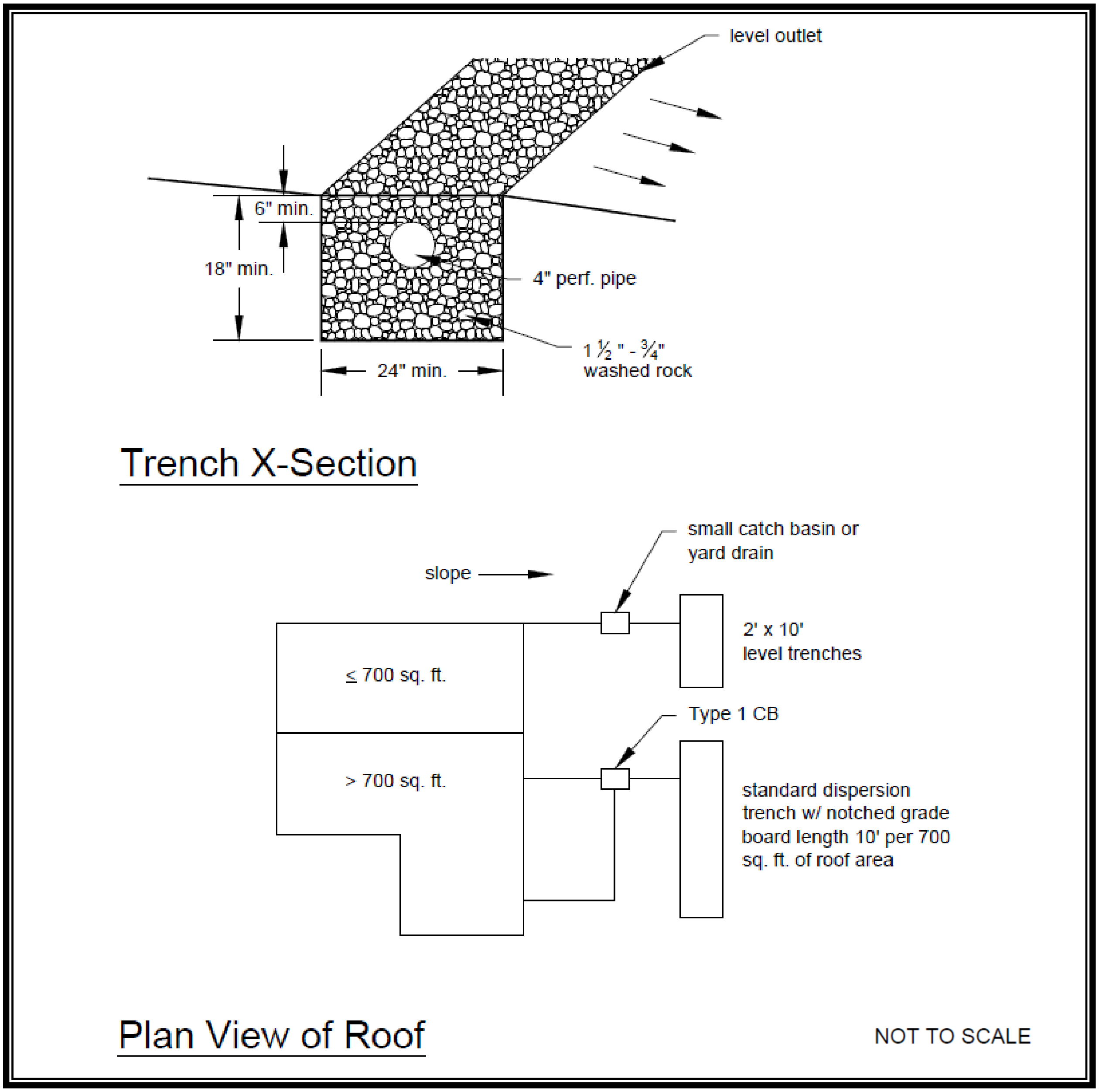
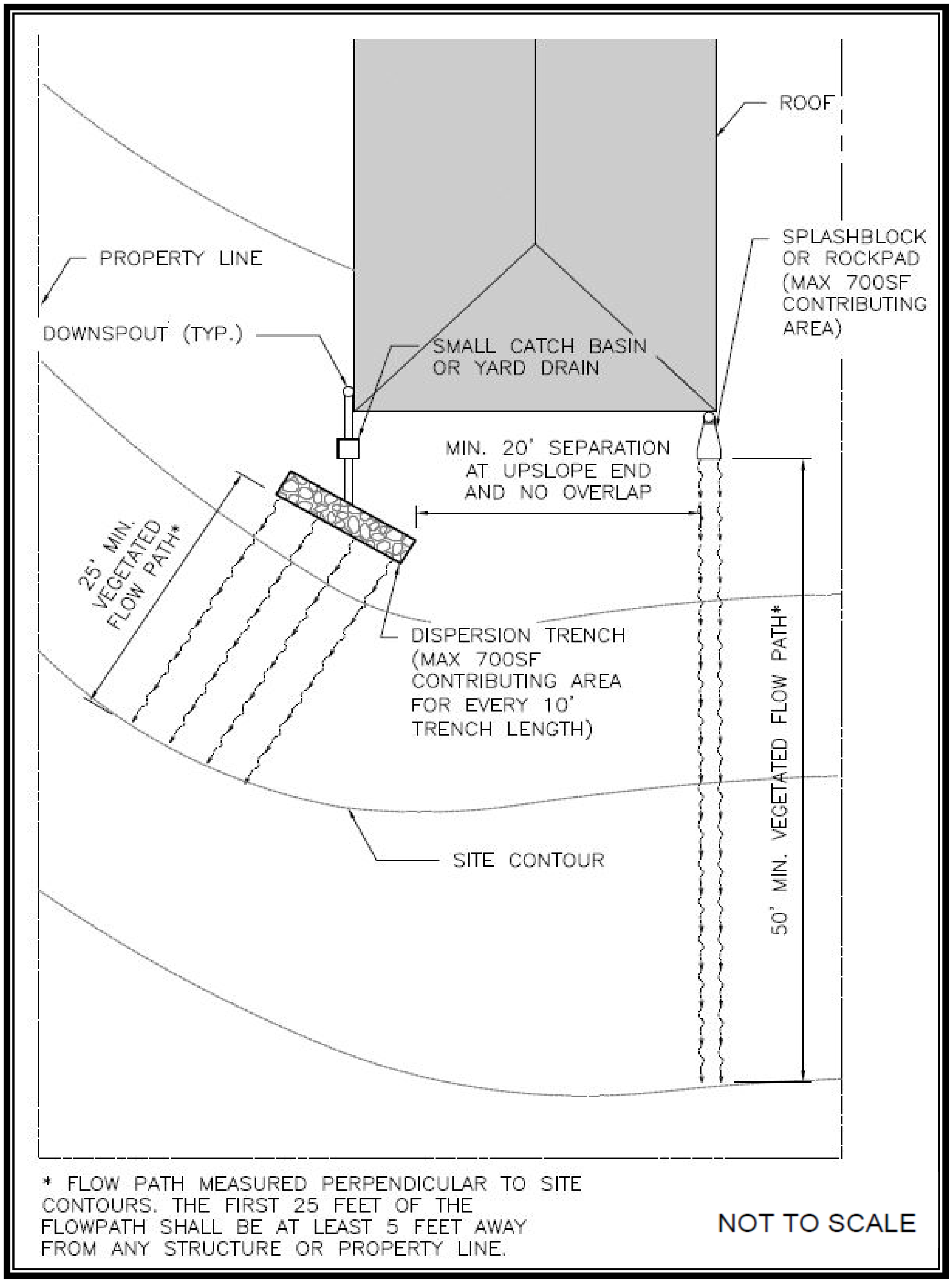


Figure 15.4. Typical Downspout Dispersion Trench.



Source: Pierce County

Figure 15.5. Typical Downspout Dispersion Trench.

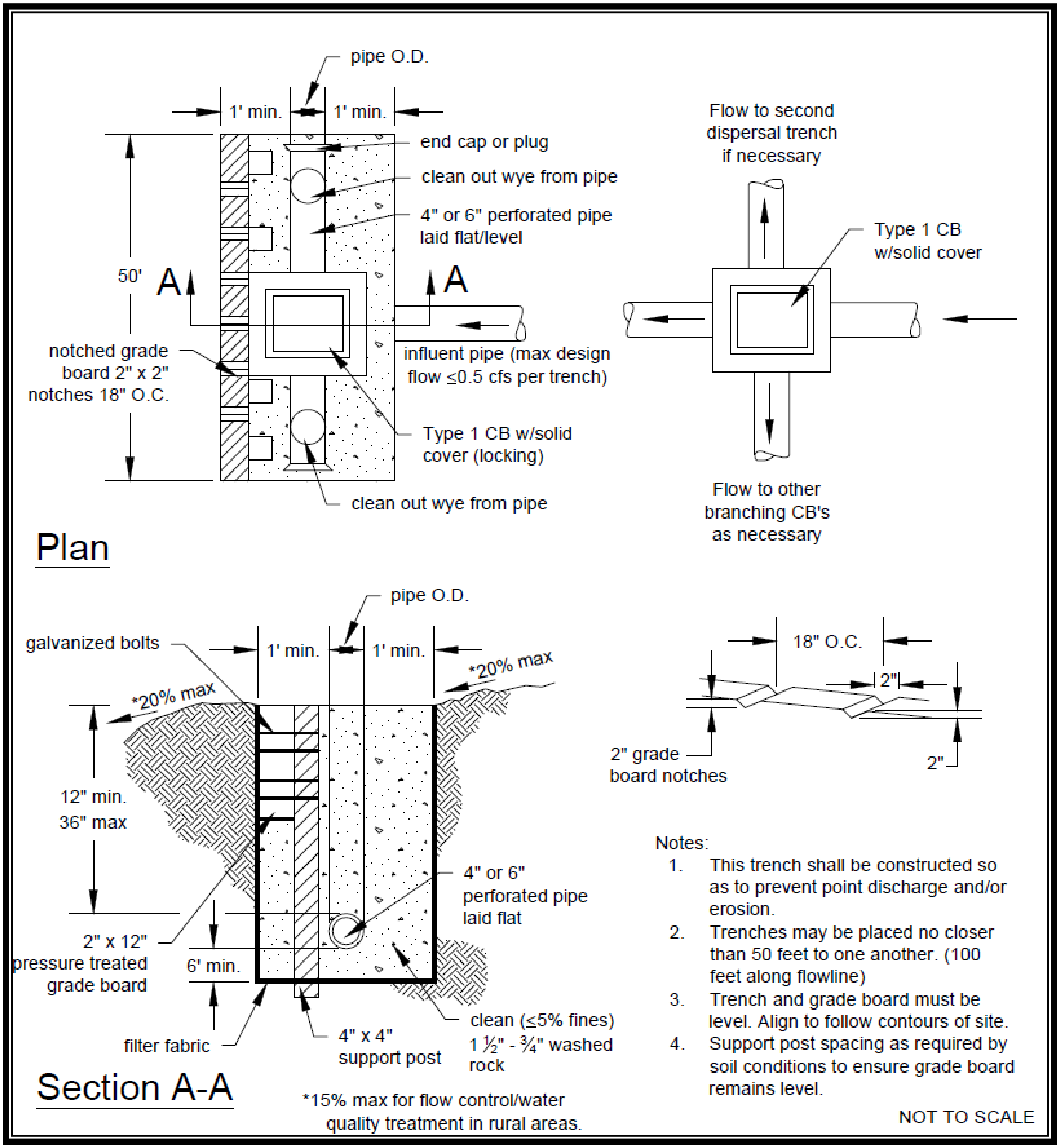


Figure 15.6. Standard Dispersion Trench with Notched Grade Board.

15.4.5 Splashblocks

This section provides additional design criteria specific to splashblocks.

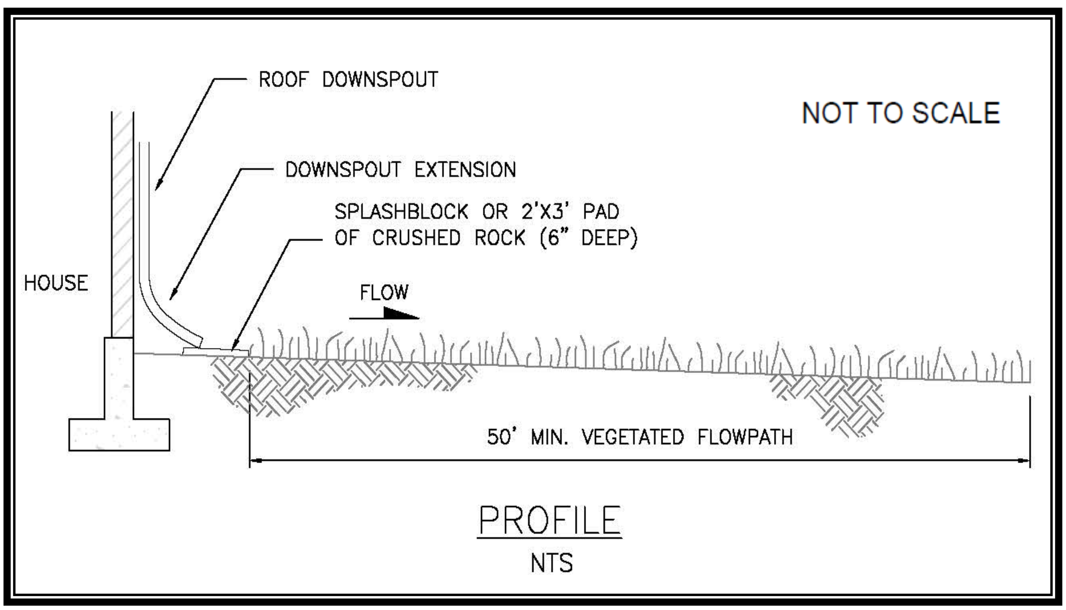
- Splashblocks shown in Figure 15.7 may be used for downspouts discharging to a vegetated flowpath at least 10 feet in width and 50 feet in length as measured from the downspout to the downstream property line, structure, critical areas (i.e., stream, wetland), or other impervious surface
- A maximum of 700 square feet of roof area may drain to each splashblock
- 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 discharge point.

Construction Criteria

See Volume II, Section 3.3, for dispersion facility construction requirements.

Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.



Source: Pierce County

Figure 15.7. Typical Downspout Splashblock Dispersion.

15.5 Perforated Stub-Out Connections (Ecology BMP T5.10C)

15.5.1 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 downstream drainage system. Figure 15.8 illustrates a perforated stub-out connection. These systems are intended to provide some infiltration during drier months. During the wet, winter months, they may provide little or no flow control.

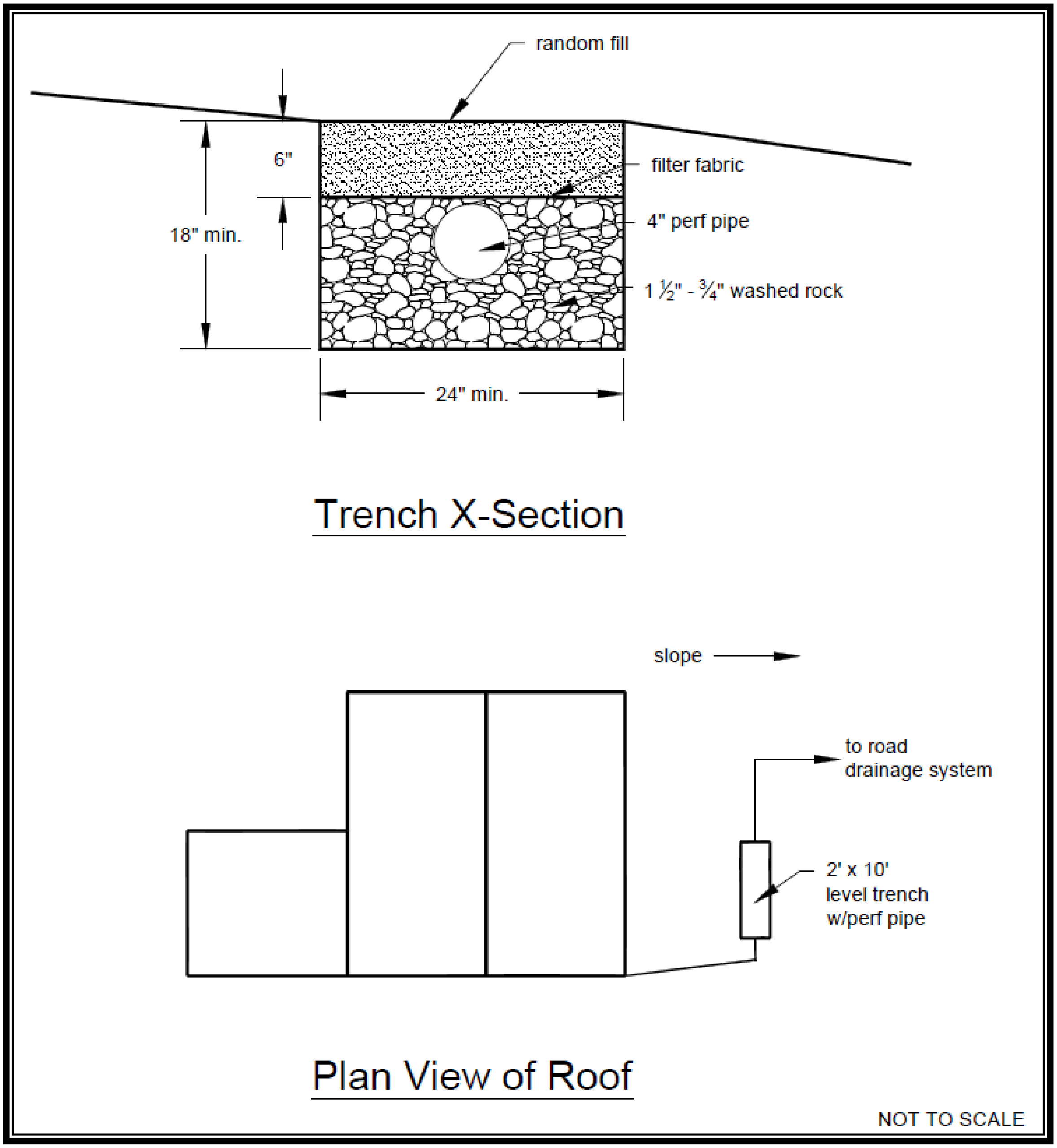


Figure 15.8. Perforated Stub-Out Connection.

15.5.2 Applications and Limitations

- Perforated stub-outs are not appropriate where the highest estimated groundwater level or other impermeable layer is less than 1 foot below the trench bottom.
- In projects subject to Minimum Requirement #5 (see Volume I, Section 4.2.6), perforated stub-out connections may be used only when all other higher priority on-site stormwater management BMPs are not feasible.
- Select the location of the connection to allow a maximum amount of runoff to infiltrate into the ground (ideally a dry, relatively well-drained location).
- To facilitate maintenance, do not locate the perforated pipe portion of the system under impervious or heavily compacted surfaces (e.g., driveways and parking areas).
- Use the same setbacks as for downspout infiltration systems (see Section 15.3, Downspout Infiltration Systems), with the following modification to the setback from on-site or adjacent septic systems.
    - Apply the prescribed setbacks from on-site or adjacent septic systems to the perforated portion of the pipe (not the discharge point)
    - The perforated portion of the pipe shall not be upgradient of the drainfield primary and reserve areas. This requirement can be waived if site topography will clearly prohibit flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that this is unnecessary.
- Do not place the perforated portion of the pipe within 300 feet of an erosion hazard area, a landslide hazard area (as defined by Title 16.20.050 TMC), or above slopes greater than 20 percent, unless a geotechnical professional has analyzed and mitigated the slope stability impacts of the perforated stub-out connection, and appropriate analysis indicates that the impacts are negligible.
- Perforated stub-outs are not appropriate where connecting pipe discharges to a stormwater facility designed to meet Minimum Requirement #7: Flow Control.

15.5.3 Modeling and Sizing

Any flow reduction is variable and unpredictable; therefore, no flow control credits are given for perforated stub-outs. No computer modeling techniques are allowed that allocate any reduction in flow rates or volumes from the connected area.

15.5.4 Perforated Stub-Out Design Criteria

Perforated stub-out connections consist of at least 10 feet of perforated pipe per 5,000 square feet of roof area, laid in a level, 2-foot-wide trench backfilled with a 12-inch-minimum depth of washed drain rock. Lay the 4- or 6-inch-diameter perforated pipe level with 6 to 8 inches of drain rock below the bottom of the pipe. Cover the rock trench with filter fabric and a minimum of 6 inches of fill (see Figure 15.8).

15.5.5 Operations and Maintenance Criteria

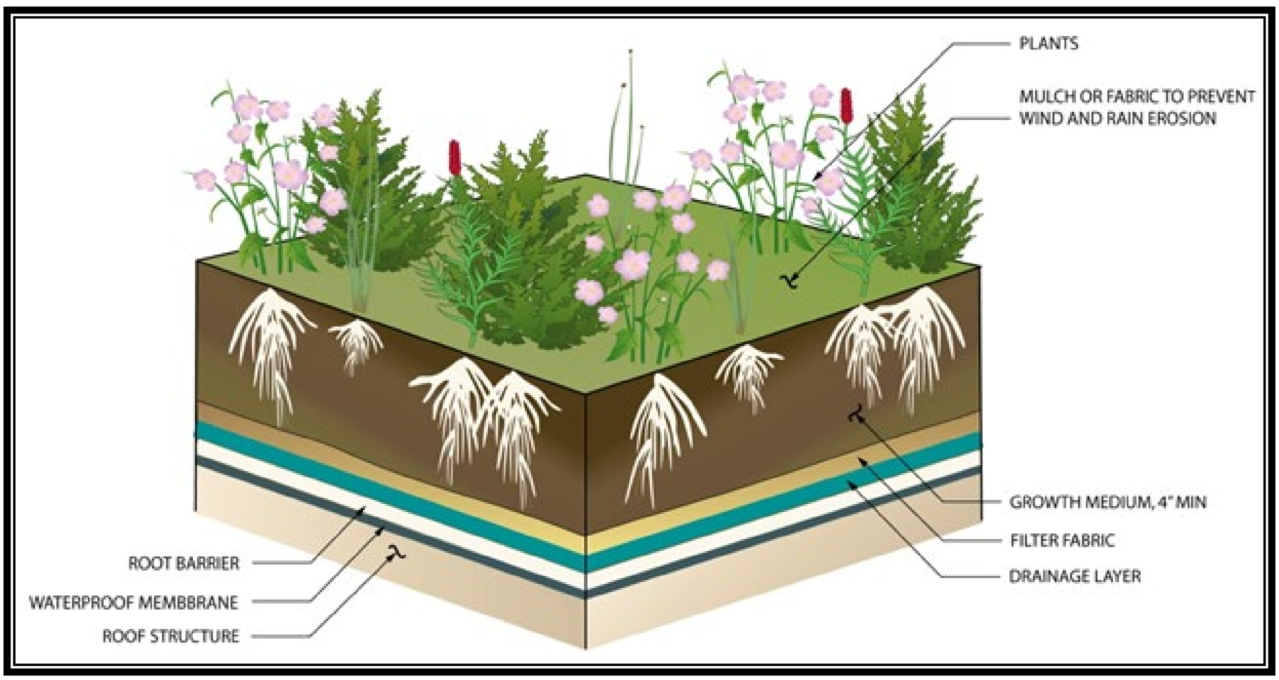
See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements (refer to maintenance requirements for infiltration basins and trenches).

Chapter 16 – Vegetated Roofs (Ecology BMP T5.17)

16.1 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. Because vegetated roofs are an integral component of the building structure, and the design and construction approaches continue to be refined as this technology evolves, this section focuses primarily on the stormwater elements of vegetated roof design. Other technical resources, such as the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012), are referenced in this section for additional guidance and information.

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 16.1). 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.



Source: Pierce County

Figure 16.1. Vegetated Roof.

16.2 Applications and Limitations

- Vegetated roofs can be used to help meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, vegetated roofs can also help achieve compliance with Minimum Requirement #5.
- 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 International Building Code (IBC) Section 1604 for general structural requirements.

16.3 Modeling and Sizing

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 16.1 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 16.1. Continuous Modeling Assumptions for Vegetated Roofs.

Variable	Assumption
Computational Time Step	15 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, 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 (feet)	The length of the surface flowpath to the roof drain
Slope of Rooftop (feet/feet)	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. The exfiltrated flow (flow infiltrated through the growth medium and collected by the drainage layer) is tracked as "groundwater" in WWHM.

The depth of the growth medium 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 vegetated roof, additional downstream flow control measures may be required. For additional guidance on modeling and sizing see the 2019 Ecology Manual, Volume III, Section III-2.

16.4 Vegetated Roof Design Criteria

The following sections provide a description and general specifications for the common components of vegetated roofs. Typical components of a vegetated roof are shown in Figure 16.2. 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 *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for a more detailed description of the components of and design criteria for vegetated roofs, as well as additional references and design guidance.

16.4.1 Roof Slope

For flow control compliance, the vegetated roof slope must be between 5 and 22 degrees (1:12 and 5:12). Roofs of this slope are generally the easiest to install, are the least complex, and provide the greatest stormwater storage capacity per inch of growth medium. Roofs with slopes greater than 10 degrees (2H:12V) require an analysis of engineered slope stability.

16.4.2 Vegetation

Vegetation 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 *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for additional vegetation guidance for vegetated roofs.

Minimum requirements associated with vegetation design include:

- Plans must specify that vegetative coverage of selected plants must achieve 90 percent 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 a 2-year establishment period.

16.4.3 Growth Medium

Vegetated roofs use a lightweight 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 *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for additional guidance on growth medium design.

Minimum requirements associated with the growth medium design include:

- The growth medium must be a minimum of 4 inches deep.
- 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.

16.4.4 Drainage Layer

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. Refer to the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for additional guidance on drainage layer design.

16.4.5 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 to 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.

16.5 Construction Criteria

The growth medium must be protected from over compaction during construction.

16.6 Operations and Maintenance Criteria

Vegetated roofs are designed to need very little maintenance and, if designed correctly, should have a longer lifespan than traditional roofs because of the protective nature of the soil structure. Nevertheless, inspections should be performed regularly to identify any leakage of the membrane system or blockages of the overflow system. See Minimum Requirement #9 in Volume I, Section 4.2.10, and the Stormwater Facility Maintenance Standards on the city web site for information on maintenance requirements.

Chapter 17 – Roof Rainwater Collection Systems (Ecology BMP T5.20)

17.1 Description

Roof rainwater collection systems are designed to collect stormwater runoff from non-polluting surfaces (typically roofs) and to make use of the collected water. Reuse of the runoff can be for irrigation, potable, and non-potable uses, but requires different levels of storage and water quality treatment, depending on the intended use. Rainwater collection systems have been designed and installed in many locations throughout the northwest, including Pacific Plaza in Tacoma and the Bullitt Center in Seattle. The most abundant use of water collection and reuse systems in the northwest has been in some island communities where potable water is scarce. In those cases, the systems have been sized and designed to capture all rooftop runoff with adequate treatment for reuse as a potable water source. Rainwater collection and reuse systems are also commonly referred to as “rainfall catchment” and “rainwater harvesting” systems.

Because of the wide variety of uses and scenarios that can apply to rooftop rainwater collection and use, this section focuses primarily on the stormwater elements of rainwater collection design. Additional guidance and information on issues such as modeling indoor water use can be found in the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) and other resources.

17.2 Applications and Limitations

- Rainwater collection systems can be used to help meet the flow control standards of Minimum Requirement #7.
- When used in combination with other on-site stormwater management BMPs, Rainwater collection systems can also help achieve compliance with Minimum Requirement #5.
- Rainwater collection systems can also be effective in reducing stormwater volume for projects where infiltration is not permitted or desired.
- Rainwater collection has higher stormwater management benefits when designed for uses that occur regularly through the wet season (e.g., toilet flushing and cold water laundry).
- Highly developed areas or commercial centers where larger buildings, especially multistory buildings, cover nearly all of the area are highly suitable for rainwater collection systems because it might not be feasible to preserve natural protection areas. In highly developed areas, any type of stormwater management is expensive due to the high cost of land; therefore, the cost of a rainwater collection and reuse system can be more competitive.

- Roof rainwater collection systems have an additional benefit of decreasing demands on the treated potable water supply.

- Using a roof rainwater collection system as a potable source will require approval by the Washington State Department of Health and/or the Thurston County Public Health and Social Services Department.

Using rain barrels to capture rainfall can be beneficial for providing a small amount of irrigation and an educational aspect to the benefits of water reuse. However, rain barrels generally do not provide enough storage of seasonal runoff to be considered to meet the performance goals of Minimum Requirement #5 or #7, or the general performance requirements of LID projects, unless prior approval is obtained from the city.

17.3 Modeling and Sizing

- Roof rainwater collection systems must be sized according to roof area, monthly rainfall patterns, and anticipated water usage of connected plumbing facilities. To estimate the storage volume required, the volume of rainfall from the roof surface should be plotted over time against curves showing the amount of water use anticipated. Use monthly average rainfall for City of Tumwater, shown in Table 17.1.

Table 17.1. City of Tumwater Monthly Average Rainfall.

Month	Amount	Month	Amount
January	8.51 inches	July	0.67 inch
February	5.82 inches	August	1.31 inch
March	4.85 inches	September	2.36 inches
April	3.11 inches	October	4.66 inches
May	1.84 inches	November	7.66 inches
June	1.42 inches	December	8.52 inches

Note: The rainfall depths above represent the average monthly rainfall from 1951 through 2008 measured at the Olympia Regional Airport NOAA station < https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00024227/detail>.

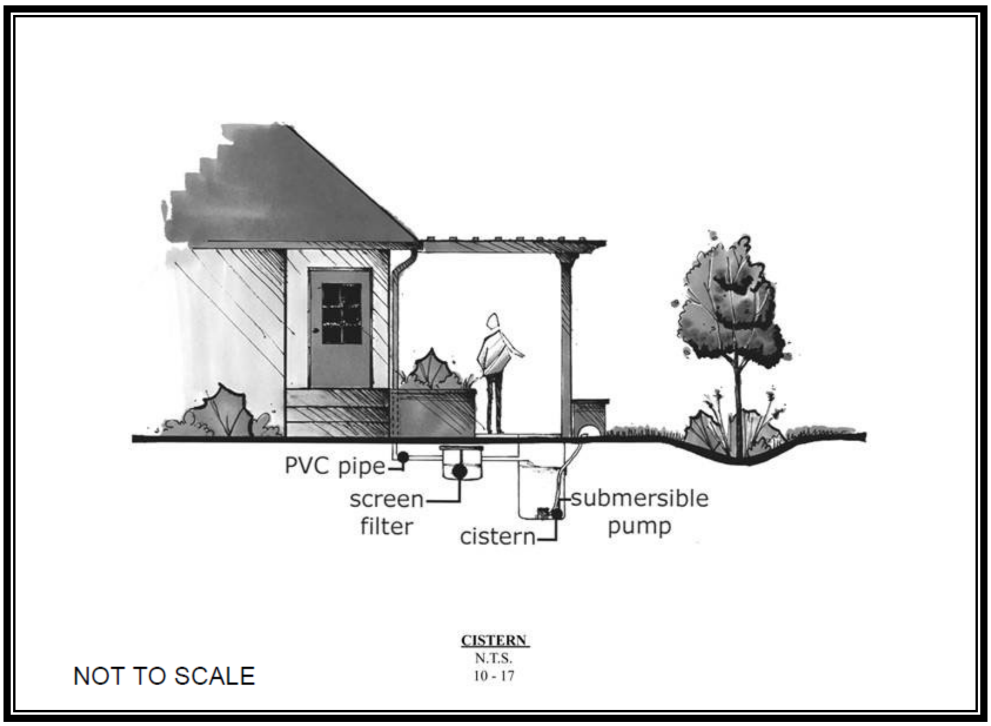
- Rainwater collection systems also experience water losses due to roofing material texture, evaporation, and inefficiencies in the collection process, which can account for up to a 25 percent loss of volume. As noted previously, additional guidance and information on modeling and sizing for indoor water use can be found in the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) and other resources.

17.4 General Roof Rainwater Collection System Design Criteria

Rainwater collection systems can be designed as part of the foundation to fit under a house (adding about 1 foot in height), or can be placed next to a house, either above or below ground. When runoff storage is incorporated into the building design, it must be submitted for approval as part of the building permit. Figure 17.1 illustrates an example cistern installation.

- Rainwater reuse systems that supply non-potable water should be designed to augment the supply of treated water and, therefore, should be designed to use the stored rainfall runoff first and use the treated water supply when the stored rainfall runoff is depleted.

- Refer to the *Low Impact Development Technical Guidance Manual for Puget Sound* (WSU and PSP 2012) for additional guidance for design of rainwater harvesting systems and cistern design requirements specific to indoor use of harvested rainwater.



Source: Pierce County

Figure 17.1. Cistern.

17.5 Construction Criteria

Rainwater harvesting systems must be constructed according to the manufacturer's recommendations, the International Building Codes, and all applicable laws.

17.6 Operations and Maintenance Criteria

Maintenance covenants shall provide for annual inspections of systems to ensure pumps and filters are working properly and the design level of water quality is being maintained.

See Minimum Requirement #9 in Volume I, Section 4.2.10, and the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

Chapter 18 – Detention Ponds

18.1 Description

This section presents the methods, criteria, and details for design and analysis of detention ponds, which provide for the temporary storage of increased surface water runoff resulting from development, pursuant to the performance standards set forth in Minimum Requirement #7 for flow control (Volume I, Section 4.2.8).

The design criteria in this section are for detention ponds. However, many of the criteria also apply to infiltration basins (Chapter 14), and water quality wet ponds and combined detention/wet ponds (see Chapters 23 through 27). Standard details for detention ponds and key detention pond structures are provided in Figures 18.1 through 18.5. Control structure design requirements are provided in Chapter 21.

18.2 Methods of Analysis

18.2.1 Detention Volume and Outflow

The volume and outflow design for detention ponds must be in accordance with Minimum Requirements #7 in Volume 1, Section 4.2 and the hydrologic analysis and design methods in Volume III. Design requirements for restrictor orifice structures are given in Chapter 21.

Note: The design water surface elevation is the highest elevation that occurs in order to meet the required outflow performance for the pond.

18.2.2 Detention Ponds in Infiltrative Soils

Detention ponds may occasionally be sited on till soils that are sufficiently permeable for a properly functioning infiltration system (see Chapter 2). These detention ponds have a surface discharge but may also utilize infiltration as a second pond outflow. Detention ponds sized with infiltration as a second outflow must meet all the requirements of Chapter 2 for infiltration basins, including a Soils Report, testing, water quality treatment, groundwater protection, presettling, and construction techniques.

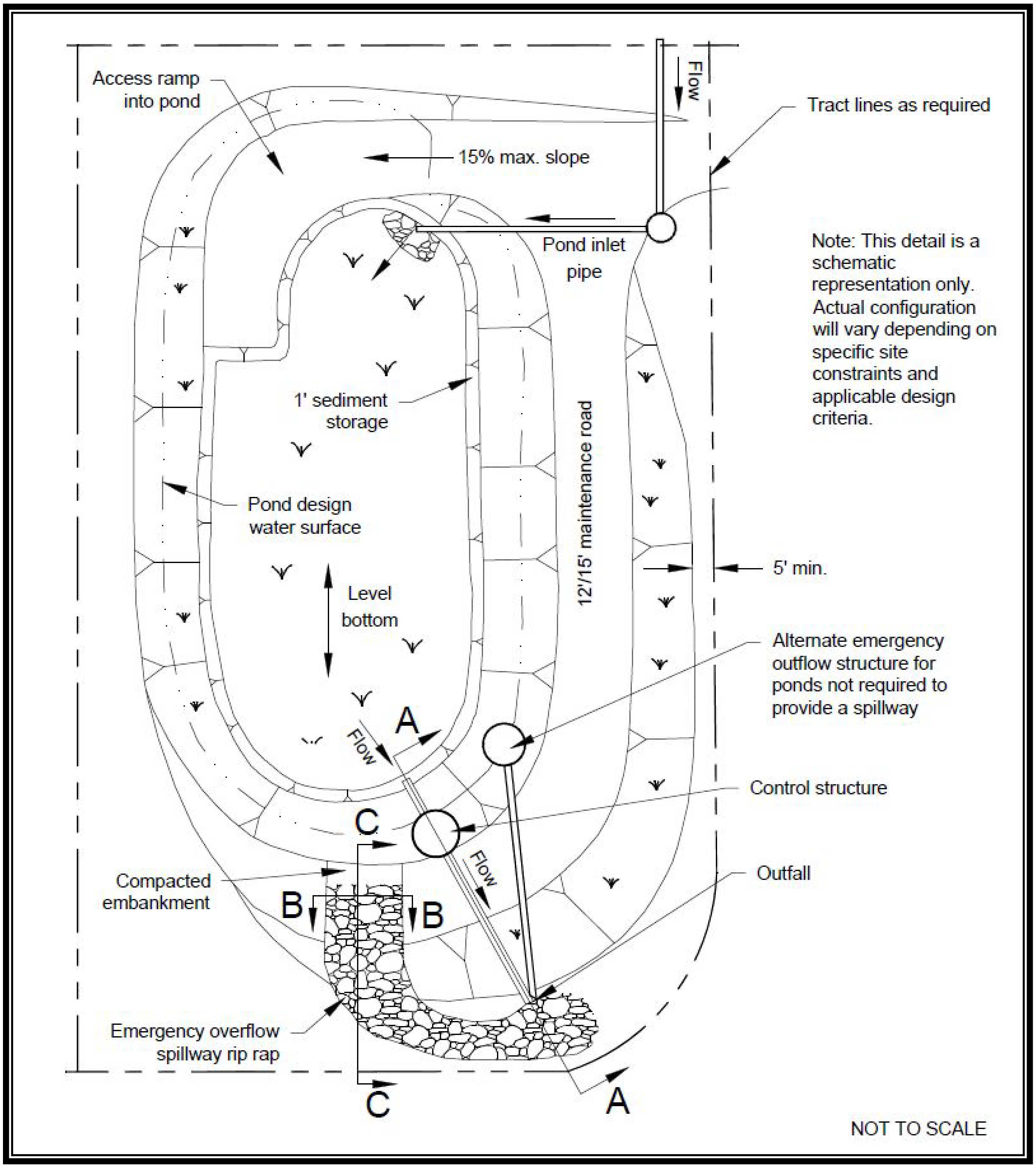
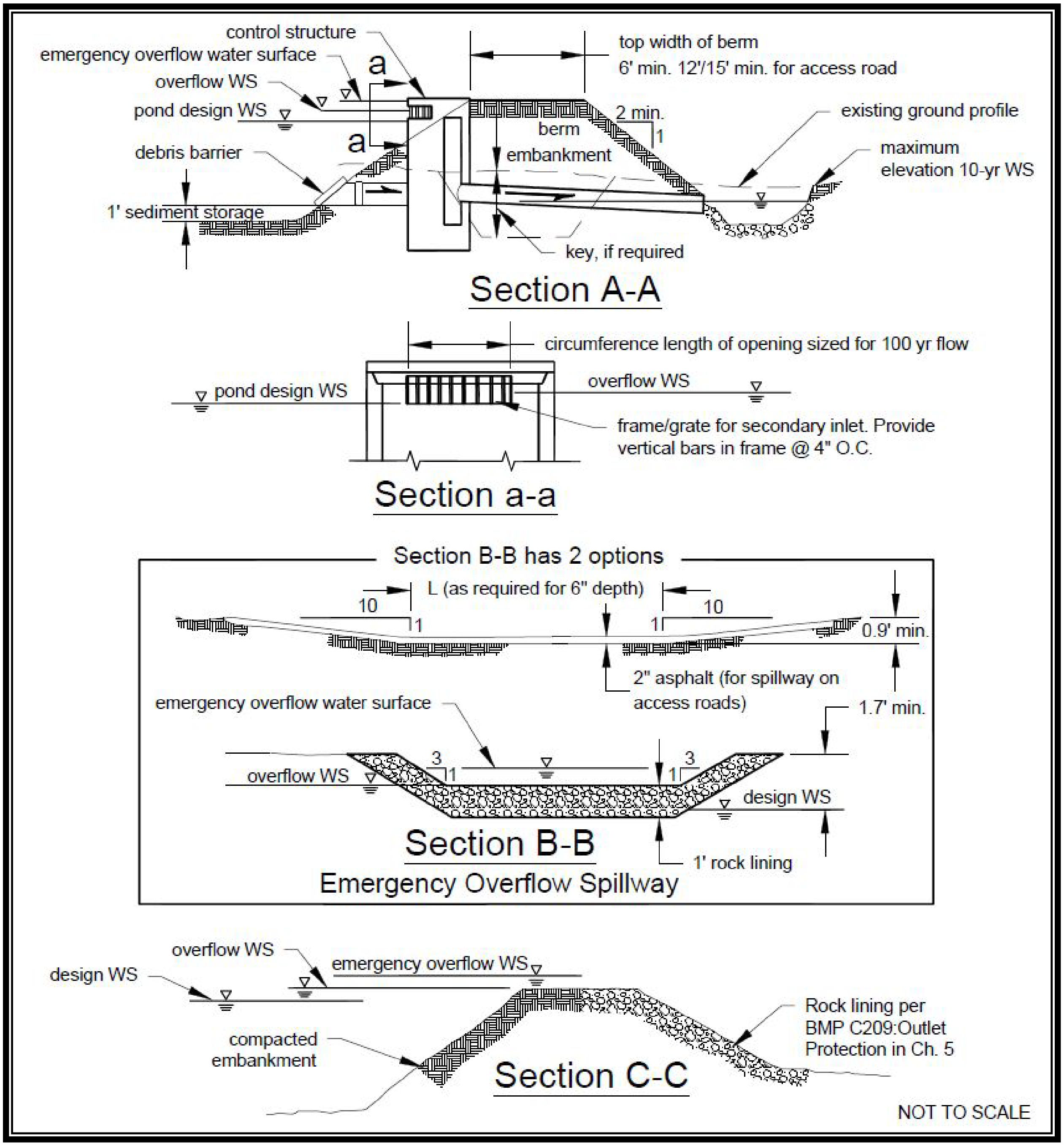


Figure 18.1. Typical Detention Pond.



Note: This detail is a schematic representation only. Actual configuration will vary depending on specific site constraints and applicable design criteria.

Figure 18.2. Typical Detention Pond Sections.

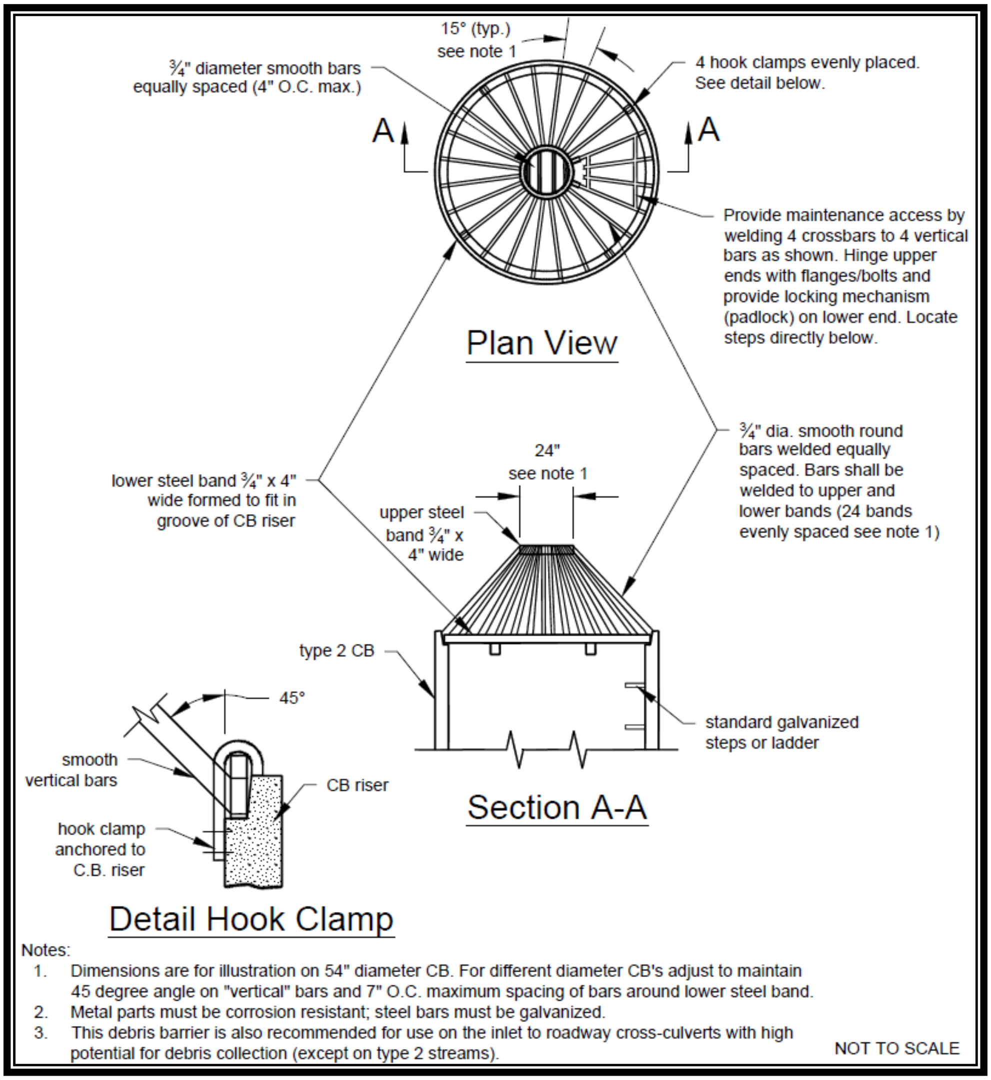


Figure 18.3. Overflow Structure Debris Barrier.

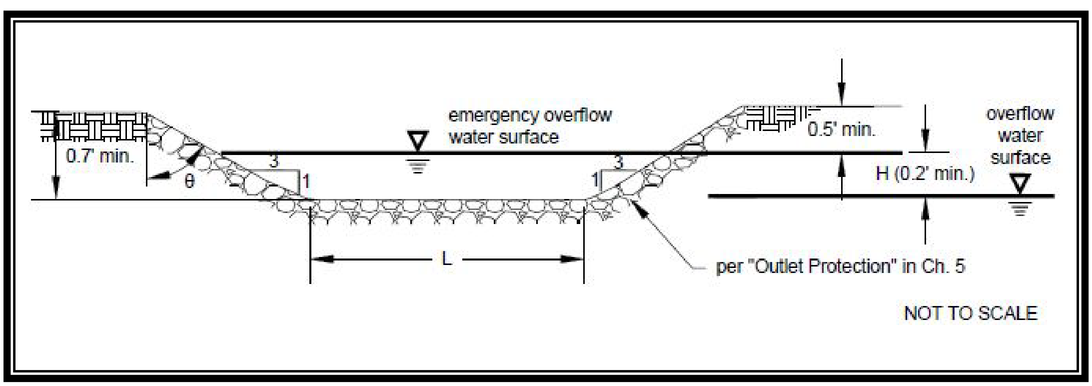
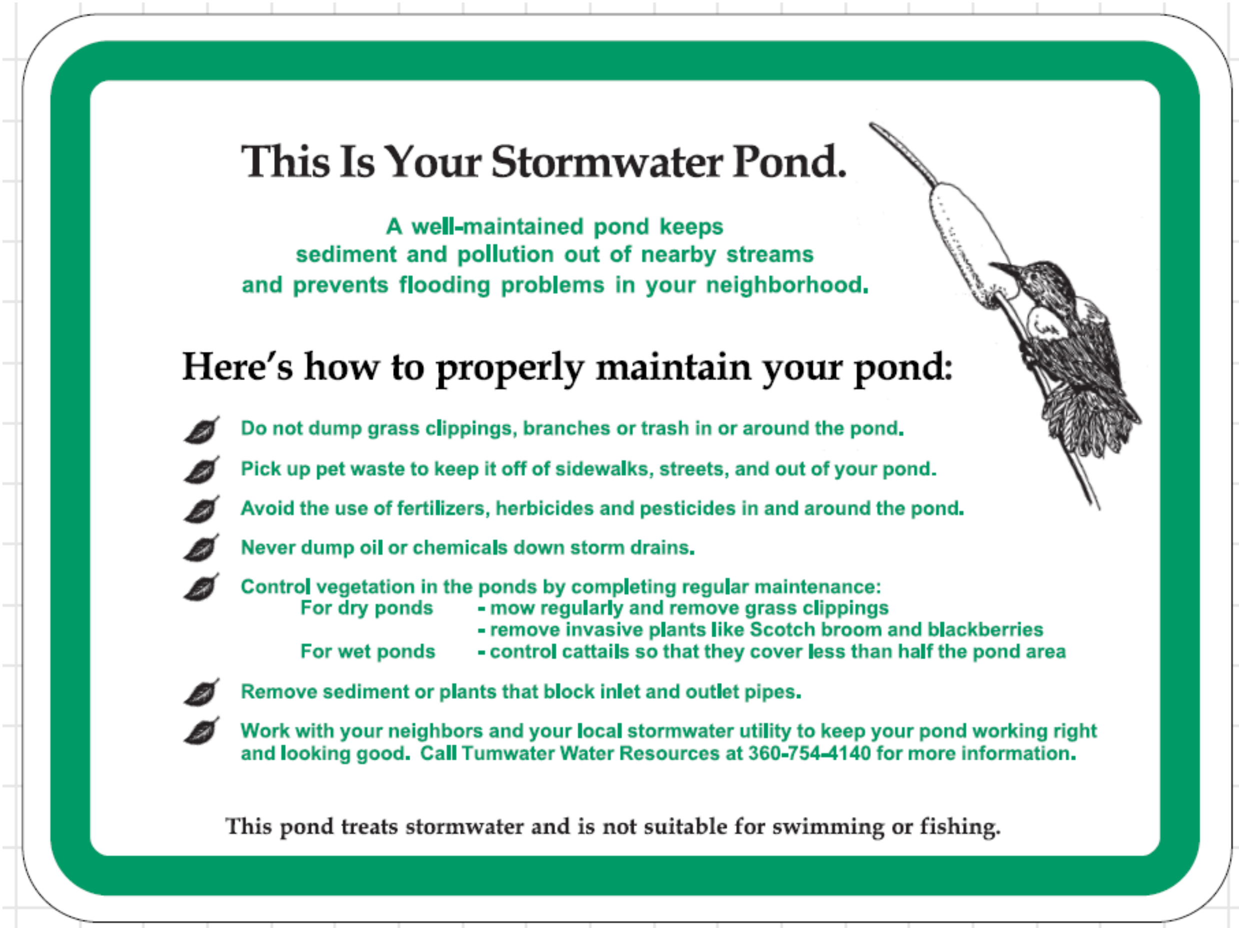


Figure 18.4. Weir Section for Emergency Overflow Spillway.



(Contact the city for current dimensions)

Figure 18.5. Example of Stormwater Pond Sign Provided by the City of Tumwater.

18.2.1 Emergency Overflow Spillway Capacity

For impoundments of less than 10 acre-feet, the emergency overflow spillway weir section must be designed to pass the 100-year recurrence interval runoff event for developed conditions, assuming a broad-crested weir. The **broad-crested weir equation** for the spillway section (see also Figure 18.4), for example, would be:

$$Q_{100} = C\,(2g)^{1/2}\left[\frac{2}{3}LH^{3/2} + \frac{8}{15}(\mathrm{Tan}\,\theta)\,H^{5/2}\right] \qquad \text{(Equation 1)}$$

Where:

Q_{100} = peak flow for the 100-year recurrence interval runoff event (cfs) indicated by an approved continuous runoff model using a 15-minute time step.

C = discharge coefficient (0.6)

g = gravity (32.2 feet/sec^2)

L = length of weir (feet)

H = height of water over weir (feet)

θ = angle of side slopes

Assuming C = 0.6 and Tan θ = 3 (for 3:1 slopes), the equation becomes:

$$Q_{100} = 3.21[LH^{3/2} + 2.4\ H^{5/2}] \qquad \text{(Equation 2)}$$

To find width L for the weir section, the equation is rearranged to use the computed Q_{100} and trial values of H (0.2 feet minimum):

$$L = [Q_{100}/(3.21H^{3/2})] - 2.4\ H \quad \text{or 6 feet minimum} \qquad \text{(Equation 3)}$$

18.3 General Detention Design

- Ponds must be designed as flow-through systems. (However, parking lot storage may be utilized through a back-up system; see Chapter 22.) Developed flows must enter through a conveyance system that is separate from the control structure and outflow conveyance system. Maximizing distance between the inlet and outlet is encouraged to promote sedimentation.

- Pond bottoms must be level and be located a minimum of 1 foot (below the inlet and outlet to provide sediment storage.

- Design requirements for outflow control structures are specified in Chapter 21.

- A geotechnical assessment and Soils Report must be prepared for work located within 200 feet of the top of a steep slope, erosion hazard, or landslide hazard area (as defined in Title 16.20.050 TMC). The scope of the Soils Report shall include the assessment of impoundment seepage on the stability of the natural slope where the facility will be located within the setback limits set forth in this section.

- Drainage facilities should be made attractive features of the urban environment. To this end, engineers are encouraged to be creative in shaping and landscaping facilities and to consider aesthetics when choosing alternatives for parking lot paving, conveyance systems, detention facilities, weirs, structures, etc.

18.4 Dam Safety for Detention BMPs

Stormwater 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 are subject to 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. Peak flows from dam failures are typically much larger than the 100-year flows that these ponds are typically designed to accommodate.

In addition to the hydrologic and hydraulic issues related to precipitation and runoff, other dam safety requirements include geotechnical issues, construction inspection and documentation, dam breach analysis, inundation mapping, emergency action planning, and periodic inspections by project owners and by dam safety engineers. It is recommended and requested that Ecology's Dam Safety Office be contacted early in the facilities planning process. More information about dam construction and maintenance can be found on Ecology's web site at: < https://ecology.wa.gov/Water-Shorelines/Water-supply/Dams/Construction-maintenance>. >.

18.5 Side Slopes

- Interior side slopes up to the emergency overflow water surface shall not be steeper than 3H:1V unless a fence is provided (see "fencing").

- Exterior side slopes must not be steeper than 2H:1V unless analyzed and certified for stability and erosion resistance by a geotechnical engineer.

- Pond walls may be vertical retaining walls in limited circumstances as approved in advance by the Administrator, provided: 1) they are constructed of reinforced concrete per Chapter 20, Material; 2) a fence is provided along the top of the wall; 3) no more than 25 percent of the entire pond perimeter may be vertical side walls unless approved by the Administrator, 4) the design is stamped by a licensed civil engineer with structural expertise; and 5) an access ramp to the bottom of the pond is provided. Other retaining walls such as rockeries, concrete, masonry unit walls, and keystone-type wall may be used if designed by a geotechnical engineer or a civil engineer with structural expertise.

- The maximum depth of a retention or detention pond shall be 4.5 feet from the pond bottom to the top of the pond slope (not the water elevation). Deeper ponds may be allowed by the Administrator. If ponds over 4.5 feet deep have side slopes steeper than 4:1 (horizontal:vertical), then benches that are a minimum 3 feet wide shall be required for every 4.5 feet of depth. If ponds over 4.5 feet deep have sides 4:1 or flatter, benches are not required. When benches are required, they shall be constructed in a circular manner originating from the bottom of the pond. Wet ponds are also subject to a maximum depth limit for the "permanent pool" volume. Deep ponds (greater than 8 feet) may stratify during summer and create low oxygen conditions near the bottom resulting in rerelease of phosphorus and other pollutants back into the water.

18.6 Embankments

Pond berm embankments shall satisfy the following criteria.

- Construct pond berm embankments on native, consolidated soil (or adequately compacted and stable fill soils analyzed by a geotechnical assessment), which is free of loose surface soil materials, roots, and other organic debris.

- Construct pond berm embankments greater than 4 feet in height by excavating a “key” equal to 50 percent of the berm embankment cross-sectional height and width (minimum 3 feet), unless specified otherwise by a geotechnical engineer (except on till soils where the “key” minimum depth can be reduced to 1 foot of excavation into the till).

- Pond berm embankment cores shall be constructed of compacted soil (a minimum of 95 percent of the maximum dry density, standard proctor method per ASTM D698 [compaction standards may be increased if required by the city]), with the following soil characteristics per the USDA’s textural triangle: a minimum of 30 percent clay, a maximum of 60 percent sand, and a maximum of 60 percent silt, with nominal gravel and cobble content or as recommended by a geotechnical engineer. (Note: In general, excavated glacial till will be well-suited for berm embankment material.) The core shall be adequate to make the embankment impervious.

- Exposed earth on the interior and exterior embankment side slopes shall be sodded or seeded with appropriate seed mixture (see Volume II, BMP C120) to facilitate visual inspection of the embankment. Establishment of protective vegetative cover shall be ensured with appropriate surface protection BMPs and shall be reseeded as necessary.

- Where maintenance access is provided along the top of the berm, the minimum width of the top of the berm shall be 15 feet.

- Pond berm embankments greater than 6 feet in height shall be designed by a professional engineer with geotechnical expertise.

- Embankments less than 6 feet in height shall have a minimum 6-foot top width and slopes not to exceed 2H:1V. However, maintenance access for mowing and pond access must be provided.

- Embankments adjacent to a stream or other body of water shall be sufficiently protected with riprap or bioengineering methods to prevent erosion of the pond embankment. Other erosion control measures may be necessary to protect the embankment.

Anti-seepage filter-drain diaphragms must be placed on outflow pipes in berm embankments impounding water with depths greater than 8 feet at the design water surface. See Dam Safety Guidelines, Part IV, Section 3.3.B, on pages 3-27 to 3-30. More information about dam safety can be found on Ecology's website at: < https://ecology.wa.gov/Water-Shorelines/Water-supply/Dams>.

18.7 Overflow

- Provide a primary overflow (usually a riser pipe within the control structure; see Chapter 21) in all ponds, tanks, and vaults to bypass the 100-year recurrence interval developed peak flow over or around the restrictor system. This assumes the facility will be full due to plugged orifices or high inflows. The primary overflow is intended to protect against breaching of a pond embankment (or overflows of the upstream conveyance system in the case of a detention tank or vault). The design must provide controlled discharge directly into the downstream conveyance system or another acceptable discharge point.

- Provide a secondary inlet to the control structure in ponds as additional protection against overtopping should the inlet pipe to the control structure become plugged. A grated opening ("jailhouse window") in the control structure manhole functions as a weir when used as a secondary inlet. *Note: The maximum circumferential length of this opening must not exceed one-half the control structure circumference.* The overflow structure debris barrier may also be used as a secondary inlet (see also Figure 18.3).

18.8 Emergency Overflow Spillway

- In addition to the above overflow provisions, ponds must have an emergency overflow spillway. For impoundments of 10 acre-feet or greater, the emergency overflow spillway must meet the state's dam safety requirements. For impoundments less than 10 acre-feet, ponds must have an emergency overflow spillway that is sized to pass the 100-year recurrence interval developed peak flow in the event of total control structure failure (e.g., blockage of the control structure outlet pipe) or extreme inflows. Emergency overflow spillways are intended to control the location of pond overtopping and direct overflows back into the downstream conveyance system or other acceptable discharge point.

- Provide emergency overflow spillways for ponds with constructed berms over 2 feet in height, or for ponds located on grades in excess of 5 percent. As an option for ponds with berms less than 2 feet in height and located at grades less than 5 percent, emergency overflow may be provided by an emergency overflow structure, such as a Type II manhole fitted with a birdcage as shown in Figure 18.3. The emergency overflow structure must be designed to pass the 100-year recurrence interval developed peak flow (and in no case less than 6 inches of freeboard), directly to the downstream conveyance system or another acceptable discharge point. Where an emergency overflow spillway would discharge to a slope steeper than 15 percent, consideration shall be given to providing an emergency overflow structure in addition to the spillway.

- Armor the emergency overflow spillway with riprap in conformance with BMP C209: Outlet Protection, in Volume II. The spillway must be armored for its full width, beginning at a point midway across the berm embankment and extending downstream to where emergency overflows re-enter the conveyance system.
- Emergency overflow spillway designs must be analyzed as broad-crested trapezoidal weirs, as described in Methods of Analysis in Section 19.2.
- Design the emergency overflow spillway to allow a minimum of 1 foot of freeboard above the design water surface elevation.

18.9 Access

18.9.1 Pond Access Roads

Pond access roads shall provide access to the control structure(s) and alongside the pond for vehicular maintenance access to each pond cell. In addition, roads must be provided around the entire perimeter of the pond to provide vehicular access for regular maintenance. Regular maintenance includes activities that will be done on a regular basis, such as vegetation control, in which vegetation will need to be loaded onto a truck for removal. Because each site condition and pond design is unique, there may be cases where a complete perimeter road is not necessary because regular maintenance would not be needed in some areas. In such cases, the designer may request to waive the perimeter road requirement by submitting a conceptual pond layout and a narrative that demonstrates that, where the perimeter road is being eliminated, no regular maintenance activities are anticipated. Approval will be at the city’s discretion.

Pond access roads shall be located in the same tracts as the ponds themselves, when the ponds are in tracts. When ponds are located in open space, the pond access roads may be located in open space also, provided that they are constructed so as to be aesthetically compatible with the open space use.

18.9.2 Pond Access Road Design

Access roads shall be a minimum of 15 feet in width. Perimeter roads may be 12 feet wide where they are not accessing a structure or are being used for a circular loop road in lieu of turnaround. Access roads may be constructed with an asphalt, gravel, or modular paver surface. However, access to all control structures, catch basins, and other drainage structures associated with the pond (e.g., inlet or bypass structures) must be via an asphalt surface designed to support heavy loads, including Vactor trucks. Access to an emergency spillway is not required to be asphalt surface. A paved apron must be provided where access roads connect to paved public roadways. The inside road radius for access roads to ramps and control structures shall not be less than 40 feet. Inside road radius for perimeter access roads shall not be less than 25 feet.

Manhole and catch basin lids must be in or at the edge of the access road and at least 3 feet from a property line.

When the length of a pond access road to a control structure or pond exceeds 75 feet, a vehicle turnaround must be provided, designed to accommodate vehicles having a maximum length of 31 feet and an inside wheel path radius of 40 feet. The vehicle turn around requirement may be waived if the access road around the perimeter of the pond is entirely paved, and can be used in a continuous drive back to the entrance with no turnarounds.

Access roads to control structures shall have a maximum slope of 12 percent.

18.9.3 Pond Access Gates or Bollards

Vehicle access shall be limited by a double gate if a pond is fenced or by bollards if the pond is not fenced. A minimum of one locking access road gate shall be provided that meets WSDOT State Standard Plan L30.10. Bollards shall consist of two fixed bollards on the outside of the access road, and two removable bollards equally spaced between the fixed bollards; if placed in the traveled way, all four bollards shall be removable. Fence gates shall only be placed on straight sections of the access road.

When the access road connects to an arterial street (or any street with speed posted as 35 miles per hour), the access gates and bollards must be set back at least 20 feet from the street right-of-way.

18.9.4 Access Ramps

Pond access ramps shall be provided to <u>all</u> cells unless <u>all</u> of following conditions apply.

- Cell bottoms are accessible or reachable by trackhoes from the perimeter access road,
- A truck can be loaded without the truck accessing the bottom of the cell, and
- No point in the bottom of the cell is more than 40 feet from the center of the access road.

Trackhoe maximum reach from an access road is 20 feet. Cell bottoms will be considered accessible where at least one of the side slopes of the cell is no steeper than 3H:1V. Truck loading will be considered achievable where the cell depth (measured from bottom of cell to access road surface) is 4 feet or less at a point along the pond perimeter road where a truck can be parked and loaded.

18.9.5 Access Ramp Design

The access ramp shall have a minimum width of 15 feet and a maximum grade of 15 percent if paved. An alternate ramp surface can be constructed with a maximum slope of 12 percent by laying a geotextile fabric over the native soil, placing quarry spalls (2- to 4-inch) 6 inches thick, then providing a 2-inch-thick, crushed rock surface.

When an access ramp is required (see Section 18.9.4), the ramp must extend to the pond bottom if the cell bottom is greater than 1,500 square feet (measured without the ramp). If the pond bottom is less than 1,500 square feet (measured without the ramp), the ramp may end at an elevation 4 feet above the cell bottom.

The internal berm of a wet pond or combined detention and wet pond may be considered the maintenance access to the next cell if the following conditions are met.

- The berm is no more than 4 feet above either cell bottom
- The berm is designed to support the weight of a trackhoe (considering the berm is normally submerged and saturated)
- The berm side slopes are no steeper than 3H:1V.

18.10 Fencing

- A 6-foot high fence is required around all public stormwater facility tracts.
- Fences on public facilities shall be WSDOT Type 3 chain link fence per current WSDOT standard plan unless an alternative fence type is approved by the Administrator. Access shall be provided as specified in the previous section.
- Fence material shall be No. 9 gauge galvanized steel fabric with bonded vinyl coating. Vinyl coating color shall be compatible with surrounding environment (e.g., green in open grassy areas and black or brown in wooded areas). All posts, cross bars, and gates shall be painted or coated the same color as the vinyl clad fence fabric.
- Fences shall be located at the emergency overflow water surface elevation or higher, a minimum of 1 foot inside the tract or easement boundary, and where applicable a minimum of 5 feet from the top slope catch point.
- On private facilities, fences need only be constructed for those slopes steeper than 3H:1V. If more than 10 percent of slopes are steeper than 3H:1V, it is recommended that the entire pond be fenced.
- A fence is also required where a pond impoundment wall is greater than 24 inches in height.
- Other regulations such as the IBC may require fencing of vertical walls.
- Detention ponds on school sites will need to comply with safety standards developed by the Washington State Department of Health (DOH) and the

superintendent for public instruction. These standards include what is called a "non-climbable fence." One example of a non-climbable fence is a chain-link fence with a tighter mesh, so children cannot get a foothold for climbing. For school sites, and possibly for parks and playgrounds, the designer should consult the DOH Office of Environmental Programs.

- Fences discourage access to portions of a pond where steep side slopes (steeper than 3:1) increase the potential for slipping into the pond. Fences also serve to guide those who have fallen into a pond to side slopes that are flat enough (flatter than 3:1 and unfenced) to allow for easy escape.

- Any pipe stem access driveway to a facility shall be fenced with a WSDOT Type 4 chain link fence with a 14-foot gate. Access shall be provided as specified in the Section 18.9.

- Access road gates shall be 16 feet wide (minimum) and consist of two 8-foot-wide, swinging sections. Provide additional vehicular access gates as needed to facilitate maintenance access.

- Pedestrian access gates (if needed) shall be a minimum of 4 feet wide and meet WSDOT State Standard Plan L-30.10-02.

- For metal baluster fences, IBC standards apply.

- Wood fences may be used in subdivisions where the fence will be maintained by homeowners' associations or adjacent lot owners.

- Wood fences shall have pressure-treated posts (ground-contact-rated) either set in 24-inch-deep concrete footings or attached to footings by galvanized brackets. Rails and fence boards may be cedar, pressure-treated fir, or hemlock.

18.11 Signage

Detention ponds, infiltration basins, wet ponds, and combined ponds shall have a sign placed for maximum visibility from adjacent streets, sidewalks, and paths. The city provides these signs for free upon written request to Water Resources and Sustainability or the Administrator (Figure 18.5). Educational sign applications may be obtained from the city web site or the Administrator and submitted it to Water Resources and Sustainability. Installation criteria are provided below. Contact the Administrator for related open space and landscaping criteria.

18.11.1 Installation Criteria for City-Provided Sign

- Posts: Pressure treated, beveled tops, 1.5 inches higher than sign.

- Installation: Secure to chain link fence if available. Otherwise, install on one 4″x4″ post, pressure treated, mounted atop gravel bed, installed in a 30-inch concrete-filled post hole (8-inch minimum diameter). Top of sign no higher than 42 inches from ground surface.

- Placement: Face sign in direction of primary visual or physical access. Do not block any access road. Do not place within 6 feet of structural facilities (e.g., manholes, spillways, pipe inlets).

18.12 Right-of-Way

Right-of-way may be needed for detention pond maintenance. It is recommended that any tract not abutting public right-of-way have a 15- to 20-foot-wide extension of the tract to an acceptable access location.

18.13 Setbacks

All setbacks shall be horizontal unless otherwise specified.

All **detention ponds** shall maintain minimum setback distances as follows unless modified with written approval by the Thurston County Public Health and Social Services Department for wells and septic facilities. To request a variance from setbacks not related to wells and septic systems, the project proponent may submit a request to the Administrator documenting the impracticality or infeasibility of the setback, which may require written recommendations from a geotechnical engineer.

- 1 foot positive vertical clearance from maximum water surface to structures within 25 feet
- 5 feet from maximum water surface to septic tank or distribution box
- 20 feet from maximum water surface to property lines and on-site structures
- 10 feet from maximum water surface to building sewer
- 30 feet from maximum water surface to septic drainfields and drainfield reserve areas for single-family, on-site, sewage disposal systems
- 100 feet from maximum water surface to septic drainfields and drainfield reserve areas for community, on-site, sewage disposal systems
- 50 feet from top of slopes steeper than 15 percent and greater than 10 feet high. A geotechnical assessment and Soils Report must be prepared addressing the potential impact of the facility on the slope. The geotechnical assessment may recommend a reduced setback, but in no case shall the setback be less than the vertical height of the slope.
- 100 feet from well to stormwater control and water quality facility, maximum water surface.

In addition, all stormwater vaults and tanks shall be set back from any structure or property line a distance equal to the depth of the ground disturbed in setting the structure. Vaults and tanks shall also be within tracts or easements with widths equivalent to those listed for conveyance systems in Volume III, Chapter 3.

18.14 Seeps and Springs

Intermittent seeps along cut slopes are typically fed by a shallow groundwater source (interflow) flowing along a relatively impermeable soil stratum. These flows are storm driven and should discontinue after a few weeks of dry weather. However, more continuous seeps and springs, which extend through longer dry periods, are likely from a deeper groundwater source. When continuous flows are intercepted and directed through flow control facilities, adjustments to the facility design may have to be made to account for the additional base flow (unless already considered in design).

18.15 Planting Requirements

Sod or seed exposed earth on the pond bottom and interior sides with an appropriate seed mixture. Plant all remaining areas of the tract with grass or landscape and mulch with a 3-inch cover of hog fuel or shredded wood mulch. (Note: if implementing soil preservation and amendment in replanted areas per Chapter 6, 2 to 4 inches of hog fuel/woodchip mulch is required.) Shredded wood mulch is made from shredded tree trimmings, usually from trees cleared on site. The mulch must be free of garbage and weeds and shall not contain excessive resin, tannin, or other material detrimental to plant growth. Do not use construction materials wood debris or wood treated with preservatives for producing shredded wood mulch.

18.16 Landscaping

Landscaping is encouraged for most stormwater tract areas (see below for areas not to be landscaped). However, if provided, landscaping should adhere to the criteria that follow so as not to hinder maintenance operations. Landscaped stormwater tracts may, in some instances, provide a recreational space. In other instances, “naturalistic” stormwater facilities may be placed in open space tracts. Refer to Appendix V-F for additional planting guidelines.

Follow these guidelines if landscaping is proposed for facilities:

- Do not plant trees or shrubs on berms meeting the criteria of dams regulated for safety.

- Do not plant trees or shrubs within 10 feet of inlet or outlet pipes or artificial drainage structures such as spillways or flow spreaders. Species with roots that seek water, such as willow or poplar, should be avoided within 50 feet of pipes or artificial structures.

- Restrict planting on berms that impound water permanently or temporarily during storms. This restriction does not apply to cut slopes that form pond banks, only to berms.
    - Do not plant trees or shrubs on portions of water-impounding berms taller than 4 feet high. Plant only grasses on berms taller than 4 feet.
    - Grasses allow unobstructed visibility of berm slopes for detecting potential dam safety problems such as animal burrows, slumping, or fractures in the berm.
    - 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. These trees reduce the likelihood of blow-down trees, or the possibility of channeling or piping of water through the root system, which may contribute to dam failure on berms that retain water. Examples of trees with these characteristics developed for the central Puget Sound are provided in Table 18.1.
- Plant all landscape material, including grass, in good topsoil. Native underlying soils may be made suitable for planting if amended with 4 inches of compost tilled into the subgrade. Refer to the Soil Amendment heading in Chapter 6 for additional information on soil quality standards.
- Soil in which trees or shrubs are planted may need additional enrichment or additional compost top-dressing. Consult a landscape professional, or 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 should 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-foot 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 or columnar deciduous trees along the west and south sides of ponds are recommended to reduce thermal heating. Evergreen trees or shrubs are preferred to avoid problems associated with leaf drop. Columnar deciduous trees (e.g., hornbeam, Lombardy poplar) typically have fewer leaves than other deciduous trees. In addition to shade, trees and shrubs also discourage waterfowl use and the attendant phosphorus enrichment problems they cause. Setback trees so the branches will not extend over the pond.
- Drought-tolerant species are recommended.

- Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the city through submittal of a pesticide-use plan.

Table 18.1. Small Trees and Shrubs with Fibrous Roots.

Small Trees/High Shrubs	Low Shrubs
*Red twig dogwood (*Cornus stolonifera*)	*Snowberry (*Symphoricarpos albus*)
*Serviceberry (*Amelanchier alnifolia*)	*Salmonberry (*Rubus spectabilis*)
*Filbert (*Corylus cornuta*, others)	*Rosa rugosa* (avoid spreading varieties)
Highbush cranberry (*Vaccinium opulus*)	Rock rose (*Cistus* spp.)
Blueberry (*Vaccinium* spp.)	*Ceanothus* spp. (choose hardier varieties)
Fruit trees on dwarf rootstock	New Zealand flax (*Phormium tenax*)
Rhododendron (native and ornamental varieties)	Ornamental grasses (e.g., *Miscanthus*, *Pennisetum*)

*Native species

18.16.1 Guidelines for Naturalistic Planting

Stormwater facilities, if they have a natural appearance, may be located within open space tracts. Two generic kinds of naturalistic planting are outlined below, but other options are also possible. Native vegetation is preferred in naturalistic plantings.

Open Woodland

In addition to the general landscaping guidelines above, the following are recommended.

- Landscaped islands (when mature) should cover a minimum of 30 percent or more of the tract, exclusive of the pond area.

- Underplant tree clumps with shade-tolerant shrubs and groundcover plants. The goal is to provide a dense understory that need not be weeded or mowed.

- Place landscaped islands at several elevations instead of in a “ring” around the pond, and vary the size of clumps from small to large to create variety.

- Not all islands need to have trees. Shrub or groundcover clumps are acceptable, but shade is desirable and should be considered in selecting vegetation.

  Note: Landscaped islands are best combined with the use of wood-based mulch (hog fuel) or chipped, on-site vegetation for erosion control (only for slopes *above the flow control water surface). It is often difficult to sustain a low-maintenance understory if the site was previously hydroseeded. Compost or mulch (typically used for constructed wetland soil) can be used below the flow control water surface (materials that are resistant to and preclude flotation). The construction method used for soil landscape systems can also cause natural selection of specific plant species. Consult a soil restoration or wetland soil scientist for site-specific recommendations.*

Northwest Savannah or Meadow

In addition to the general landscape guidelines above, the following are recommended.

- Landscape islands (when mature) should cover 10 percent or more of the site, exclusive of the pond area.

- Planting groundcovers and understory shrubs is encouraged to eliminate the need for mowing under the trees when they are young.

- Landscape islands should be placed at several elevations instead of in a "ring" around the pond.

- The remaining site area should be planted with an appropriate grass seed mix, which may include meadow or wildflower species. Native or dwarf grass mixes are preferred. Table 18.2 gives an example of dwarf grass mix developed for central Puget Sound.

  Note: Amended soil or good topsoil is required for all plantings.

- Creating areas of emergent vegetation in shallow areas of the pond is recommended. Native wetland plants, such as sedges (*Carex* spp.), bulrush (*Scirpus* spp.), water plantain (*Alisma* spp.), and burreed (*Sparganium* spp.) are recommended. If the pond does not hold standing water, a clump of wet-tolerant, non-invasive shrubs, such as salmonberry or snowberry, is recommended below the detention design water surface.

  Note: This landscape style is best combined with the use of grass or sod for site stabilization and erosion control.

- Seed Mixes. The seed mixes listed in Table 18.2 is a recommended low-growing, non-invasive seed mix appropriate for very wet areas that are not regulated wetlands (if planting in wetland areas, see Chapter 25). Other mixes may be appropriate, depending on the soil type and hydrology of the area. This mixture assumes a target goal of 150 seeds per square foot and should be applied at a rate of 36 pounds per acre.

Table 18.2. Low Growing Wet Area Seed Mix.			
Common Name/Latin Name	**Percent Species Composition**	**Desired Seeds per Square Foot**	**PLS Pounds/Acre**
California brome/*Bromus carinatus*	15	23	9.8
Columbia brome/*Bromus vulgaris*	18	27	8.1
Tufted hairgrass/*Deschampsia cespitosa*	15	23	0.4
California oatgrass/*Danthonia californica*	15	23	4.7
Native red fescue/*Festuca rubra* var. *rubra*	17	26	2.2
Western manna grass/*Glyceria occidentalis*	10	15	3.3
Meadow barley/*Hordeum brachyantherum*	10	15	7.7
*Modified Briargreen, Inc. Hydroseeding Guide Wetlands Seed Mix.			Total: 36.2

18.17 Maintenance

Maintenance is of primary importance if detention ponds are to continue to function as originally designed. Hence, provisions to facilitate maintenance operations must be built into the project when it is installed. The City of Tumwater, a designated group such as a homeowners' association, or some individual must accept responsibility for maintaining the structures and the impoundment area. A specific Maintenance and Source Control Manual must be developed, outlining the schedule and scope of maintenance operations. See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for additional information on maintenance requirements.

Handle any standing water and sediments removed during maintenance in a manner consistent with the 2019 Ecology Manual, Volume IV, Appendix IV-B, and the approved Maintenance and Source Control Manual for the facility.

Chapter 19 – Detention Tanks

19.1 Description

This section presents the methods, criteria, and details for design and analysis of detention tanks, which provide for the temporary storage of increased surface water runoff resulting from development, pursuant to the performance standards set forth in Minimum Requirement #7 for flow control (Volume I, Section 4.2.8).

Detention tanks are underground storage facilities typically constructed with large-diameter, corrugated metal or high-density polyethylene (HDPE) pipe. Detention tanks are not to be perforated; they are not intended to provide infiltration of stormwater. Standard detention tank details are shown in Figures 19.1 and 19.2. Control structure details are covered in Chapter 21.

19.2 Methods of Analysis

19.2.1 Detention Volume and Outflow

The volume and outflow design for detention tanks must be in accordance with Volume I, Section 4.1.8, Minimum Requirement #7, and the hydrologic analysis and design methods in Volume III. Restrictor and orifice design are provided in Chapter 21.

19.3 Detention Tank Design Criteria

19.3.1 General

Typical design guidelines are:

- Tanks may be designed as flow-through systems with manholes in line (see Figure 19.1) to promote sediment removal and facilitate maintenance. Tanks may be designed as backup systems if preceded by water quality facilities, since little sediment should reach the inlet/control structure and low head losses can be expected because of the proximity of the inlet/control structure to the tank.

- The detention tank bottom must be located 1.0 foot below the inlet and outlet to provide dead storage for sediment.

- The minimum pipe diameter for a detention tank is 36 inches.

- Tanks larger than 36 inches may be connected to each adjoining structure with a short section (2-foot maximum length) of 36-inch minimum diameter pipe.

- Tanks shall not be located under the travel way in public rights-of-way. For single-family plats and planned unit developments (PUDs), planned residential developments, or planning and development district detention tanks shall be located in separate tracts. No structures that inhibit access or maintenance shall be constructed or placed atop detention tanks.

- If the tank has no access riser, provide an air vent (see Figure 19.1).
- Details of outflow control structures are given in Chapter 21.

Note: Control and access manholes must have additional ladder rungs to allow ready access to all tank access pipes when the catch basin sump is filled with water.

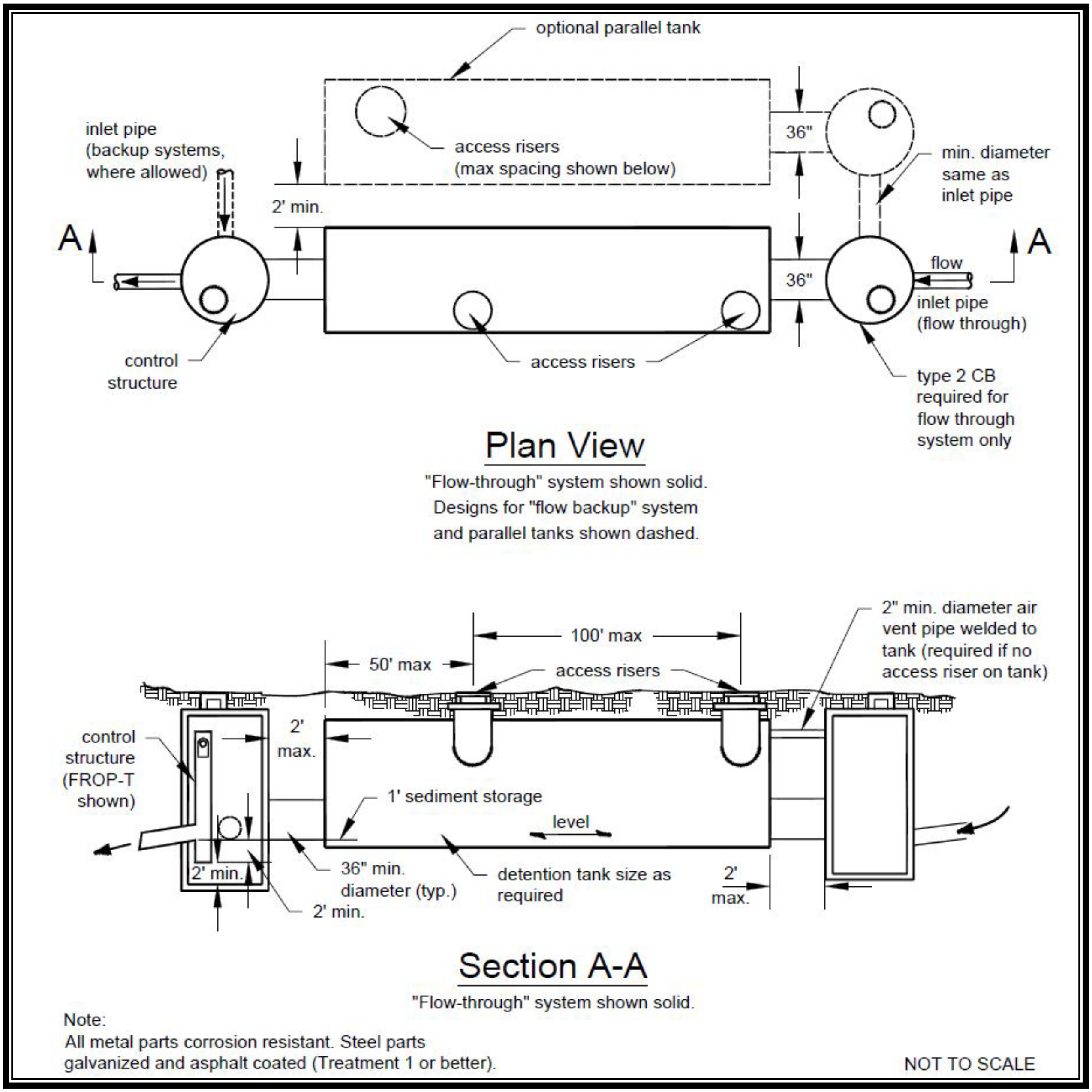


Figure 19.1. Typical Detention Tank.

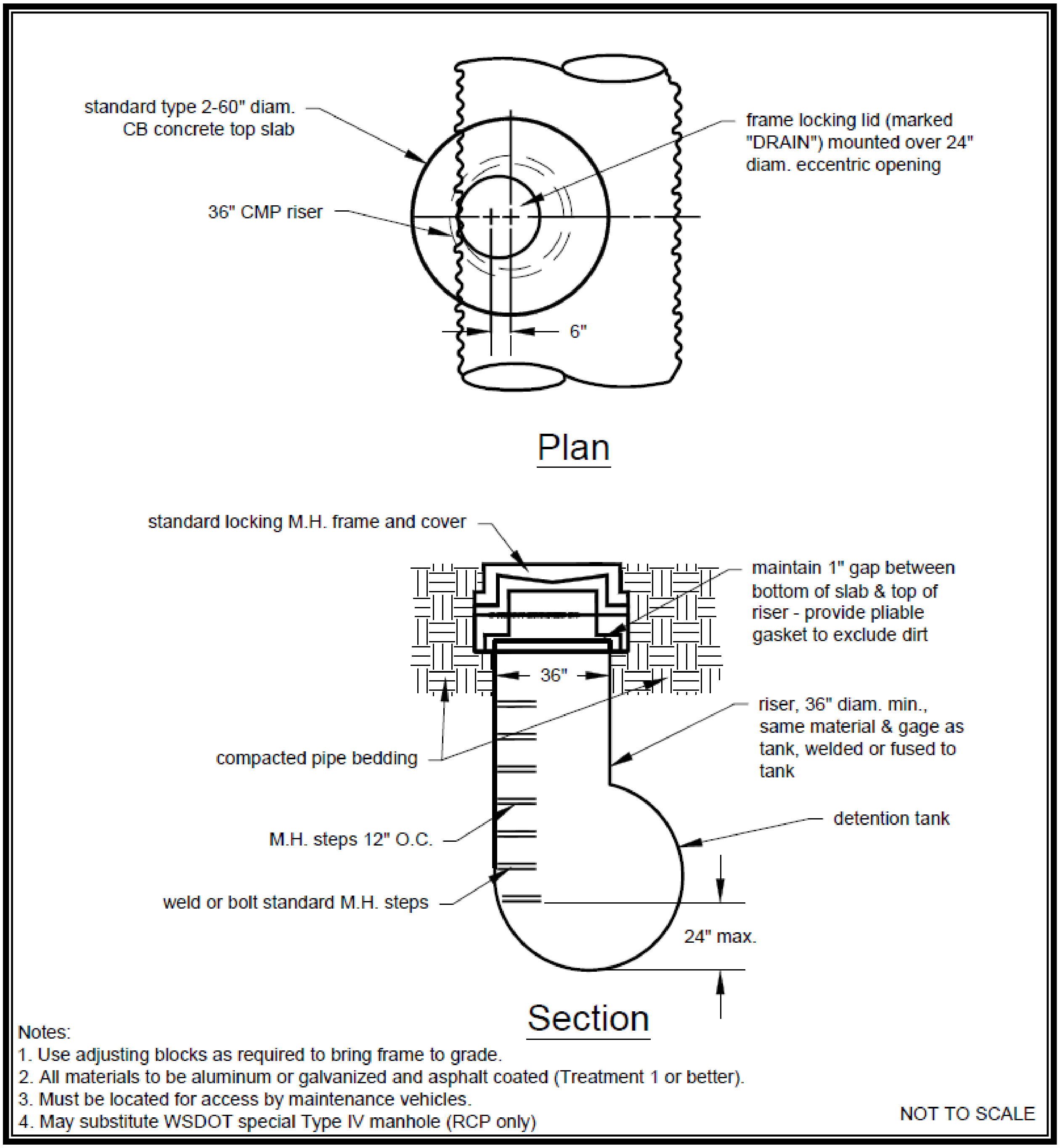


Figure 19.2. Detention Tank Access Detail.

19.3.1 Materials

Galvanized metals leach zinc into the environment, especially in standing water situations. This can result in zinc concentrations that can be toxic to aquatic life. Therefore, use of galvanized materials in stormwater facilities and conveyance systems is prohibited. Use other metals, such as aluminum or stainless steel, or plastics. Pipe material, joints, and protective treatment for tanks shall be in accordance with Section 9.05 of the WSDOT Standard Specifications.

19.3.2 Structural Stability

Tanks must meet structural requirements for overburden support and traffic loading if appropriate. H-20 live loads must be accommodated for tanks lying under parking areas and access roads. Design metal tank end plates for structural stability at maximum hydrostatic loading conditions. Flat end plates generally require thicker gauge material than the pipe and/or require reinforcing ribs. Place tanks on stable, well consolidated native material with suitable bedding. Do not place tanks in fill slopes, unless analyzed through a geotechnical assessment for stability and constructability.

19.3.3 Buoyancy

In moderately pervious soils where seasonal groundwater may induce flotation, balance buoyancy tendencies either by ballasting with backfill or concrete backfill, providing concrete anchors, increasing the total weight, or providing subsurface drains to permanently lower the groundwater table. Calculations that demonstrate stability must be documented.

19.3.4 Access

The following access requirements shall be used. See also Figure 19.2.

- The maximum depth from finished grade to tank invert shall be 12 feet.
- Position access openings a maximum of 50 feet from any location within the tank.
- All tank access openings shall have round, solid, locking lids (usually 1/2- to 5/8-inch-diameter, Allen-head cap screws).
- A 36-inch minimum diameter, corrugated metal pipe, riser-type manhole (see Figure 19.2), of the same gauge as the tank material, may be used for access along the length of the tank and at the upstream terminus of the tank in a backup system. The top slab shall be separated (1-inch minimum gap) from the top of the riser to allow for deflections from vehicle loadings without damaging the riser tank.
- Make all tank access openings readily accessible by maintenance vehicles.
- Tanks must comply with the Occupational Safety and Health Administration (OSHA) confined space requirements, which include clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.

19.3.5 Access Roads

Access roads are needed to all detention tank control structures and risers. Design and construct access roads as specified for detention ponds in Chapter 18.

19.3.6 Maintenance

Build provisions to facilitate maintenance operations into the project when it is installed. Maintenance must be a basic consideration in design and in determination of first cost. See Minimum Requirement #9 in Volume I, Section 4.2.10, the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

Chapter 20 – Detention Vaults

20.1 Description

This section presents the methods, criteria, and details for design and analysis of detention vaults, which provide for the temporary storage of increased surface water runoff resulting from development, pursuant to the performance standards set forth in Minimum Requirement #7 for flow control (Volume I, Section 4.2.8).

Detention vaults are box-shaped, underground storage facilities typically constructed with reinforced concrete. Detention vaults are not intended to infiltrate stormwater and should not be perforated. A standard detention vault detail is provided in Figure 20.1. Control structure details are covered in Chapter 21.

20.2 Methods of Analysis

20.2.1 Detention Volume and Outflow

The volume and outflow design for detention vaults must be in accordance with Volume I, Section 4.2.8, Minimum Requirement #7 and the hydrologic analysis and design methods in Volume III. Restrictor and orifice design are given in Chapter 21.

20.3 Detention Vault Design Criteria

20.3.1 General

Typical design guidelines are:

- Detention vaults may be designed as flow-through systems with bottoms level (longitudinally) or sloped toward the inlet to facilitate sediment removal. Distance between the inlet and outlet should be maximized (as feasible).

- The detention vault bottom may slope at least 5 percent from each side towards the center, forming a broad “V” to facilitate sediment removal. More than one “V” may be used to minimize vault depth. However, the vault bottom may be flat with 1 foot of sediment storage if removable panels are provided over the entire vault. It is recommended that the removable panels be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.

- The invert elevation of the outlet must be elevated above the bottom of the vault to provide an average 12 inches of sediment storage over the entire bottom. The outlet must also be elevated a minimum of 2 feet above the orifice to retain oil within the vault.

- Details of outflow control structures are given in Chapter 21.

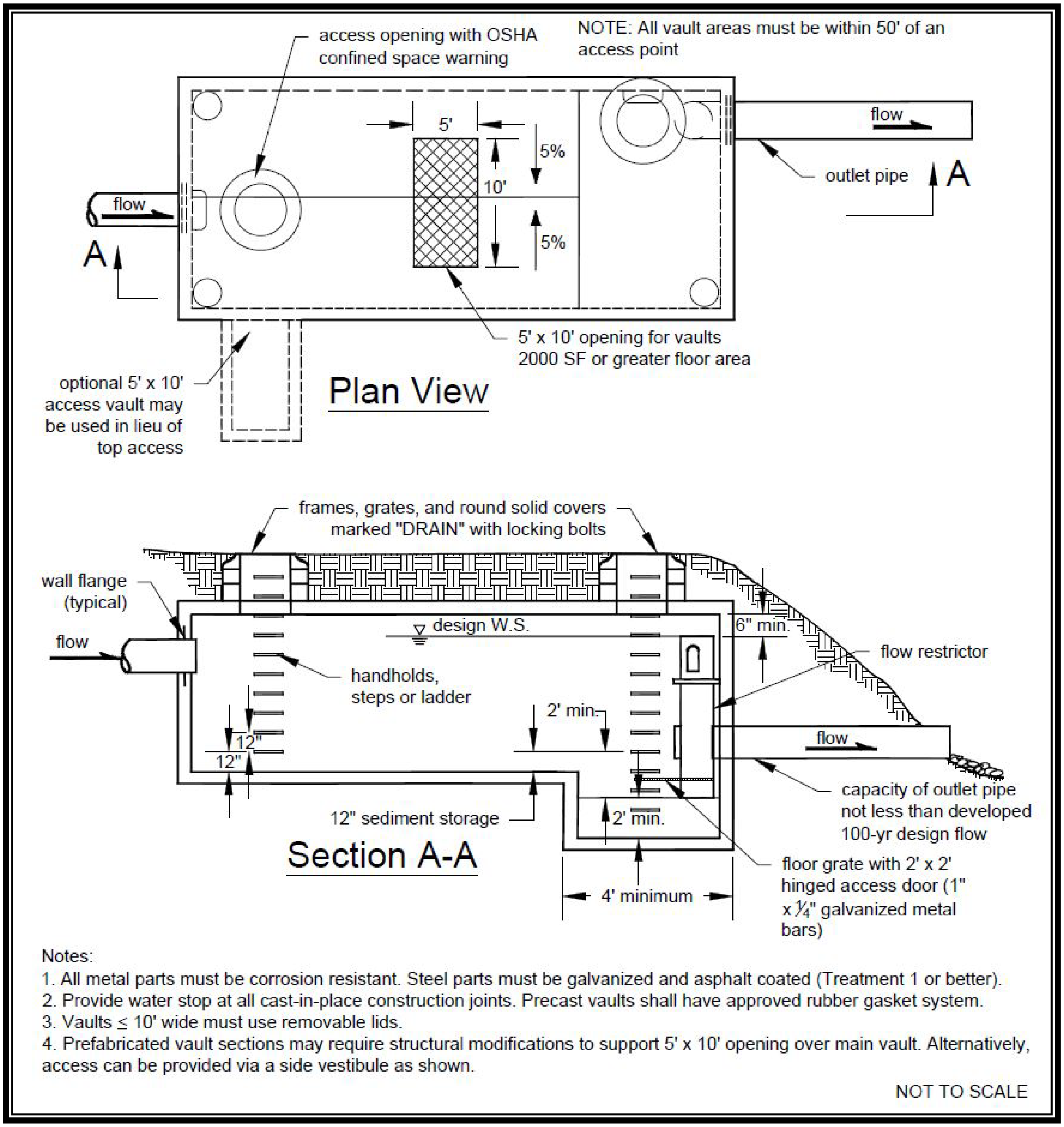


Figure 20.1. Typical Detention Vault.

20.3.1 Materials

Minimum 3,000 psi structural reinforced concrete may be used for detention vaults. Provide all construction joints with water stops.

20.3.2 Structural Stability

All vaults must meet structural requirements for overburden support and H-20 traffic loading (see *Standard Specifications for Highway Bridges*, 1998 Interim Revisions, American Association of State Highway and Transportation Officials). Cast-in-place wall sections must be designed as retaining walls. Structural designs for cast-in-place vaults must be stamped by a licensed civil engineer with structural expertise. Place vaults on stable, well-consolidated native material with suitable bedding. Do not place vaults in fill slopes, unless analyzed through a geotechnical assessment for stability and constructability.

In addition to these requirements, vaults located within a fire apparatus access roadway (fire lane) subject to the staging of fire-fighting operations shall be designed for actual fire apparatus loads and stabilizer (outrigger) loads.

20.3.1 Access

Provide access over the inlet pipe and outlet structure. The following access requirements shall be met.

- Position access openings a maximum of 50 feet from any location within the tank. Additional access points may be needed on large vaults. Provide access to each "V" if more than one "V" is provided in the vault floor.
- For vaults with greater than 1,250 square feet of floor area, provide a 5 x 10-foot removable panel over the inlet pipe (instead of a standard frame, grate, and solid cover). Or, provide a separate access vault.
- For vaults under roadways, locate the removable panel outside the travel lanes. Or, provide multiple standard locking manhole covers. Ladders and hand-holds need only be provided at the outlet pipe and inlet pipe, and as needed to meet OSHA confined space requirements. Vaults providing manhole access at 12-foot spacing need not provide corner ventilation pipes as specified below.
- All access openings, except those covered by removable panels, shall have round, solid, locking lids, or 3-foot square, locking, diamond plate covers.
- Vaults with widths 10 feet or less must have removable lids.
- The maximum depth from finished grade to the vault invert must be 20 feet.
- Internal structural walls of large vaults shall be provided with openings sufficient for maintenance access between cells. Size and situate the openings to allow access to the maintenance "V" in the vault floor.
- The minimum internal height must be 7 feet from the highest point of the vault floor (not sump), and the minimum width must be 4 feet. However, concrete vaults may be a minimum 3 feet in height and width if used as tanks with access manholes at each end, and if the width is no larger than the height. Also, the minimum internal height requirement may not be needed for any areas covered by removable panels.

- Vaults must comply with the OSHA confined space requirements, including clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser(s), just under the access lid.

- Provide ventilation pipes (minimum 12-inch-diameter or equivalent) in all four corners of vaults to allow for artificial ventilation prior to entry of maintenance personnel into the vault. Or, provide removable panels over the entire vault.

20.3.2 Access Roads

Access roads are needed to the access panel (if applicable), the control structure, and at least one access point per cell They may be designed and constructed as specified for detention ponds in Chapter 18.

20.3.3 Maintenance

Build provisions to facilitate maintenance operations into the project when it is installed. Maintenance must be a basic consideration in design and in determination of first cost. See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

Chapter 21 – Control Structure Design

21.1 Description

Control structures are catch basins or manholes with a restrictor device for controlling outflow from a facility to meet the desired performance. Riser-type restrictor devices ("Ts" or "FROP-Ts") also provide some incidental oil/water separation to temporarily detain oil or other floatable pollutants in runoff due to accidental spill or illegal dumping.

A restrictor device usually consists of two or more orifices and/or a weir section sized to meet performance requirements. Several publicly available and proprietary stormwater modeling programs are capable of sizing control structures. As such, the Methods of Analysis section (methods and equations for design of control structure restrictor devices) is included at the end of this section, rather than at the beginning as with the flow control BMPs above.

Standard control structure details are provided in Figures 21.1 through 21.3.

21.2 Multiple Orifice Restrictor

In most cases, control structures need only two orifices: one at the bottom and one near the top of the riser, although additional orifices may best utilize detention storage volume. Several orifices may be located at the same elevation if necessary to meet performance requirements.

- Minimum orifice diameter is 0.5 inch. Note: In some instances, a 0.5-inch bottom orifice will be too large to meet target release rates, even with minimal head. In these cases, the live storage depth need not be reduced to less than 3 feet in an attempt to meet the performance standards. A smaller orifice diameter may be permitted if a screen is utilized to protect the orifice from fouling.

- Orifices may be constructed on a T-section or on a baffle, as shown in Figures 21.1 through 21.3.

- In some cases, performance requirements may require the top orifice/elbow to be located too high on the riser to be physically constructed (e.g., a 13-inch-diameter orifice positioned 6 inches from the top of the riser). In these cases, a notch weir in the riser pipe may be used to meet performance requirements (see Figure 21.4, presented later in this section).

- Consideration must be given to the backwater effect of water surface elevations in the downstream conveyance system. High tailwater elevations may affect performance of the restrictor system and reduce live storage volumes.

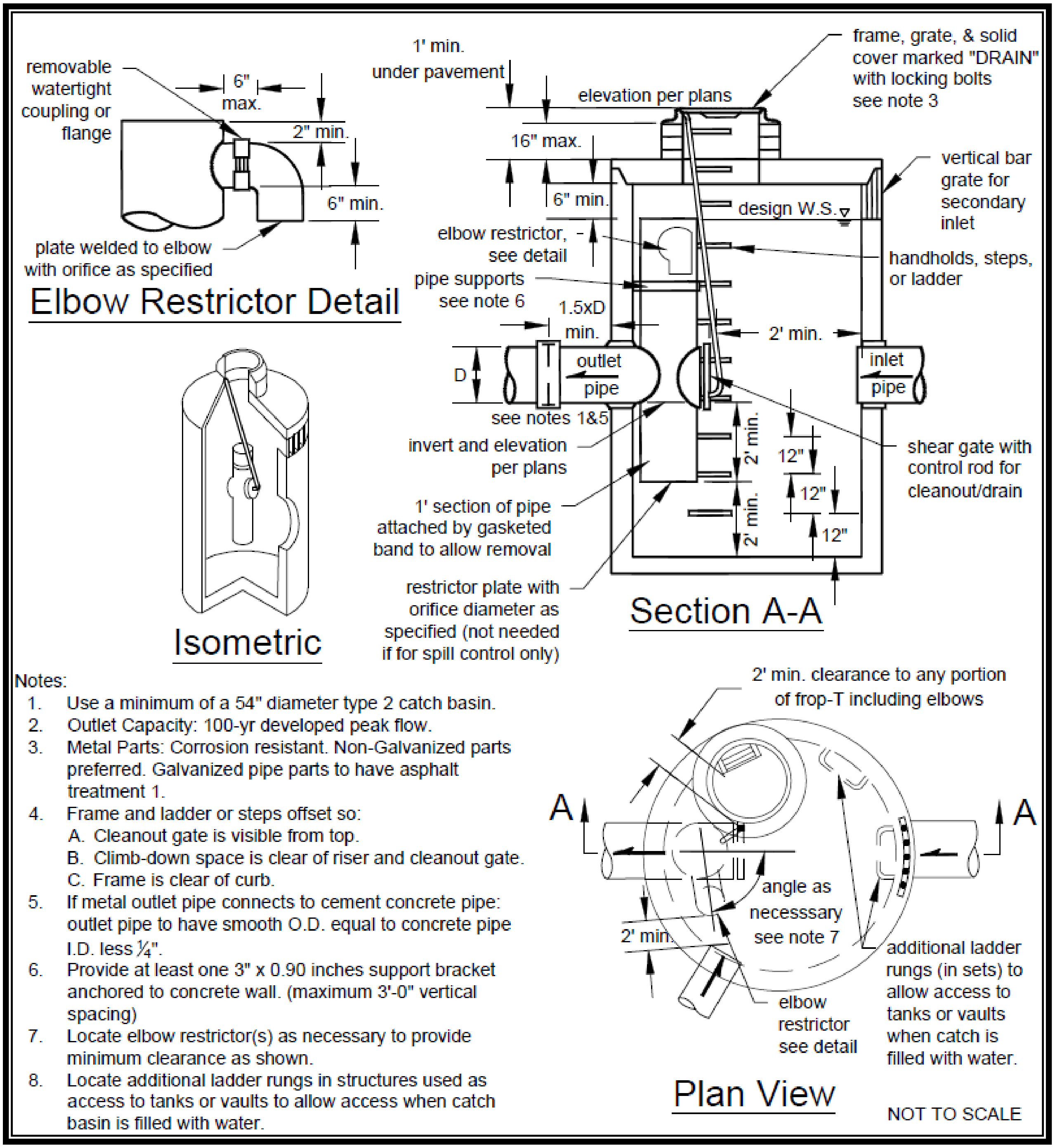
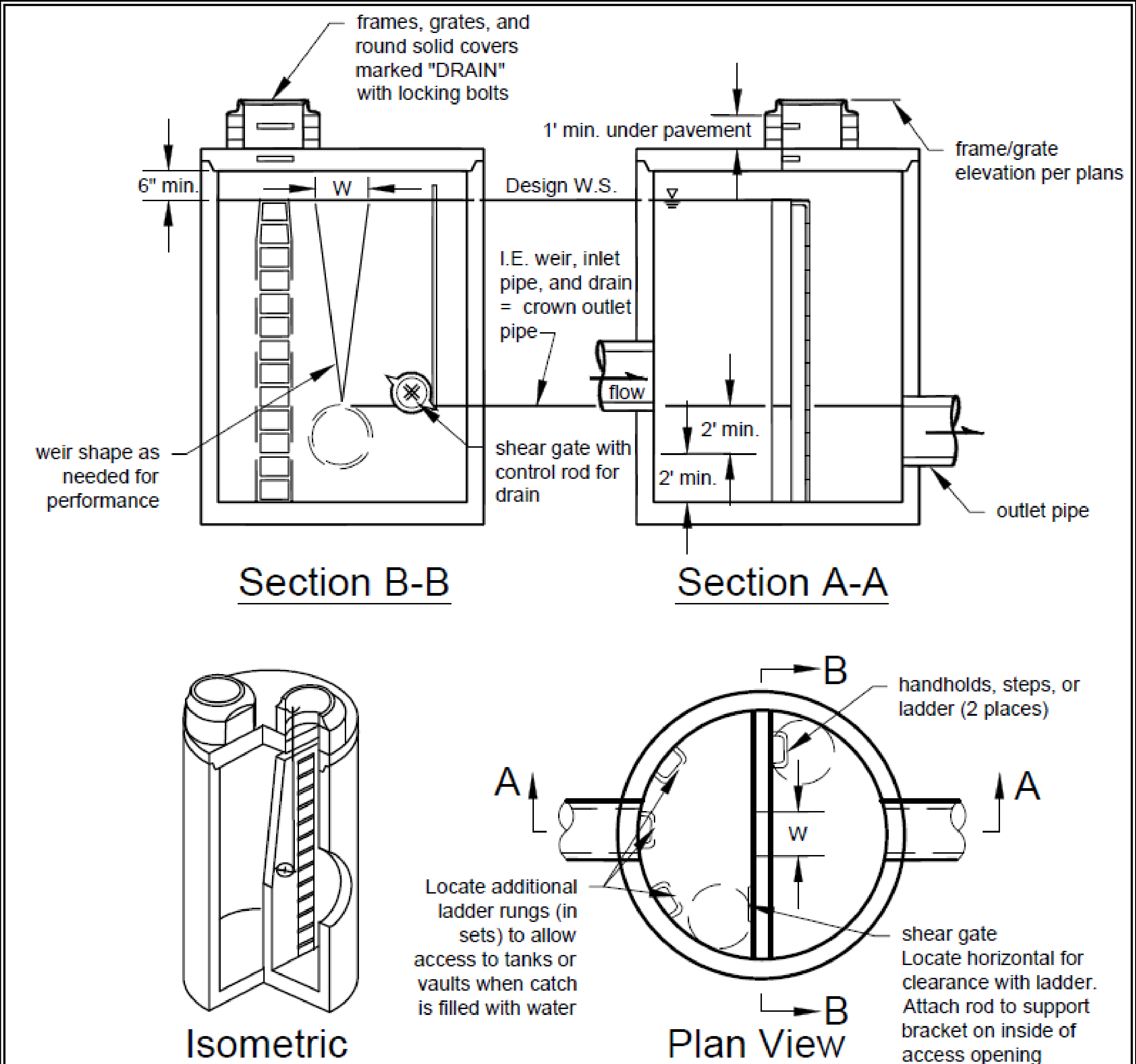


Figure 21.1. Flow Restrictor (tee).



Notes:
1. Outlet Capacity: 100-year developed peak flow.
2. Metal Parts: corrosion resistant steel parts galvanized and asphalt coated.
3. Catch Basin: type 2 min. 72" diameter.
4. Baffle Wall: to be designed with concrete reinforcing as required.
5. Spill containment must be provided to temporarily detain oil or floatable pollutants in runoff due to accidental spill or illegal dumping.

NOT TO SCALE

Figure 21.2. Flow Restrictor (baffle).

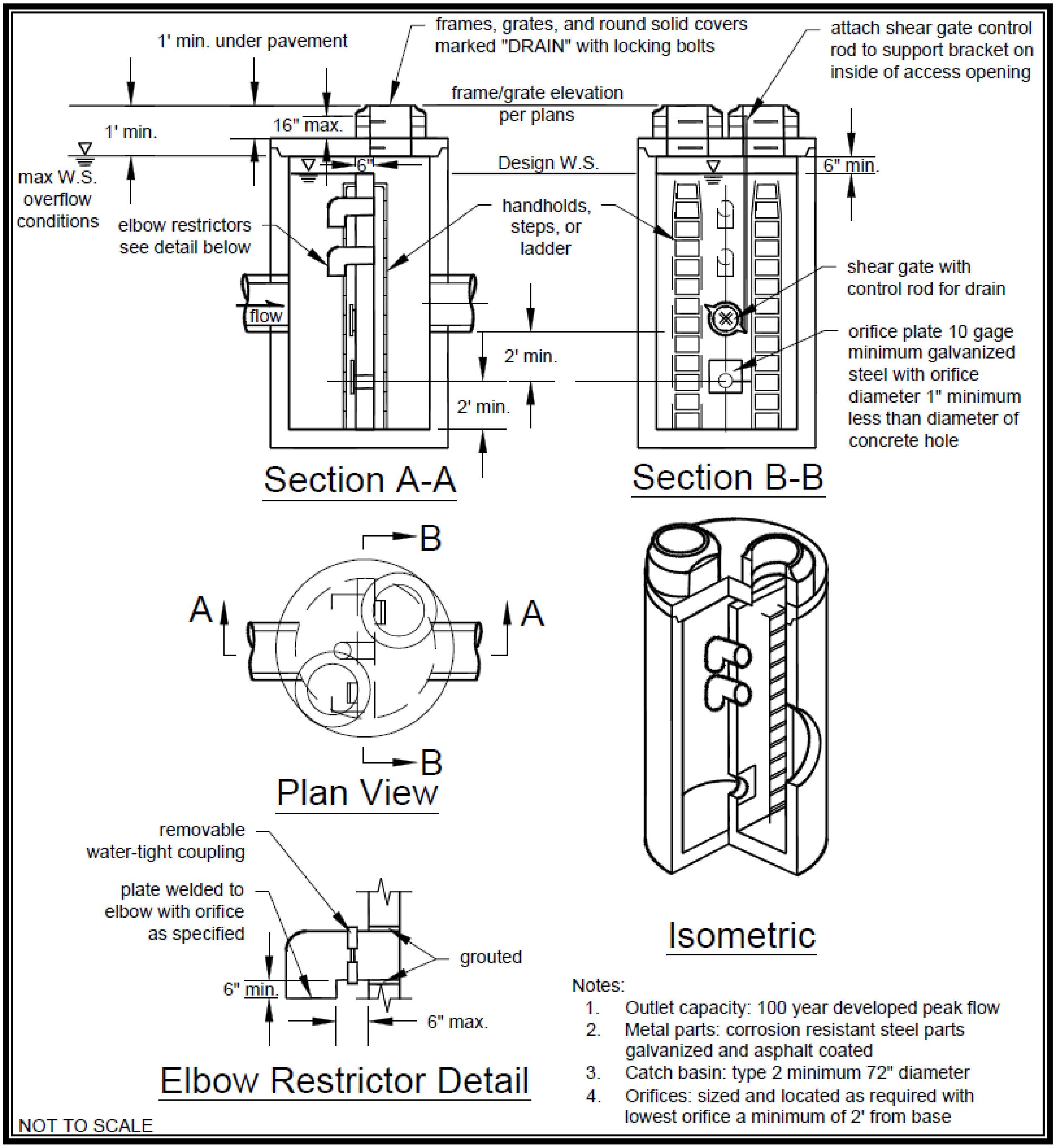


Figure 21.3. Control Structure Details.

21.3 Riser and Weir Restrictor

- Properly designed weirs may be used as flow restrictors (see Section 21.4, Methods of Analysis). However, they must be designed to provide for primary overflow of the developed 100-year recurrence interval peak flow discharging to the detention facility.

- The combined orifice and riser (or weir) overflow may be used to meet performance requirements; however, the design must still provide for primary overflow of the developed 100-year recurrence interval peak flow assuming all orifices are plugged. Figure 21.8 (presented later in this section) can be used to calculate the head in feet above a riser of given diameter and flow.

21.3.1 Access

The following access requirements shall apply:

- Provide an access road to the control structure for inspection and maintenance. Design and construct the access road as specified for detention ponds in Chapter 18.

- Manhole and catch basin lids for control structures must be locking, and rim elevations must match proposed finish grade.

- Manholes and catch basins must meet the OSHA confined space requirements, which include clearly marking entrances to confined space areas. This may be accomplished by hanging a removable sign in the access riser, just under the access lid.

21.3.2 Information Plate

It is recommended that a brass or stainless steel plate be permanently attached inside each control structure with the following information engraved on the plate.

- Name and file number of project

- Name and company of: 1) developer, 2) engineer, and 3) contractor

- Date constructed

- Date of manual used for design

- Outflow performance criteria

- Release mechanism size, type, and invert elevation

- List of stage, discharge, and volume at 1-foot increments

- Elevation of overflow
- Recommended frequency of maintenance.

21.3.1 Maintenance

Control structures and catch basins have a history of maintenance-related problems, and it is imperative that a good maintenance program be established for their proper functioning. Typically, sediment builds up inside the structure, and blocks or restricts flow to the inlet. To prevent this problem, routinely clean out these structures—at least twice per year. Conduct regular inspections of control structures to detect the need for non-routine cleanout, especially if construction or land-disturbing activities occur in the contributing drainage area.

Install a 15-foot-wide access road to the control structure for inspection and maintenance.

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site for additional information on maintenance requirements.

21.4 Methods of Analysis

This section presents the methods and equations for design of **control structure restrictor devices**. Included are details for the design of orifices, rectangular sharp-crested weirs, V-notch weirs, sutro weirs, and overflow risers.

21.4.1 Orifices

Flow-through orifice plates in the standard T-section or turn-down elbow may be approximated by the general equation:

$$Q = C\,A\sqrt{2gh} \qquad \text{(Equation 4)}$$

where:

Q = flow (cfs)

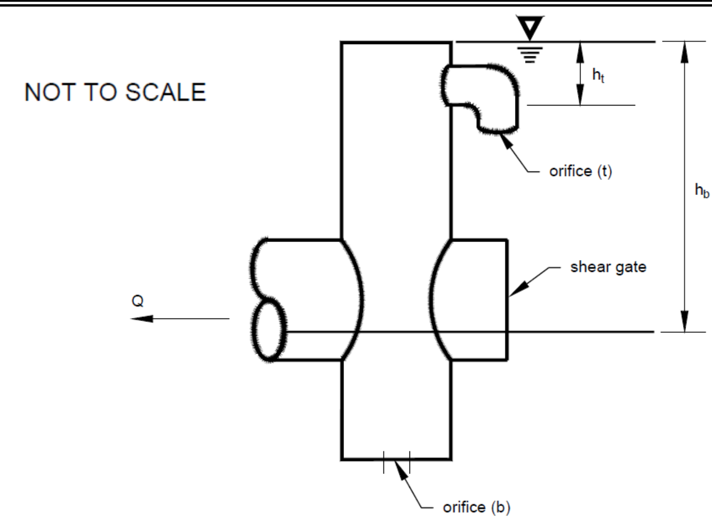
C = coefficient of discharge (0.62 for plate orifice)

A = area of orifice ($feet^2$)

h = hydraulic head (feet)

g = gravity (32.2 $feet/sec^2$)

Figure 21.4 illustrates this simplified application of the orifice equation.



$$Q = CA_b\sqrt{2gh_b} + CA_t\sqrt{2gh_t}$$
$$= C\sqrt{2g}(A_b\sqrt{h_b} + A_t\sqrt{h_t})$$

h_b = distance from hydraulic grade line at the 2 – year flow of the outflow pipe to the overflow elevation

Figure 21.4. Simple Orifice.

The diameter of the orifice is calculated from the flow. The orifice equation is often useful when expressed as the orifice diameter in inches:

$$d = \sqrt{\frac{36.88Q}{\sqrt{h}}} \qquad \text{(Equation 5)}$$

Where:

d = orifice diameter (inches)

Q = flow (cfs)

h = hydraulic head (feet)

Rectangular Sharp-Crested Weir. The rectangular sharp-crested weir design shown in Figure 21.5 may be analyzed using standard weir equations for the fully contracted condition.

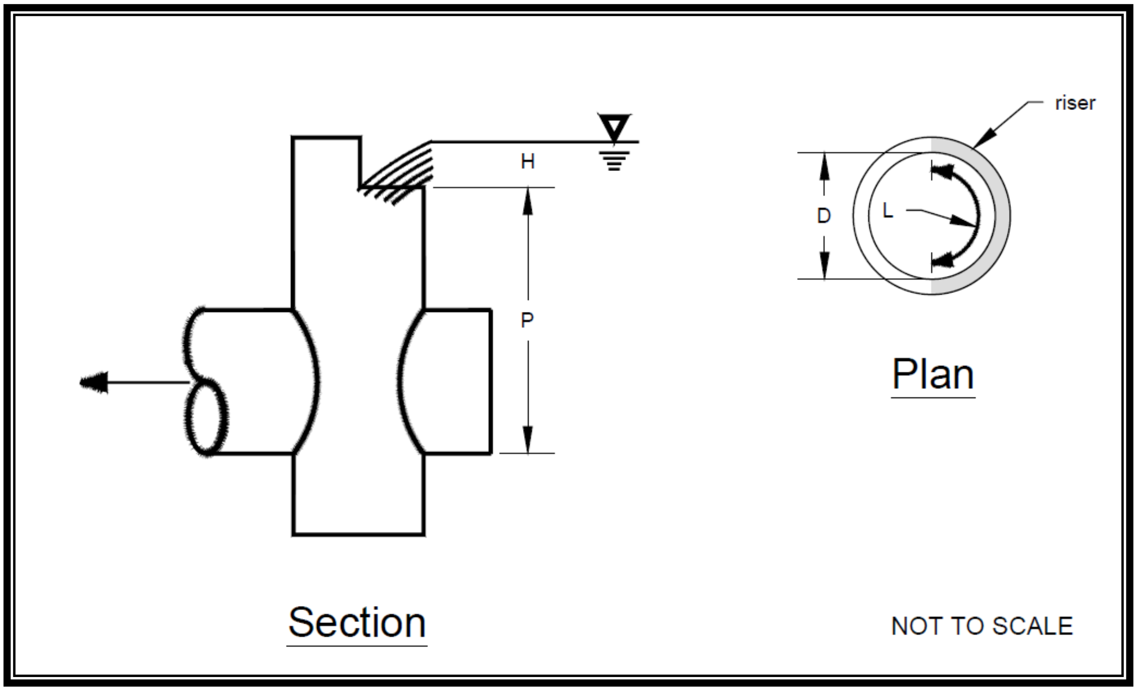


Figure 21.5. Rectangular Sharp-Crested Weir.

$$Q = C\,(L - 0.2H)H^{3/2} \qquad \text{(Equation 6)}$$

Where:

Q = flow (cfs)

C = 3.27 + 0.40 H/P (feet)

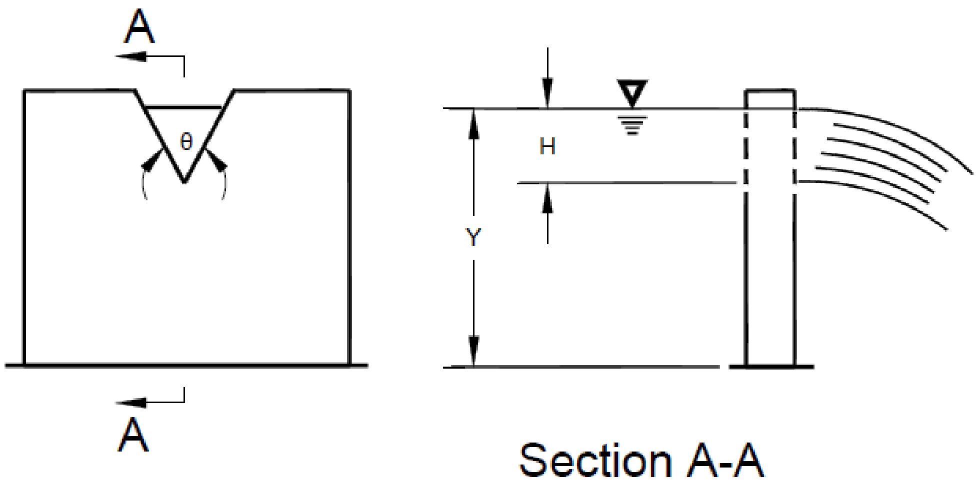
H, P are as shown above

L = length (feet) of the portion of the riser circumference as necessary not to exceed 50 percent of the circumference

D = inside riser diameter (feet)

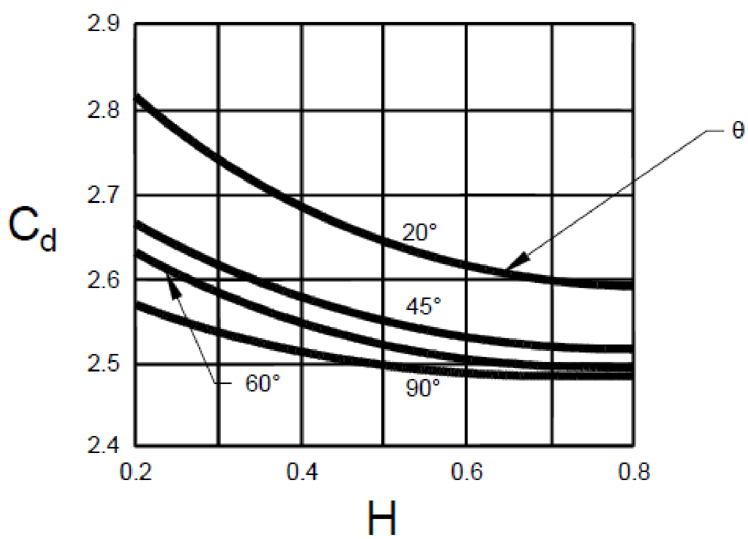
Note that this equation accounts for side contractions by subtracting 0.1H from L for each side of the notch weir.

V-Notch Sharp – Crested Weir. V-notch weirs as shown in Figure 21.6 may be analyzed using standard equations for the fully contracted condition.



$$Q = C_d(\tan\frac{\theta}{2})H^{\frac{5}{2}} \text{ in cfs}$$

Where values of C_d may be taken from the following chart:



NOT TO SCALE

Figure 21.6. V-Notch, Sharp-Crested Weir.

Proportional or Sutro Weir. Sutro weirs are designed so that the discharge is proportional to the total head. This design may be useful in some cases to meet performance requirements.

A sutro weir consists of a rectangular section joined to a curved portion that provides proportionality for all heads above the line A-B (see Figure 21.7). The weir may be symmetrical or non-symmetrical.

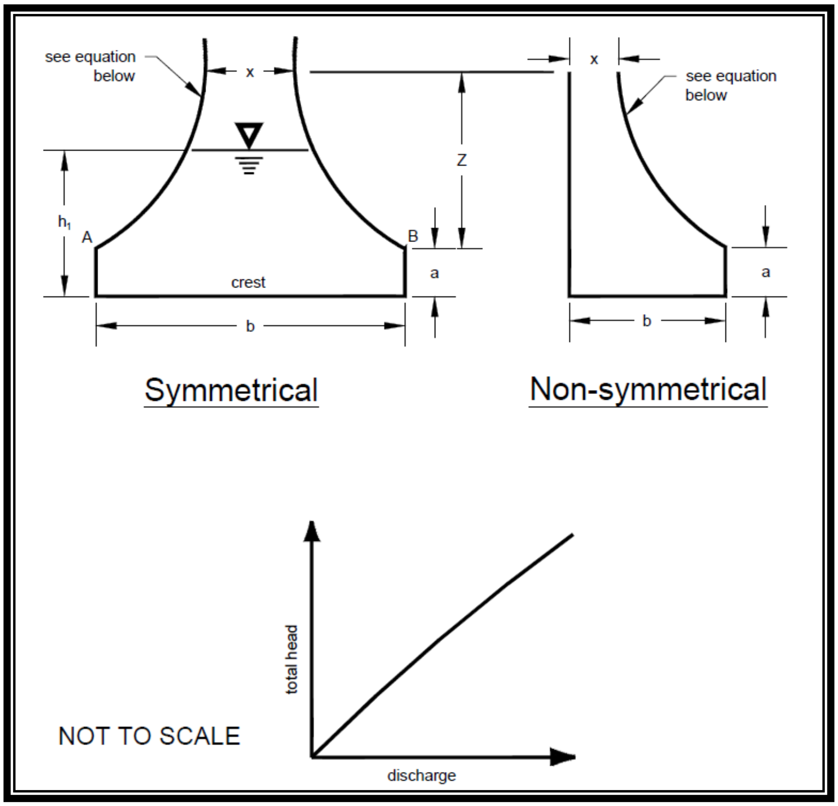


Figure 21.7. Sutro Weir.

For this type of weir, the curved portion is defined by the following equation (calculated in radians):

$$\frac{x}{b} = 1 - \frac{2}{\pi} Tan^{-1} \sqrt{\frac{Z}{a}} \qquad \text{(Equation 7)}$$

where a, b, x and Z are as shown in Figure 21.7. The head-discharge relationship is:

$$Q = C_d \, b \sqrt{2ga} \left(h_1 - \frac{a}{3}\right) \qquad \text{(Equation 8)}$$

Values of C_d for both symmetrical and non-symmetrical sutro weirs are summarized in Table 21.1.

Riser Overflow. The nomograph in Figure 21.8 can be used to determine the head (in feet) above a riser of given diameter and for a given flow (usually the 100-year recurrence interval peak flow for developed conditions).

Table 21.1. Values of Cd for Sutro Weirs.

C_d Values, Symmetrical					
	b (feet)				
a (feet)	0.50	0.75	1.0	1.25	1.50
0.02	0.608	0.613	0.617	0.6185	0.619
0.05	0.606	0.611	0.615	0.617	0.6175
0.10	0.603	0.608	0.612	0.6135	0.614
0.15	0.601	0.6055	0.610	0.6115	0.612
0.20	0.599	0.604	0.608	0.6095	0.610
0.25	0.598	0.6025	0.6065	0.608	0.6085
0.30	0.597	0.602	0.606	0.6075	0.608
C_d Values, Non-Symmetrical					
	b (feet)				
a (feet)	0.50	0.75	1.0	1.25	1.50
0.02	0.614	0.619	0.623	0.6245	0.625
0.05	0.612	0.617	0.621	0.623	0.6235
0.10	0.609	0.614	0.618	0.6195	0.620
0.15	0.607	0.6115	0.616	0.6175	0.618
0.20	0.605	0.610	0.614	0.6155	0.616
0.25	0.604	0.6085	0.6125	0.614	0.6145
0.30	0.603	0.608	0.612	0.6135	0.614

Note: When b > 1.50 or a > 0.30, use C_d = 0.6.

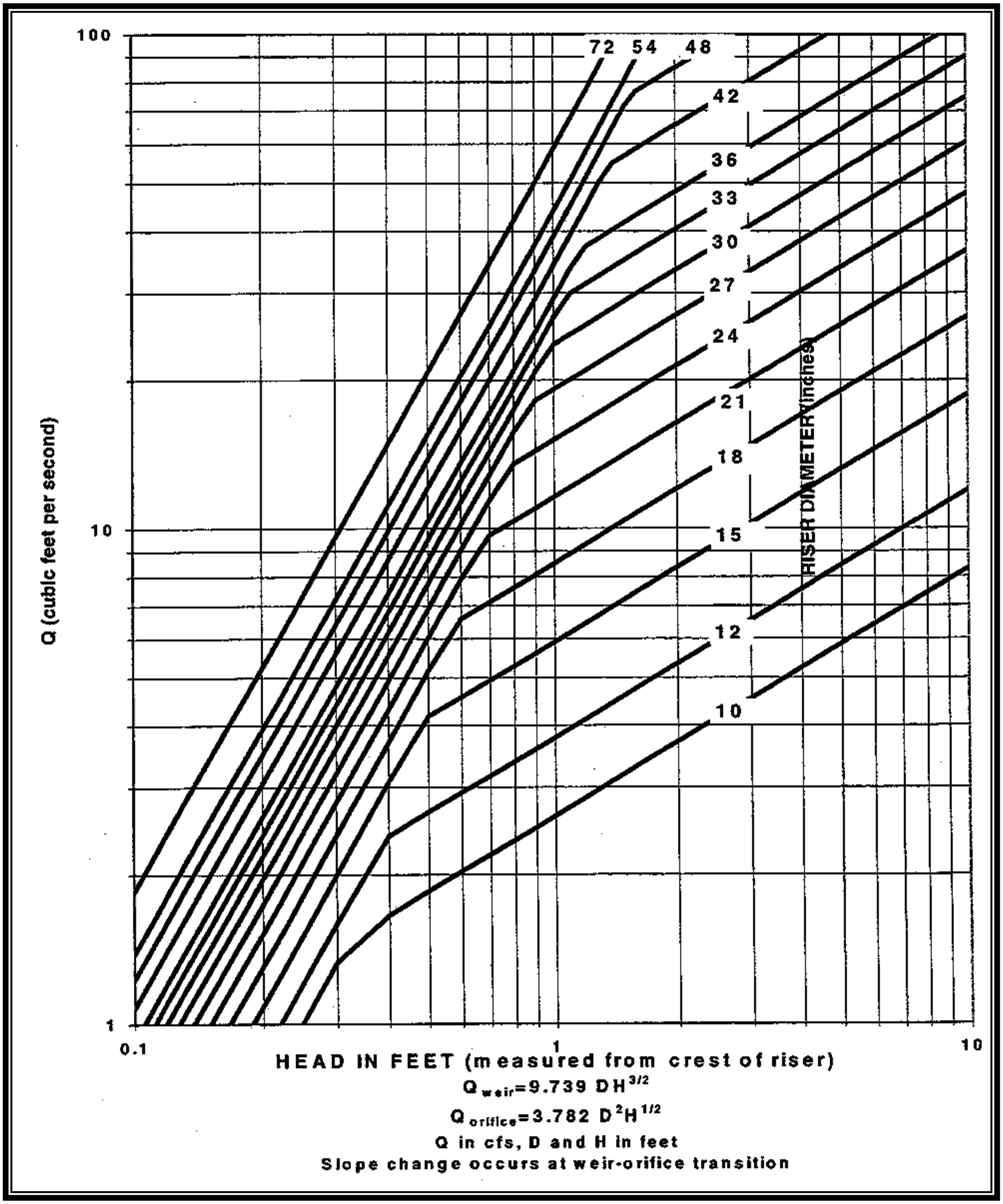


Figure 21.8. Riser Inflow Curves.

Chapter 22 – Other Detention Facilities

This section presents other design options for detaining flows to meet flow control facility requirements.

22.1 Use of Parking Lots for Additional Detention

Private parking lots may be used to provide additional detention volume for runoff events greater than the 2-year recurrence interval runoff event provided all of the following are met.

- The depth of water detained does not exceed 1 foot at any location in the parking lot for runoff events up to and including the 100-year recurrence interval event.
- The gradient of the parking lot area subject to ponding is 1 percent or greater.
- The detained water is completely contained on site (exclusive of the designed overflow) and does not impact other properties or the public right-of-way.
- The emergency overflow path is 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 are free of ponding water for all runoff events up to and including the 100-year recurrence interval event.

22.2 Use of Roofs for Detention

Detention ponding on roofs of structures may be used to meet flow control requirements provided all of the following are met.

- The roof support structure is analyzed by a structural engineer to address the weight of ponded water.
- The roof area subject to ponding is sufficiently waterproofed to achieve a minimum service life of 30 years.
- The minimum pitch of the roof area subject to ponding is 1/4 inch per 1 foot.
- An overflow system is included in the design to safely convey the 100-year recurrence interval peak flow from the roof.
- A mechanism is included in the design to allow the ponding area to be drained for maintenance purposes or in the event the restrictor device is plugged.

Chapter 23 – Infiltration and Bioretention Treatment Facilities

23.1 Purpose

This section provides site suitability, design, and maintenance criteria for infiltration treatment systems. Infiltration treatment BMPs serve the dual purpose of removing pollutants (total suspended solids, heavy metals, phosphates, and organics) and recharging aquifers.

A stormwater infiltration treatment facility is an impoundment, typically a basin, trench, gallery, or bioretention system, in which soil removes pollutants from stormwater. The infiltration treatment BMPs described in this section include:

- Infiltration Treatment Basins
- Infiltration Treatment Trenches
- Infiltration Treatment Galleries
- Bioretention Cells, Swales, and Planter Boxes
- Compost-Amended, Vegetated Filter Strip (CAVFS).

Note that the soil infiltration requirements for water quality treatment are substantially different from those for flow control. Infiltration treatment soils must contain sufficient organic matter and/or clays to sorb, decompose, and/or filter stormwater pollutants. Pollutant/soil contact time, soil sorptive capacity, and soil aerobic conditions are important design considerations. Specific requirements are outlined in Sections 23.3 and 23.4.

23.2 Applications and Limitations

The infiltration and bioretention BMPs listed above are capable of achieving most of the performance objectives cited in Volume I, Section 4.3 for specific treatment menus. In general, these treatment techniques can capture and remove or reduce the target pollutants to levels that will not adversely affect public health or beneficial uses of surface and groundwater resources, and will not cause a violation of groundwater quality standards. However, at the time this manual was published, the approved bioretention soil mixes presented in this manual (see Chapter 9) were known to release elevated levels of nutrients for a period of time after installation. Although recent research has identified methods to mitigate these nutrient export issues, the methods have not yet been formally approved. Therefore, as per Volume I, Section 4.3, bioretention constructed with imported composted materials (as well as CAVFS, for similar reasons) is not approved for use within 0.25 mile of any fresh water bodies or conveyance systems tributary to fresh water bodies. Project proponents should contact the Administrator for the latest information on bioretention soil mix options and requirements in groundwater protection areas and critical aquifer recharge areas.

Infiltration treatment systems are typically installed:

- As off-line systems (or on-line systems for small drainages)
- As a polishing treatment for street/highway runoff after pretreatment for total suspended solids and oil
- As part of a treatment train
- As retrofits at sites with limited land areas, such as residential lots, commercial areas, parking lots, and open space areas
- With appropriate pretreatment for oil and silt control to prevent clogging. Appropriate pretreatment devices include a presettling basin, wet pond/vault, constructed wetland, media filter, and oil/water separator. An infiltration basin is preferred over a trench or gallery for ease of maintenance.

Also note that the terms “bioretention” and “rain garden” are sometimes used interchangeably. However, in the City of Tumwater (in accordance with Ecology’s distinction), the term “bioretention” is used to describe an engineered facility that includes designed soil mixes and perhaps underdrains and control structures. The term “rain garden” is used to describe a landscape feature to capture stormwater on small project sites. Notable differences between rain gardens and bioretention areas include:

- Rain gardens have less restrictive design criteria for the soil mix and do not include underdrains and other control structures.
- Rain gardens are an on-site stormwater management BMP option for projects that only have to comply with Minimum Requirements #1 through #5.
- Bioretention areas are an on-site stormwater management BMP option for: 1) projects that only have to comply with Minimum Requirements #1 through #5; and 2) projects that trigger Minimum Requirements #1 through #10.
- Bioretention areas and rain gardens are applications of the same LID concept and can be highly effective for reducing surface runoff and removing pollutants.

23.3 Soil Requirements for Infiltration for Water Quality Treatment

Infiltration treatment (i.e., using an infiltration basin, trench, or gallery, as opposed to rain gardens, bioretention, or filter strips that each have specific soil mix requirements) meets the requirements for *basic*, *phosphorus*, and *enhanced* treatment if 91 percent of the influent runoff file (indicated by WWHM) is successfully infiltrated within 48 hours.

Soil suitability criteria #1 and #2, below, apply for infiltration treatment basins, trenches, and galleries. Related requirements for bioretention areas are covered in Chapter 9. (Note: Bioretention designs may also be used without imported compost materials in areas where the native soils meet the criteria in this section.) Conformance with the criteria below shall be documented in the project Soils Report.

Soil suitability criterion #1: The measured (initial) soil infiltration rate (field measured, before safety factors) must be 9 inches per hour or less. Design (long-term) infiltration rates up to 3.0 inches per hour can be used with approval by the City of Tumwater, if the infiltration receptor is not a sole-source aquifer and, in the judgment of the site professional, the treatment soil has characteristics comparable to those specified in soil suitability criterion #2 (summarized below) to adequately control the target pollutants.

Soil suitability criterion #2: To a minimum depth of 18 inches (measured from bottom of facility):

- CEC of the soil must be greater than or equal to 5 milliequivalents per 100 grams 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 City of Tumwater.

- Organic content of the treatment soil (ASTM D2974): Organic matter can increase the sorptive capacity of the soil for some pollutants. A minimum of 1 percent organic content is necessary.

- Depth of soil below permeable pavements serving as PGHS may be reduced to 1 foot if the permeable pavement does not accept run-on from other surfaces.

For all infiltration treatment facilities, the site infiltration rate must be determined using one of the methods described in detail in Appendix V-A.

23.4 Best Management Practices for Infiltration and Bioretention Treatment

Although they are very effective at water quality treatment, four of the five BMPs discussed below (infiltration treatment basins; infiltration treatment trenches; infiltration treatment galleries; and bioretention cells, swales, and planter boxes) are more commonly designed to provide flow control. Therefore, the design details for these BMPs are provided in Chapters 6 through 17. This includes the imported soil requirements for bioretention BMPs, which meet the enhanced treatment requirements and do not typically require pretreatment. Selection of a specific BMP should be coordinated with the treatment facility menus provided in Volume I, Section 4.3. Soil suitability criteria #1 and #2 (in Section 23.3 above) must be met for infiltration treatment basins and trenches, as well as for bioretention BMPs designed without imported compost materials (i.e., if used in phosphorus treatment areas).

23.5 Infiltration Treatment Basins (Ecology BMP T7.10)

See Chapter 2 for information pertinent to infiltration basins, trenches, and galleries. See Chapter 14 for information specific to infiltration basins.

23.6 Infiltration Treatment Trenches (Ecology BMP T7.20)

See Chapter 2 for information pertinent to infiltration basins, trenches, and galleries. See Chapter 12 for information specific to infiltration trenches.

23.7 Infiltration Treatment Galleries

See Chapter 2 for information pertinent to infiltration basins, trenches, and galleries. See Chapter 13 for information specific to infiltration galleries.

23.8 Bioretention Cells, Swales, and Planter Boxes (Ecology BMP T7.30)

See Chapter 9 for information specific to bioretention cells, swales, and planter boxes.

23.9 Compost-Amended Vegetated Filter Strip (CAVFS) (Ecology BMP T7.40)

The CAVFS is a variation of the basic vegetated filter strip that adds soil amendments to the roadside embankment (see Figure 23.1). The soil amendments 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.

23.9.1 Applications and Limitations

CAVFS can be used to meet basic runoff treatment and enhanced runoff treatment objectives. It has practical application in areas where there is space for roadside embankments that can be built to the CAVFS specifications.

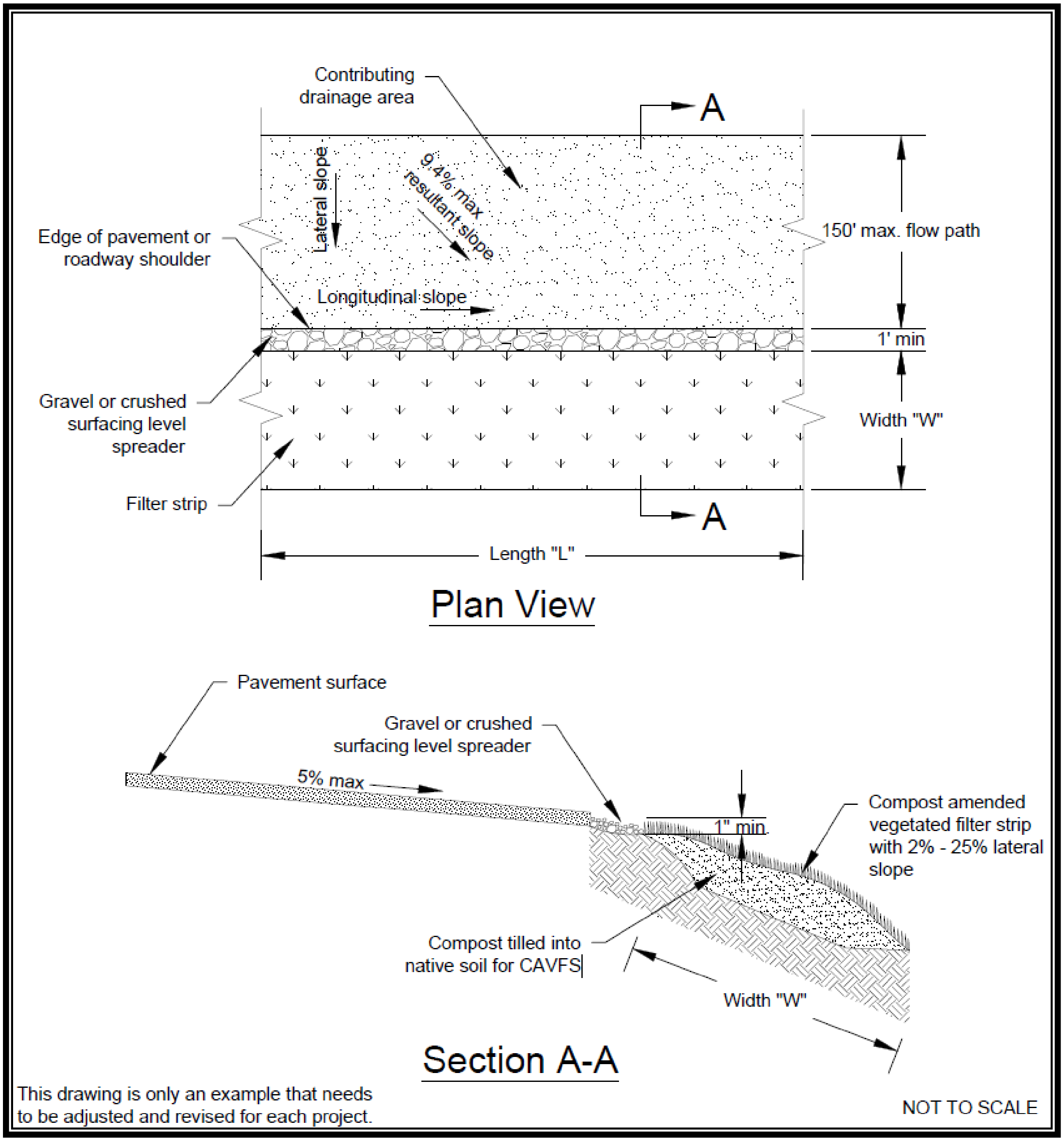


Figure 23.1. Example of a Compost-Amended, Vegetated Filter Strip (CAVFS).

23.9.2 Soil Design Criteria

The CAVFS design incorporates composted material into the native soils in accordance with the criteria in postconstruction soil quality and depth BMP requirements for turf areas (see Chapter 6). However, as noted below, the compost shall not contain biosolids or manure. The goal is to create a healthy soil environment for a lush growth of turf.

- Soil/Compost Mix
  - Presumptive approach: Place and rototill 1.75 inches of composted material into 6.25 inches of soil (a total amended depth of about 9.5 inches), for a settled depth of 8 inches. Water or roll to compact soil to 85 percent maximum. Plant grass.
  - Custom approach: Place and rototill the calculated amount of composted material into a depth of soil needed to achieve 8 inches of settled soil at 5 percent organic content. Water or roll to compact soil to 85 percent maximum. Plant grass. The amount of compost or other soil amendments used varies by soil type and organic matter content. If there is a good possibility that site conditions may already contain a relatively high organic content, then it may be possible to modify the preapproved rate described above and still be able to achieve the 5 percent organic content target.
  - The final soil mix (including compost and soil) shall have an initial saturated hydraulic conductivity less than 12 inches per hour, and a minimum long-term hydraulic conductivity of 1 inch per hour, per ASTM Designation D 2434 (Standard Test Method for Permeability of Granular Soils) at 85 percent compaction per ASTM Designation D 1557 (Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort). Infiltration rate and hydraulic conductivity are assumed to be approximately the same in a uniform mix soil.

    Note: Long-term saturated hydraulic conductivity is determined by applying the appropriate infiltration correction factors as explained in Section 9.6.9, Determining Design Bioretention Soil Mix Infiltration Rate, in bioretention cells, swales, and planter boxes (Chapter 9).
  - The final soil mixture shall have a minimum organic content of 5 percent by dry weight per ASTM Designation D 2974 (Standard Test Method for Moisture, Ash and Organic Matter of Peat and Other Organic Soils).
  - Achieving the above recommendations will depend on the specific soil and compost characteristics. In general, the recommendation can be achieved with 60 percent to 65 percent loamy sand mixed with 25 percent to 30 percent compost or 30 percent sandy loam, 30 percent coarse sand, and 30 percent compost.

  - The final soil mixture shall be tested prior to installation for fertility, micronutrient analysis, and organic material content.
  - Clay content for the final soil mix shall be less than 5 percent.
  - Compost must not contain biosolids, manure, any street or highway sweepings, or any catch basin solids.
  - The pH for the soil mix should be between 5.5 and 7.0. If the pH falls outside the acceptable range, it may be modified with lime to increase the pH or iron sulfate plus sulfur to lower the pH. The lime or iron sulfate must be mixed uniformly into the soil prior to use in LID areas.
  - The soil mix shall be uniform and free of stones, stumps, roots, or other similar material larger than 2 inches.
  - When placing topsoil, it is important that the first lift of topsoil is mixed into the top of the existing soil. This allows the roots to penetrate the underlying soil easier and helps prevent the formation of a slip plane between the two soil layers.

- Soil Component
  - The texture for the soil component of the LID BMP soil mix should be loamy sand (USDA soil textural classification).

- Compost Component
  - Follow the specifications for compost for bioretention cells, swales, and planter boxes in (see Section 9.6).

23.9.3 Landscaping (planting considerations) and Vegetation Establishment

Plant vegetated filter strips with grass that can withstand relatively high-velocity flows as well as wet and dry periods. Projects may also incorporate native vegetation into filter strips, such as small shrubs to make the system more effective in treating runoff and providing root penetration into subsoils, thereby enhancing infiltration. Consult a landscape architect for recommendations on grasses and plants suitable for the project site.

23.9.4 Design Modeling Method

The CAVFS will have an “element” in most of the approved continuous runoff models that should be used for determining the amount of water that is treated by the CAVFS. To fully meet treatment requirements, 91 percent of the influent runoff file must pass through the soil profile of the CAVFS. Water that merely flows over the surface is not considered to be treated. Approved continuous runoff models should be able to report the amount of water that is designed to pass through the soil profile.

Chapter 24 – Filtration Treatment Facilities

24.1 Purpose

This section presents criteria for the design and construction of runoff treatment filters including basin, vault, and linear filters. Filtration treatment facilities collect and treat design runoff volumes to remove total suspended solids, phosphorous, and insoluble organics (including oils) from stormwater. See Minimum Requirement #9 in Volume I, Section 4.2.10; Volume I, Section 3.3.3; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements. This section discusses media filter drains (previously referred to as the Ecology embankment).

Media filter drains are expected to achieve the:

- Basic treatment goal
- Phosphorous treatment goal
- Enhanced treatment goal: greater than 30 percent reduction of dissolved copper, and greater than 60 percent reduction of dissolved zinc.

24.2 Performance Objectives

Refer to Volume I, Section 3.3 for descriptions of the basic, oil, phosphorus, and enhanced treatment goals.

24.3 Media Filter Drain (Ecology BMP T8.40)

The MFD, previously referred to as the Ecology embankment, is a linear, flow-through, stormwater runoff treatment device that can be sited along roadway side slopes (conventional design) and medians (dual media filter drains), borrow ditches, or other linear depressions. Cut-slope applications may also be considered. The MFD can be used where available right-of-way is limited, sheet flow from the roadway surface is feasible, and lateral gradients are generally less than 25 percent (4H:1V). The MFD has a GULD for basic, enhanced, and phosphorus treatment. Updates/changes to the use-level designation and any design changes will be posted on WSDOT Highway Runoff Manual web page <https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/manuals/highway-runoff-manual>.>.

Media filter drains have four basic components: a gravel no-vegetation zone, a grass strip, the MFD mix bed, and a conveyance system for flows leaving the MFD mix. This conveyance system usually consists of a gravel-filled underdrain trench or a layer of crushed surfacing base course. This layer of crushed surfacing base course must be porous enough to allow treated flows to freely drain away from the MFD mix.

Typical MFD configurations are shown in Figures 24.1, 24.2, and 24.3.

The MFD removes suspended solids, phosphorus, and metals from roadway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration.

The underdrain trench is an option for hydraulic conveyance of treated stormwater to a desired location, such as a downstream flow control facility or stormwater outfall. The trench's perforated underdrain pipe is a protective measure to ensure free flow through the MFD mix and to prevent prolonged ponding. It may be possible to omit the underdrain pipe if it can be demonstrated that the pipe is not necessary to maintain free flow through the MFD mix and underdrain trench.

It is critical to note that water must sheet flow across the MFD. Channelized flows or ditch flows running down the middle of the dual MFD (continuous off-site inflow) shall be minimized.

24.3.1 Application and Limitations

In many instances, conventional runoff treatment is not feasible due to right-of-way constraints (such as adjoining wetlands and geotechnical considerations). The MFD and the dual MFD designs (Figures 24.1 and 24.1) are runoff treatment options that can be sited in most right-of-way confined situations. In many cases, a MFD or a dual MFD can be sited without the acquisition of additional right-of-way needed for conventional stormwater facilities or capital-intensive expenditures for underground wet vaults.

Applications

Media Filter Drain

The MFD can achieve basic, phosphorus, and enhanced water quality treatment.

Since maintaining sheet flow across the MFD is required for its proper function, the ideal locations for MFDs in roadway settings are roadway side slopes or other long, linear grades with lateral side slopes less than 4H:1V, and longitudinal slopes no steeper than 5 percent. As side slopes approach 3H:1V, without design modifications, sloughing may become a problem due to friction limitations between the separation geotextile and underlying soils. The longest flowpath from the contributing area delivering sheet flow to the MFD shall not exceed 150 feet.

If there is sufficient roadway embankment width, the designer should consider placing the grass strip and media mix downslope when feasible. The project engineer must ensure the MFD does not intercept seeps, springs, or groundwater.

Dual Media Filter Drain for Roadway Medians

The dual MFD is fundamentally the same as the side-slope version. It differs in siting and is more constrained with regard to drainage options. Prime locations for dual MFDs in a roadway setting are medians, roadside drainage, borrow ditches, or other linear depressions. It is critical for water to sheet flow across the dual MFD. Channelized flows or ditch flows running down the middle of the dual MFD (continuous off-site inflow) shall be minimized.

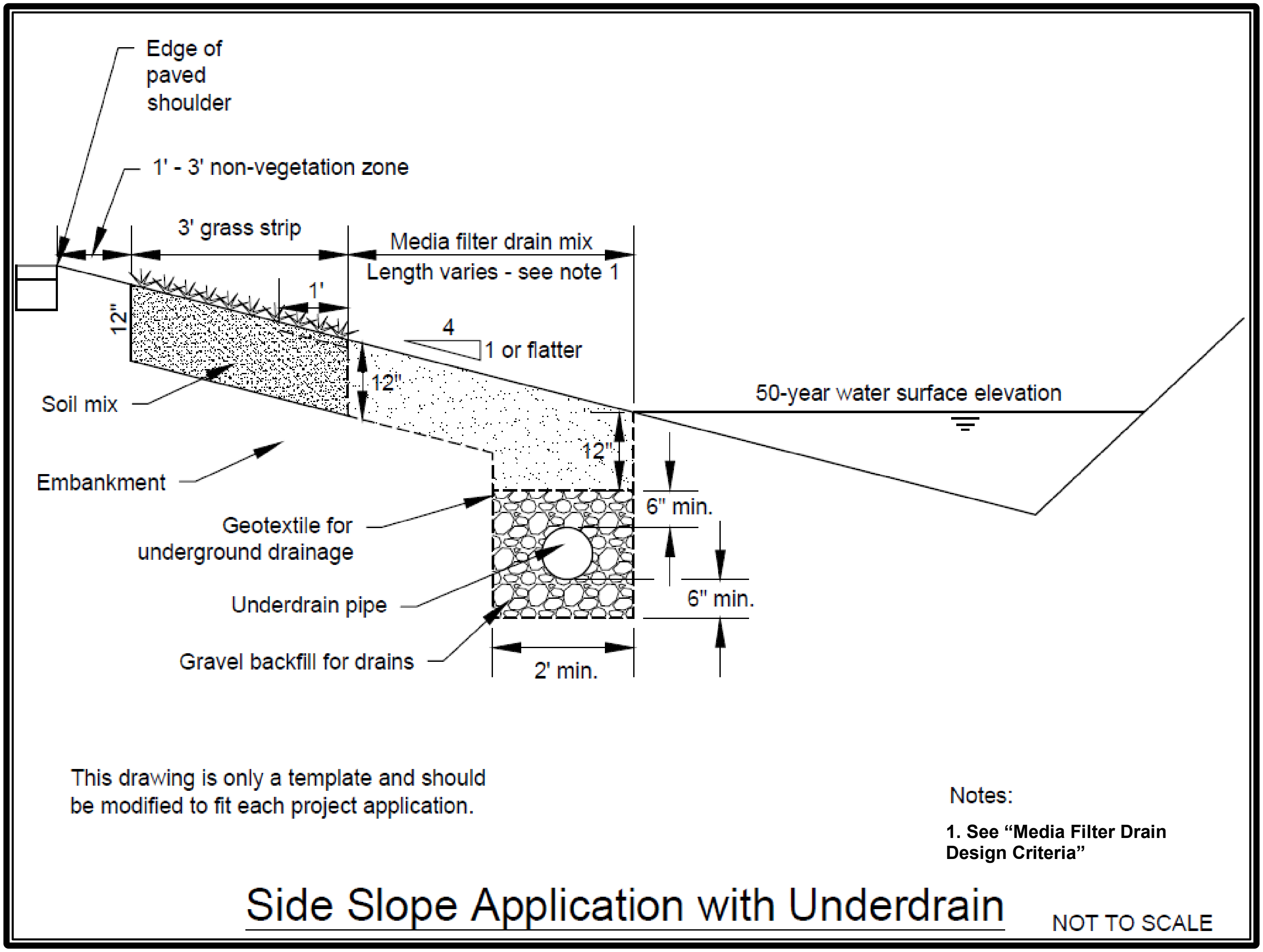


Figure 24.1. Media Filter Drain: Cross-Section.

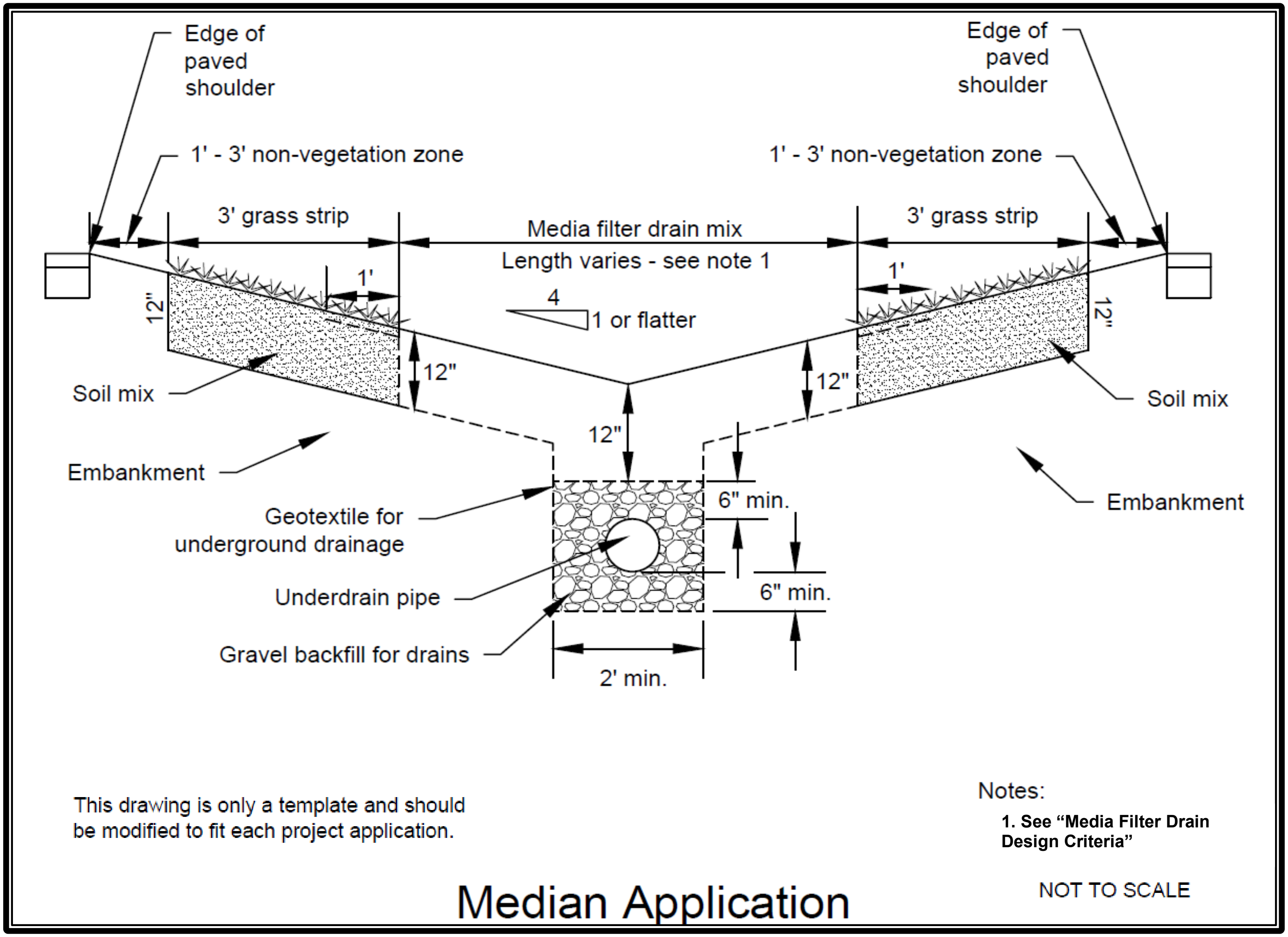
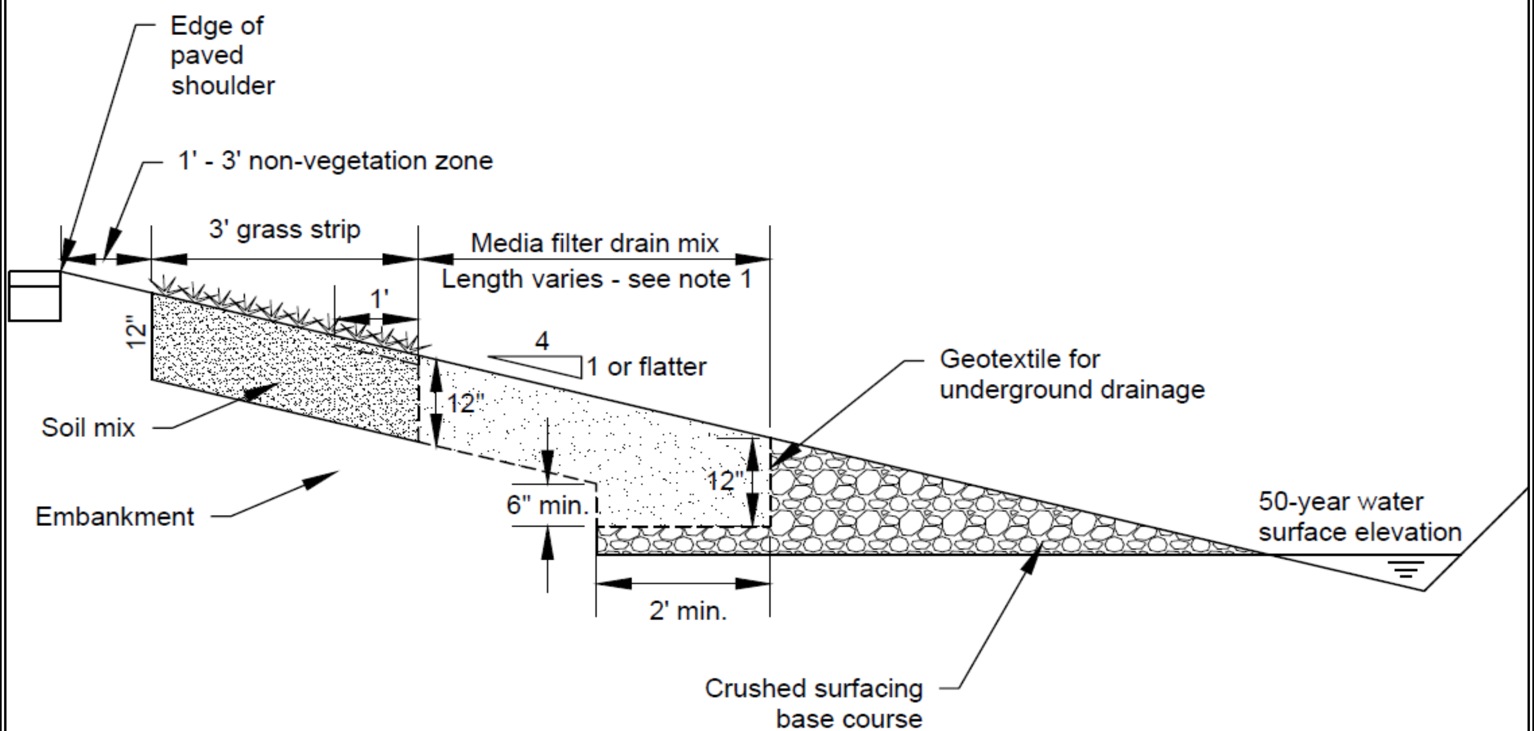


Figure 24.2. Dual Media Filter Drain: Cross-Section.



This drawing is only a template and should be modified to fit each project application.

Notes:

1. **See "Media Filter Drain Design Criteria"**

NOT TO SCALE

Side Slope Application without Underdrain

Figure 24.3. Filter Drain without Underdrain Trench.

Limitations

Steep Slopes

Avoid construction on longitudinal slopes steeper than 5 percent. Avoid construction on 3H:1V lateral slopes and preferably use less than 4H:1V slopes. In areas where lateral slopes exceed 4H:1V, it may be possible to construct terraces to create 4H:1V slopes or to otherwise stabilize up to 3H:1V slopes. (For details, see the Sizing Criteria and Filter Geometry subsections in the Media Filter Drain Design Criteria section below.)

Wetlands

Do not construct in wetlands and wetland buffers. In many cases, an MFD (due to its small lateral footprint) can fit within the roadway fill slopes adjacent to a wetland buffer. In situations where the roadway fill prism is located adjacent to wetlands, an interception trench/underdrain will need to be incorporated as a design element in the MFD.

Shallow Groundwater

Mean high water table levels at the project site need to be determined to ensure the MFD mix bed and the underdrain (if needed) will not become saturated by shallow groundwater.

Unstable Slopes

In areas where slope stability may be problematic, consult a geotechnical engineer.

Areas of Seasonal Groundwater Inundations or Basement Flooding

Site-specific piezometer data may be needed in areas of suspected seasonal high groundwater inundations. The hydraulic and runoff treatment performance of the dual MFD may be compromised due to backwater effects and lack of sufficient hydraulic gradient.

Narrow Roadway Shoulders

In areas where there is a narrow roadway shoulder that does not allow enough room for a vehicle to fully stop or park, consider placing the MFD farther down the embankment slope. This will reduce the amount of rutting in the MFD and decrease overall maintenance repairs.

24.3.2 Media Filter Drain Design Criteria

The basic design concept behind the MFD and dual MFD is to fully filter all runoff through the MFD mix. Therefore, the infiltration capacity of the medium and drainage below needs to match or exceed the hydraulic loading rate.

Media Filter Drain Mix Bed Sizing Procedure

The MFD mix shall be a minimum of 12 inches deep, including the section on top of the underdrain trench.

For runoff treatment, sizing of the MFD mix bed is based on the requirement that the runoff treatment flow rate from the pavement area, $Q_{Roadway}$, cannot exceed the long-term infiltration capacity of the MFD, $Q_{Infiltration}$:

$$Q_{Roadway} \leq Q_{Infiltration}$$

For western Washington, $Q_{Roadway}$ is the flow rate at or below which 91 percent of the runoff volume for the developed threshold discharge areas will be treated, based on a 15-minute time step and can be determined using and approved continuous runoff model.

The long-term infiltration capacity of the MFD is based on the following equation:

$$\frac{LTIR * L * W}{C * FS} = Q_{Infiltration}$$

where:

LTIR = Long-term infiltration rate of the MFD mix (use 10 inches per hour for design) (in/hr)

L = Length of media filter drain (parallel to roadway) (feet)

W = Width of the media filter drain mix bed (feet)

C = Conversion factor of 43,200 ((in/hr)/(feet/sec))

FS = Factor of safety (equal to 1.0, unless unusually heavy sediment loading is expected)

Assuming that the length of the MFD is the same as the length of the contributing pavement, solve for the width of the MFD:

$$W \geq \frac{Q_{Roadway} * C * FS}{LTIR * L}$$

Western Washington project applications of this design procedure have shown that, in almost every case, the calculated width of the MFD does not exceed 1 foot. Therefore, Table 24.1 was developed to simplify the design steps and should be used to establish an appropriate width.

Table 24.1. Western Washington Design Widths for Media Filter Drains.

Pavement Width That Contributes Runoff to the MFD	Minimum MFD Width[a]
≤ 20 feet	2 feet
≥ 20 and ≤ 35 feet	3 feet
> 35 feet	4 feet

[a] Width does not include the required 1-to-3-foot gravel vegetation-free zone or the 3-foot filter strip width (see Figure 24.1).

Sizing Criteria

Width

The width of the MFD mix bed is determined by the amount of contributing pavement routed to the MFD. The surface area of the MFD mix bed needs to be sufficiently large to fully infiltrate the runoff treatment design flow rate using the long-term filtration rate of the MFD mix. For design purposes, a 50 percent safety factor is incorporated into the long-term MFD mix filtration rate to accommodate variations in slope, resulting in a design filtration rate of 10 inches per hour. The MFD mix bed shall have a bottom width of at least 2 feet in contact with the conveyance system below the MFD mix.

Length

In general, the length of a MFD or dual MFD is the same as the contributing pavement. Any length is acceptable as long as the surface area MFD mix bed is sufficient to fully infiltrate the runoff treatment design flow rate.

Cross-Section

In profile, the surface of the MFD should preferably have a lateral slope less than 4H:1V (<25 percent). On steeper terrain, it may be possible to construct terraces to create a 4H:1V slope, or other engineering may be employed if approved by the city, to ensure slope stability up to 3H:1V. If sloughing is a concern on steeper slopes, consideration should be given to incorporating permeable soil reinforcements, such as geotextiles, open-graded/permeable pavements, or commercially available ring and grid reinforcement structures, as top layer components to the MFD mix bed. Consultation with a geotechnical engineer is required.

Inflow

Runoff is conveyed to an MFD using sheet flow from the pavement area. The longitudinal pavement slope contributing flow to a MFD shall be less than 5 percent.

Although there is no lateral pavement slope restriction for flows going to a MFD, the designer must ensure flows remain as sheet flow.

Underdrain Design

Underdrain pipe can provide a protective measure to ensure free flow through the MFD mix and is sized similar to storm drains. For MFD underdrain sizing, an additional step is required to determine the flow rate that can reach the underdrain pipe. This is done by comparing the contributing basin flow rate to the infiltration flow rate through the MFD mix and then using the smaller of the two to size the underdrain. The analysis described below considers the flow rate per foot of MFD, which allows the flexibility of incrementally increasing the underdrain diameter where long lengths of underdrain are required. When underdrain pipe connects to a stormwater drain system, place the invert of the underdrain pipe above the 25-year water surface elevation in the storm drain to prevent backflow into the underdrain system.

The following describes the procedure for sizing underdrains installed in combination with MFDs.

- Calculate the flow rate per foot from the contributing basin to the MFD. The design storm event used to determine the flow rate should be relevant to the purpose of the underdrain. For example, if the underdrain will be used to convey treated runoff to a detention BMP, size the underdrain for the 50-year storm event. (See the WSDOT Hydraulics Manual, Figure 2-2.1, for conveyance flow rate determination <www.wsdot.wa.gov/Publications/Manuals/M23-03.htm>.)

$$\frac{Q_{highway}}{ft} = \frac{Q_{highway}}{L_{MFD}}$$

where:

$\frac{Q_{highway}}{ft}$ = contributing flow rate per foot (cfs/foot)

L_{MFD} = length of MFD contributing runoff to the underdrain (feet)

- Calculate the MFD flow rate of runoff per foot given an infiltration rate of 10 in/hr through the MFD mix.

$$Q_{\frac{MFD}{ft}} = \frac{f \times W \times 1ft}{ft} \times \frac{1ft}{12in} \times \frac{1hr}{3600\sec}$$

where:

$Q_{\frac{MFD}{ft}}$ = flow rate of runoff through MFD mix layer (cfs/foot)

W = width of underdrain trench (feet) –see WSDOT Standard Plan B-55.20-00; the minimum width is 2 feet

f = infiltration rate though the MFD mix (in/hr) = 10 in/hr

- Size the underdrain pipe to convey the runoff that can reach the underdrain trench. This is taken to be the smaller of the contributing basin flow rate or the flow rate through the MFD mix layer.

$$Q_{\frac{UD}{ft}} = \text{smaller}\left\{Q_{\frac{highway}{ft}} \text{ or } Q_{\frac{MFD}{ft}}\right\}$$

where:

$Q_{\frac{UD}{ft}}$ = underdrain design flow rate per foot (cfs/foot)

- Determine the underdrain design flow rate using the length of the MFD and a factor of safety of 1.2.

$$Q_{UD} = 1.2 \times Q_{\frac{UD}{ft}} \times W \times L_{MFD}$$

where:

Q_{UD} = estimated flow rate to the underdrain (cfs)

W = width of the underdrain trench (feet) – per WSDOT Standard Specification 2-09.4; the minimum width is 2 feet

L_{MFD} = length of MFD contributing runoff to the underdrain (feet)

- Given the underdrain design flow rate, determine the underdrain diameter. See Chapter 9 (Underdrain (Optional) heading) for additional underdrain design criteria.

$$D = 16\left(\frac{(Q_{UD} \times n)}{s^{0.5}}\right)^{3/8}$$

where:

D = underdrain pipe diameter (inches)

n = Manning's coefficient

s = slope of pipe (feet/feet)

Filter Geometry

- No-Vegetation Zone: The no-vegetation zone (vegetation-free zone) is a shallow gravel zone located directly adjacent to the roadway pavement. The no-vegetation zone is a crucial element in a properly functioning MFD or other BMPs that use sheet flow to convey runoff from the roadway surface to the BMP. The no-vegetation zone functions as a level spreader to promote sheet flow and a deposition area for coarse sediments. The no-vegetation zone shall be between 1 foot and 3 feet wide. Depth will be a function of how the roadway section is built from subgrade to finish grade; the resultant cross-section will typically be triangular to trapezoidal. Within these bounds, width varies depending on maintenance spraying practices.

- Grass Strip: The width of the grass strip is dependent on the availability of space within the roadway side slope. The baseline design criterion for the grass strip within the MFD is a 3-foot minimum width, but wider grass strips are recommended if the additional space is available. The designer may consider adding aggregate to the soil mix to help minimize rutting problems from errant vehicles. The soil mix should ensure grass growth for the design life of the MFD. Composted material used in the grass strip shall meet the specifications for compost used in bioretention soil mix. See Chapter 9.

- Media Filter Drain Mix Bed: The MFD mix is a mixture of crushed rock, dolomite, gypsum, and perlite. The crushed rock provides the support matrix of the medium; the dolomite and gypsum add alkalinity and ion exchange capacity to promote the precipitation and exchange of heavy metals; and the perlite improves moisture retention to promote the formation of biomass within the MFD mix. The combination of physical filtering, precipitation, ion exchange, and biofiltration enhances the water treatment capacity of the mix. The MFD mix has an estimated initial filtration rate of 50 inches per hour and a long-term filtration rate of 28 inches per hour due to siltation. With an additional safety factor, the rate used to size the length of the MFD should be 10 inches per hour.

- Planting Considerations: Landscaping for the grass strip is the same as for biofiltration swales, unless otherwise specified in the special provisions for the project's construction documents.

- Conveyance System Below Media Filter Drain Mix:

  - The gravel underdrain trench provides hydraulic conveyance when treated runoff needs to be conveyed to a desired location such as a downstream flow control facility or stormwater outfall.

  - In Type C and D soils, an underdrain pipe would help to ensure free flow of the treated runoff through the MFD mix bed. In some Type A and B soils, an underdrain pipe may be unnecessary if most water percolates into subsoil from the underdrain trench. The need for underdrain pipe should be evaluated in all cases. The underdrain trench shall be a minimum of 2 feet wide for either the conventional or dual MFD.

The gravel underdrain trench may be eliminated if there is evidence to support that flows can be conveyed laterally to an adjacent ditch or onto a fill slope that is properly vegetated to protect against erosion. The MFD mix shall be kept free draining up to the 50-year storm event water surface elevation represented in the downstream ditch.

Materials

<u>Media Filter Drain Mix</u>

The MFD mix used in the construction of MFDs consists of the amendments listed in Table 24.2 at the end of this section. Mixing and transportation must occur in a manner that ensures the materials are thoroughly mixed prior to placement and that separation does not occur during transportation or construction operations.

These materials should be used in accordance with the following WSDOT Standard Specifications:

- Gravel Backfill for Drains, 9-03.12(4)

- Underdrain Pipe, 7-01.3(2) (see Figure 24.4)

- Construction Geotextile for Underground Drainage, 9-33.1

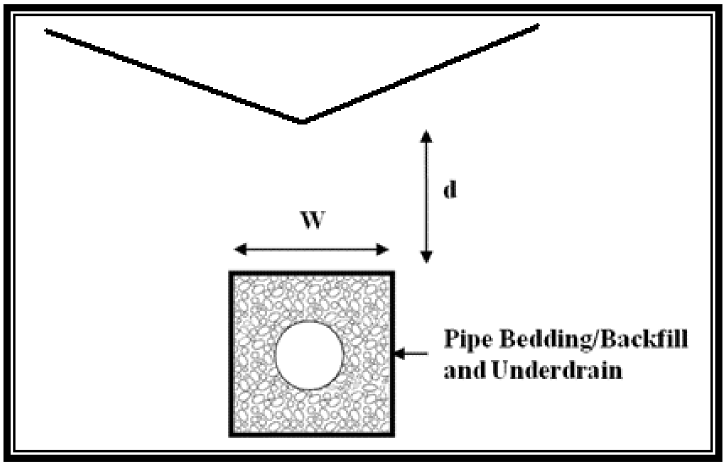


Figure 24.4. Media Filter Drain Underdrain Installation.

<u>Crushed Surfacing Base Course</u>

If the design is configured to allow the MFD to drain laterally into a ditch, the crushed surfacing base course below the MFD shall conform to Section 9-03.9(3) of the WSDOT Standard Specifications.

<u>Berms, Baffles, and Slopes</u>

See Sizing Criteria, Cross-Section, in Section 24.3.2, Media Filter Drain Design Criteria.

24.3.3 Construction Criteria

- Erosion and Sediment Control: Keep effective erosion and sediment control measures in place until grass strip is established.

- Traffic Control: Do not allow vehicles or traffic on the MFD to minimize rutting and maintenance repairs.

- Signing: Non-reflective guideposts will delineate the MFD. This practice allows personnel to identify where the system is installed and to make appropriate repairs should damage occur to the system. If the MFD is within the 1-year time of travel zone for a wellhead protection area or within a Category I critical aquifer recharge area, signage prohibiting the use of pesticides must be provided.

24.3.4 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

Table 24.2. Media Filter Drain Mix.

Amendment	Quantity
Mineral aggregate: Aggregate for MFD Mix: Aggregate for MFD Mix shall be manufactured from ledge rock, talus, or gravel in accordance with Section 3-01 of the *Standard Specifications for Road, Bridge, and Municipal Construction* (2014 or latter), which meets the following test requirements for quality. The use of recycled material is not permitted: Los Angeles Wear, 500 Revolutions 35% maximum Degradation Factor 30 minimum Aggregate for the MFD Mix shall conform to the following requirements for grading and quality: **Sieve Size Percent Passing (by weight):** 1/2″ square 100 3/8″ square 90–100 U.S. No. 4 30–56 U.S. No. 10 0–10 U.S. No. 200 0–1.5 % fracture, by weight, minimum 75 Static stripping test Pass The fracture requirement shall be at least two fractured faces and will apply to material retained on the U.S. No. 10. Aggregate for the MFD shall be substantially free from adherent coatings. The presence of a thin, firmly adhering film of weathered rock shall not be considered as coating unless it exists on more than 50% of the surface area of any size between successive laboratory sieves.	3 cubic yards
Perlite: Horticultural grade, free of any toxic materials) 0–30% passing U.S. No. 18 Sieve 0–10% passing U.S. No. 30 Sieve	1 cubic yard per 3 cubic yards of mineral aggregate
Dolomite: $CaMg(CO_3)2$ (calcium magnesium carbonate): Agricultural grade, free of any toxic materials) 100% passing U.S. No. 8 Sieve 0% passing U.S. No. 16 Sieve	10 pounds per cubic yard of perlite
Gypsum: Noncalcined, agricultural gypsum $CaSO_4 \cdot 2H_2O$ (hydrated calcium sulfate): Agricultural grade, free of any toxic materials) 100% passing U.S. No. 8 Sieve 0% passing U.S. No. 16 Sieve	**1.5 pounds per cubic yard of perlite**

Chapter 25 – Biofiltration Treatment Facilities

Note: Figures in Chapter 25 are courtesy of King County, except as noted.

25.1 Purpose

This section addresses four BMPs that are classified as biofiltration treatment facilities:

- Basic Biofiltration Swale
- Wet Biofiltration Swale
- Continuous Inflow Biofiltration Swale
- Basic Filter Strip.

Biofilters are vegetated treatment systems (typically grass) that remove pollutants by means of sedimentation, filtration, soil sorption, and/or plant uptake. They are typically configured as swales or flat filter strips.

The BMPs discussed in this section are designed to remove low concentrations and quantities of total suspended solids, heavy metals, petroleum hydrocarbons, and/or nutrients from stormwater.

25.1.1 Applications

A biofilter can be used as a basic treatment BMP for contaminated stormwater runoff from roadways, driveways, parking lots, and highly impervious ultra-urban areas, or as the first stage of a treatment train. In cases where hydrocarbons, high total suspended solids, or debris would be present in the runoff, such as high-use sites, a pretreatment system for those components would be necessary. Off-line location is preferred to avoid flattening vegetation and the erosive effects of high flows. Consider biofilters in retrofit situations where appropriate (Center for Watershed Protection 1998).

25.1.2 Site Suitability

Consider the following factors for determining site suitability:

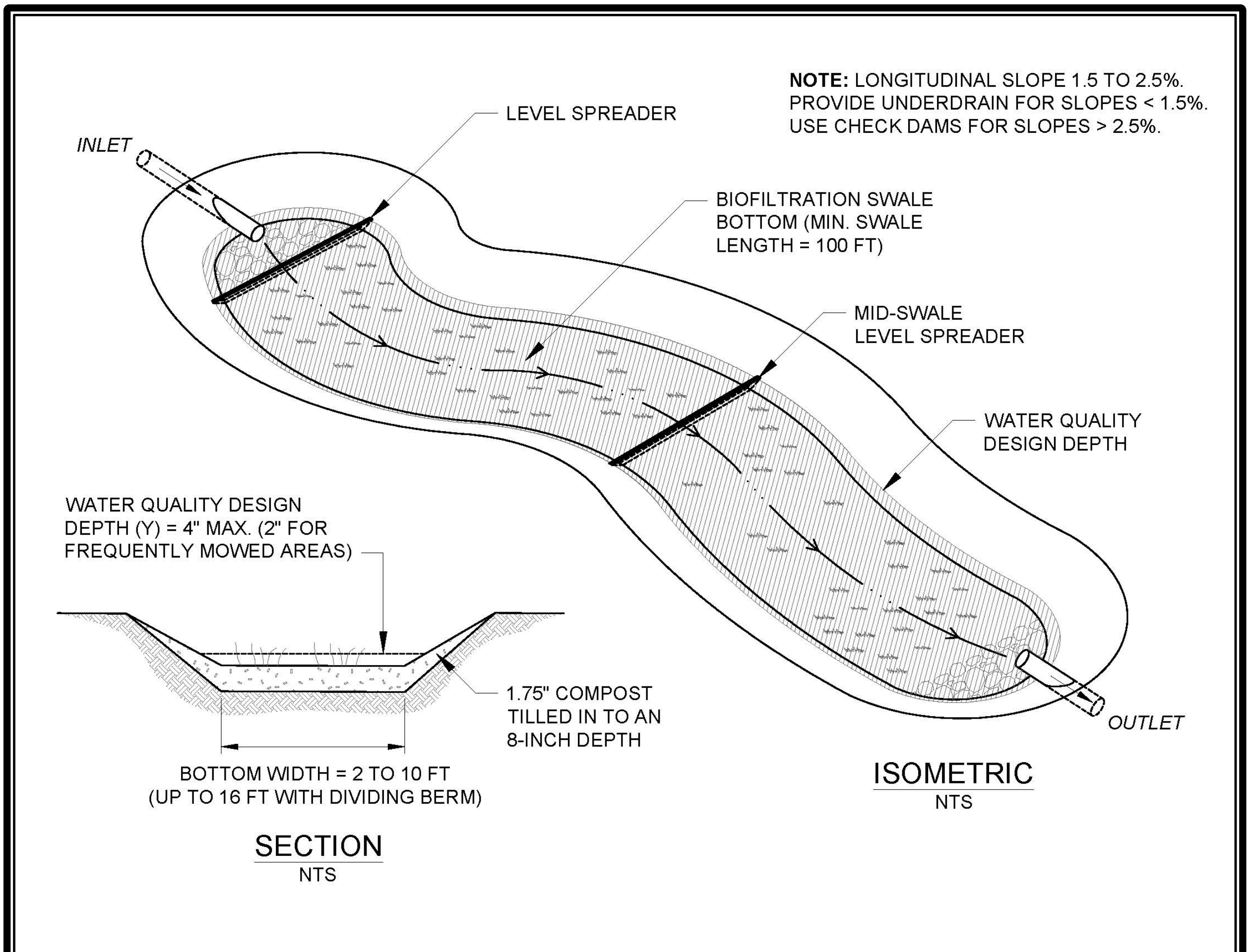
- Target pollutants are amenable to biofilter treatment
- Accessibility for operation and maintenance
- Suitable growth environment (soil, etc.) for the vegetation

- Adequate siting for a pretreatment facility if high petroleum hydrocarbon levels (oil/grease) or high total suspended solids loads could impair treatment capacity or efficiency
- If the biofilter can be impacted by snowmelts and ice, refer to Caraco and Claytor (1997) for additional design criteria.

25.2 Best Management Practices

25.2.1 Basic Biofiltration Swale (Ecology BMP T9.10)

Biofiltration swales are typically shaped as a trapezoid or a parabola. See Figure 25.1 for typical cross-sections.



Source: Seattle 2016 (reproduced with permission)

Figure 25.1. Biofiltration Swale Access Features.

25.2.2 Limitations

Data suggest that the performance of biofiltration swales is highly variable from storm to storm. It is therefore recommended that treatment methods that perform more consistently, such as wet ponds, be considered before using a biofiltration swale. Biofiltration swales downstream of devices of equal or greater effectiveness can convey runoff but should not be expected to offer a treatment benefit (Horner 2000).

25.2.3 Basic Biofiltration Swale Design Criteria

- Design criteria are specified in Table 25.1. A 9-minute hydraulic residence time is used at a multiple of the peak 15-minute water quality design flow rate (Q) representing 91 percent runoff volume as determined by an approved continuous runoff model (see Volume I, Chapter 2).

- Biofiltration swales should be designed as off-line facilities where feasible. For on-line systems, designers must evaluate the hydraulic capacity/stability for inflows greater than design flows. Bypass high flows, or control release rates into the biofilter, if necessary. When designing a swale to be off-line, the stability check is not required.

- Use a wide radius curved path to gain length where land is not adequate for a linear swale (avoid sharp bends to reduce erosion or provide for erosion protection).

- Install level spreaders (minimum 1 inch gravel) at the head and every 50 feet in swales of ≥4 feet width. Include sediment cleanouts (weir, settling basin, or equivalent) at the head of the biofilter as needed.

- Use energy dissipaters (bioengineered methods or riprap) for increased downslopes.

- Maintain access to biofilter inlet, outlet, and to mowing (Figure 25.1).

Table 25.1. Sizing Criteria.

Design Parameter	Biofiltration Swale	Filter Strip
Longitudinal Slope	0.015–0.025[a]	0.01–0.33
Maximum velocity	1 foot/sec (@ K multiplied by the water quality design flow rate); for stability, 3 feet/sec maximum	0.5 foot/sec (@ K multiplied by the water quality design flow rate)
Maximum water depth[b]	2 inches—if mowed frequently; 4 inches if mowed infrequently	1 inch maximum
Manning coefficient (22)	(0.2–0.3)[c] (0.24 if mowed infrequently)	0.35
Bed width (bottom)	(2–10 feet)[d]	—
Freeboard height	0.5 foot	—
Minimum hydraulic residence time at water quality design flow rate	9 minutes (18 minutes for continuous inflow)	9 minutes
Minimum length	100 feet	Sufficient to achieve hydraulic residence time in the filter strip
Maximum side slope	3H:1V 5H:1V preferred	Inlet edge ≥ 1 inch lower than contributing paved area
Maximum tributary drainage flowpath	—	150 feet
Maximum longitudinal slope of contributing area	—	0.05 (if steeper than 0.05, need upslope flow spreading and energy dissipation)
Maximum lateral slope of contributing area	—	0.02 (at the edge of the strip inlet)

[a] For swales, if the slope is less than 1.5 percent install an underdrain using a perforated pipe, or equivalent. Amend the soil if necessary to allow effective percolation of water to the underdrain. Install the low-flow drain 6″ deep in the soil. Slopes greater than 2.5 percent need check dams (riprap) at vertical drops of 12–15 inches. Underdrains can be made of 6-inch Schedule 40 PVC perforated pipe with 6″ of drain gravel on the pipe. The gravel and pipe must be enclosed by geotextile fabric (see Figures 25.2 and 25.3).

[b] Below the design water depth install an erosion control blanket, at least 4″ of topsoil, and the selected biofiltration mix. Above the water line use a straw mulch or sod.

[c] This range of Manning's n can be used in the equation; b = Qn/1.49y(1.67) s(0.5) – Zy with wider bottom width b, and lower depth, y, at the same flow. This provides the designer with the option of varying the bottom width of the swale depending on space limitations. Designing at the higher n within this range at the same flow decreases the hydraulic design depth, thus placing the pollutants in closer contact with the vegetation and the soil.

[d] For swale widths up to 16 feet the cross-section can be divided with a berm (concrete, plastic, compacted earth fill) using a flow spreader at the inlet (Figure 25.4).

25.2.1 Guidance for Bypassing Off-Line Facilities

Most biofiltration swales should be designed as off-line facilities. However, an on-line design is possible with approval by the City of Tumwater. Swales designed in an off-line mode must not engage a bypass until the flow rate exceeds a value determined by multiplying Q, the off-line water quality design flow rate predicted by an approved continuous runoff model, by the ratio determined in Figure 25.6b (presented later in this section). This modified design flow rate is an estimate of the design flow rate determined by using Santa Barbara Urban Hydrograph (SBUH) procedures.

25.2.2 Sizing Procedure for Biofiltration Swales

This guide provides biofilter swale design procedures in full detail, along with examples.

Preliminary Steps (P)

P-1. Determine the water quality design flow rate (Q) in 15-minute time-steps using an approved continuous runoff model. Use the correct flow rate, off-line or on-line, for the design situation.

P-2. Establish the longitudinal slope of the proposed biofilter.

P-3. Select a vegetation cover suitable for the site. Refer to Tables 25.3, 25.4, and 25.5 (presented later in the text) to select vegetation for western Washington.

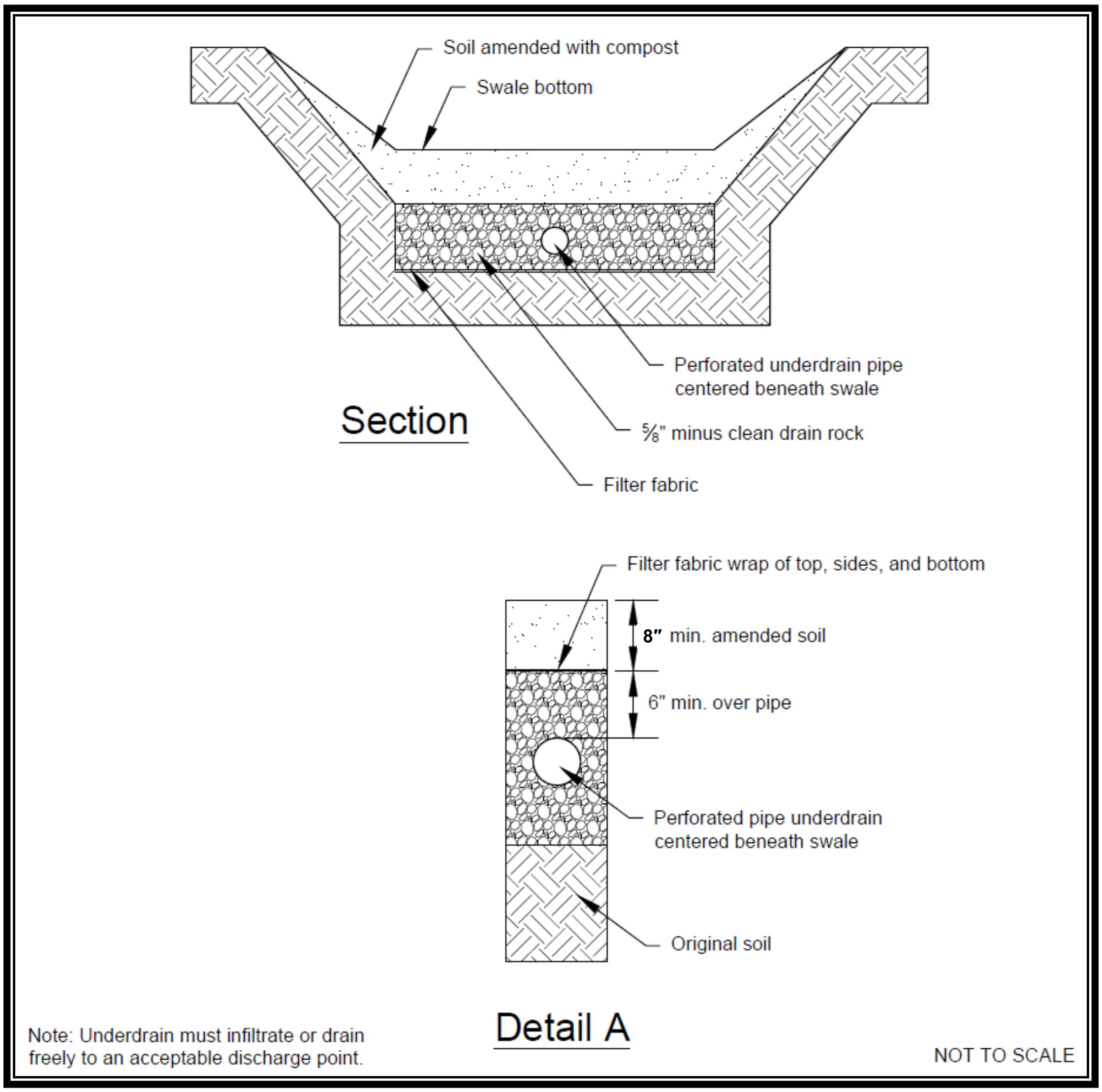


Figure 25.1. Biofiltration Swale Underdrain Detail.

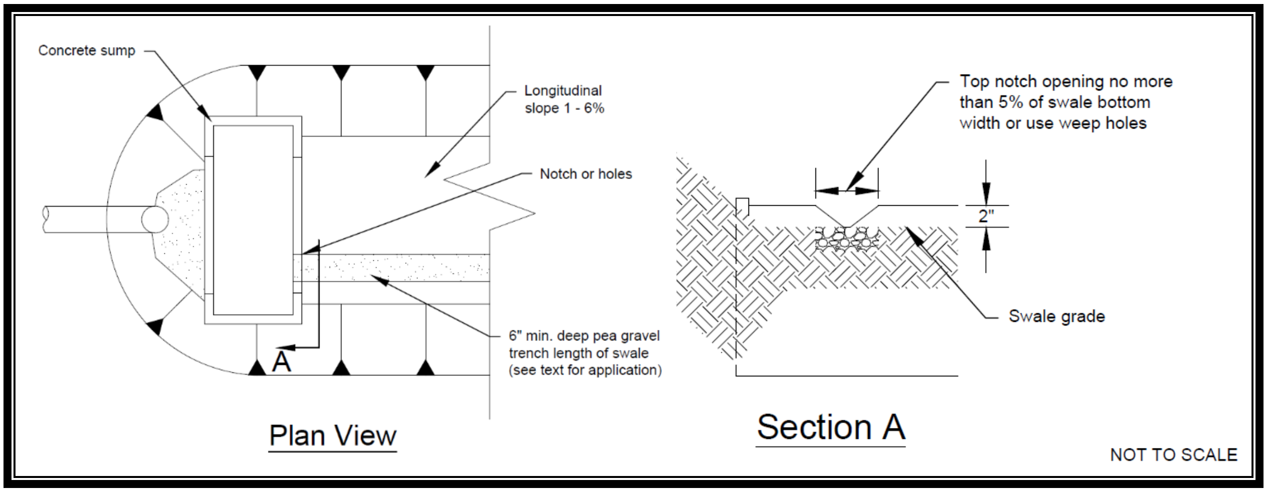


Figure 25.2. Biofiltration Swale Low-Flow Drain Detail.

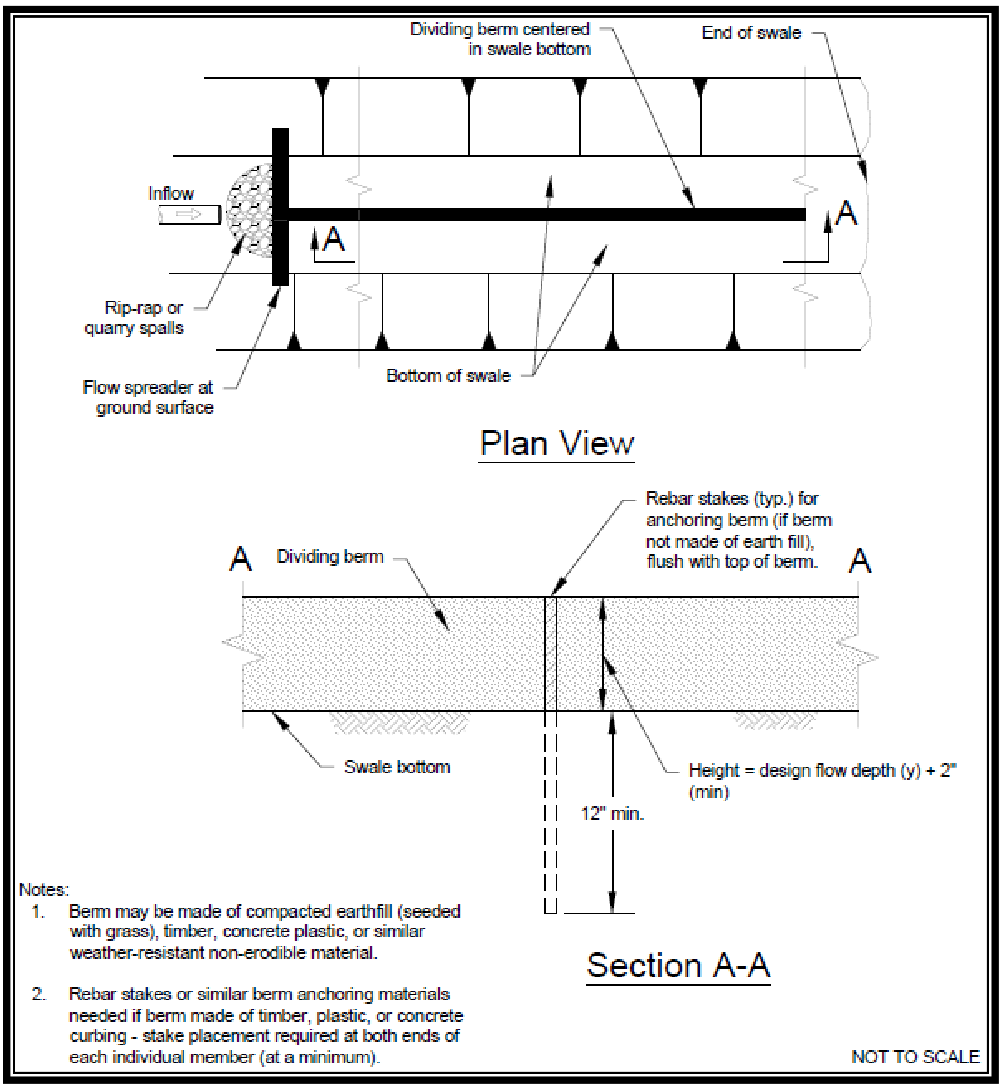


Figure 25.3. Swale Dividing Berm.

25.2.1 Design Calculations for Biofiltration Swale

The procedure recommended here is an adaptation appropriate for biofiltration applications of the type being installed in the Puget Sound region. This procedure reverses Chow's order (Chow 1959), designing first for capacity and then for stability. The capacity analysis emphasizes the promotion of biofiltration, rather than transporting flow with the greatest possible hydraulic efficiency. Therefore, it is based on criteria that promote sedimentation, filtration, and other pollutant removal mechanisms. Because these criteria include a lower maximum velocity than permitted for stability, the biofilter dimensions usually do not have to be modified after a stability check.

Design Steps (D)

D-1. Select the type of vegetation, and design depth of flow (based on frequency of mowing and type of vegetation) (Table 25.1).

D-2. Select a value of Manning's n (Table 25.1 with footnote number three).

D-3. Select swale shape-typically trapezoidal or parabolic.

D-4. Use Manning's equation and first approximations relating hydraulic radius and dimensions for the selected swale shape to obtain a working value of a biofilter width dimension:

$$Q = \frac{1.49AR^{0.67}s^{0.5}}{n} \qquad (1)$$

$$A_{rectangle} = Ty \qquad (2)$$

$$R_{rectangle} = \frac{Ty}{T + 2y} \qquad (3)$$

Where:

Q = Water quality design flow rate in 15-minute time steps (cfs)

n = Manning's n (dimensionless)

s = Longitudinal slope as a ratio of vertical rise/horizontal run (dimensionless)

A = Cross-sectional area ($feet^2$)

R = Hydraulic radius (feet)

T = top width of trapezoid or width of a rectangle (feet)

y = depth of flow (feet)

b = bottom width of trapezoid (feet)

If Equations 2 and 3 are substituted into Equation 1 and solved for T, complex equations result that are difficult to solve manually. However, approximate solutions can be found by recognizing that T>>y and Z^2>>1, and that certain terms are nearly negligible. The approximation solutions for rectangular and trapezoidal shapes are:

$$R_{rectangle} \approx y, \quad R_{trapezoid} \approx y, \quad R_{parabolic} \approx 0.67y, \qquad R_v \approx 0.5y$$

Substitute $R_{trapezoid}$ and $A_{trapezoid} = by+Zy^2$ into Equation 1, and solve for the bottom width b (trapezoidal swale):

$$b \approx \frac{2.5Qn}{1.49y^{1.67}s^{0.5}} - Zy$$

For a trapezoid, select a side slope Z of at least 3. Compute b and then top width T, where $T = b + 2yZ$. (**Note:** Adjustment factor of 2.5 accounts for the differential between the water quality design flow rate and the SBUH design flow. This equation is used to estimate an initial cross-sectional area. It does not affect the overall biofiltration swale size.)

If b for a swale is greater than 10 feet, either investigate how Q can be reduced, divide the flow by installing a low berm, or arbitrarily set b = 10 feet and continue with the analysis. For other swale shapes, refer to Figure 25.5.

D-5. Compute A:

$$A_{rectangle} = Ty \text{ or } A_{trapazoid} = by + Zy^2$$

$$A_{filter\ strip} = Ty$$

D-6. Compute the flow velocity at design flow rate:

$$V = \kappa \frac{Q}{A}$$

K = A ratio of the peak 10-minute flow predicted by SBUH to the water quality design flow rate estimated using an approved continuous runoff model. The value of K is determined from Figure 25.6a for on-line facilities, or Figure 25.6b for off-line facilities.

If V > 1.0 feet/sec (or V > 0.5 feet/sec for a filter strip), repeat steps D-1 to D-6 until the condition is met. A velocity greater than 1.0 feet/sec was found to flatten grasses, thus reducing filtration. A velocity lower than this maximum value will allow a 9-minute hydraulic residence time criterion in a shorter biofilter. If the value of V suggests that a longer biofilter will be needed than space permits, investigate how Q can be reduced (e.g., use of LID BMPs), or increase y and/or T (up to the allowable maximum values) and repeat the analysis.

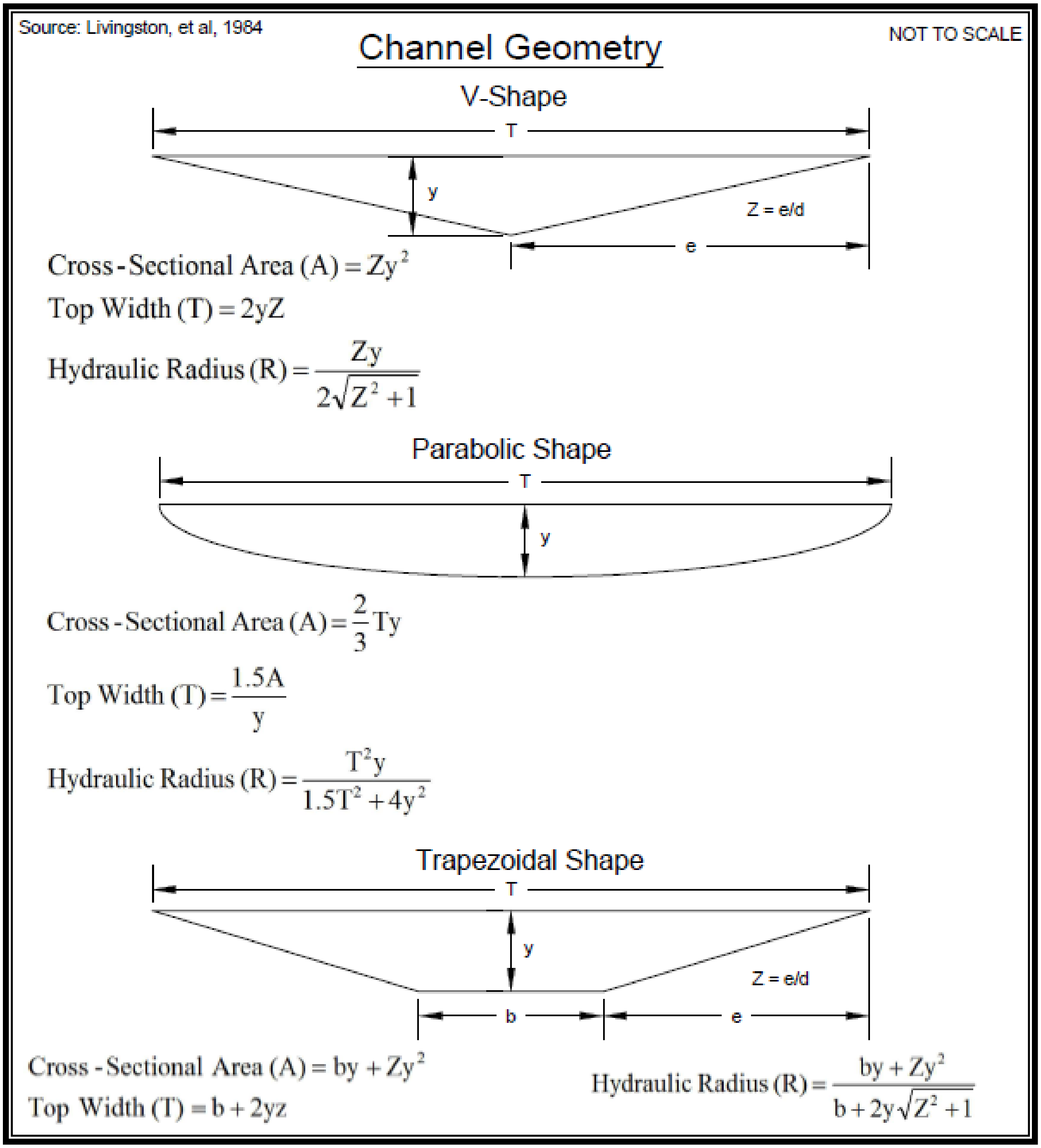
D-7. Compute the swale length (L, feet)

$$L = Vt\ (60\ \text{sec/min})$$

Where: t = hydraulic residence time (min)

Use t = 9 minutes for this calculation (use t = 18 minutes for a continuous inflow biofiltration swale). If a biofilter length is greater than the space permits, follow the advice in Step D-6.

If a length less than 100 feet results from this analysis, increase it to 100 feet, the minimum allowed. In this case, it may be possible to save some space in width and still meet all criteria. This possibility can be checked by computing V in the 100 feet biofilter for t = 9 minutes, recalculating A (if V less than 1 foot/sec) and recalculating T.



Source: Livingston, et al. 1984

Figure 25.5. Geometric Formulas for Common Swale Shapes.

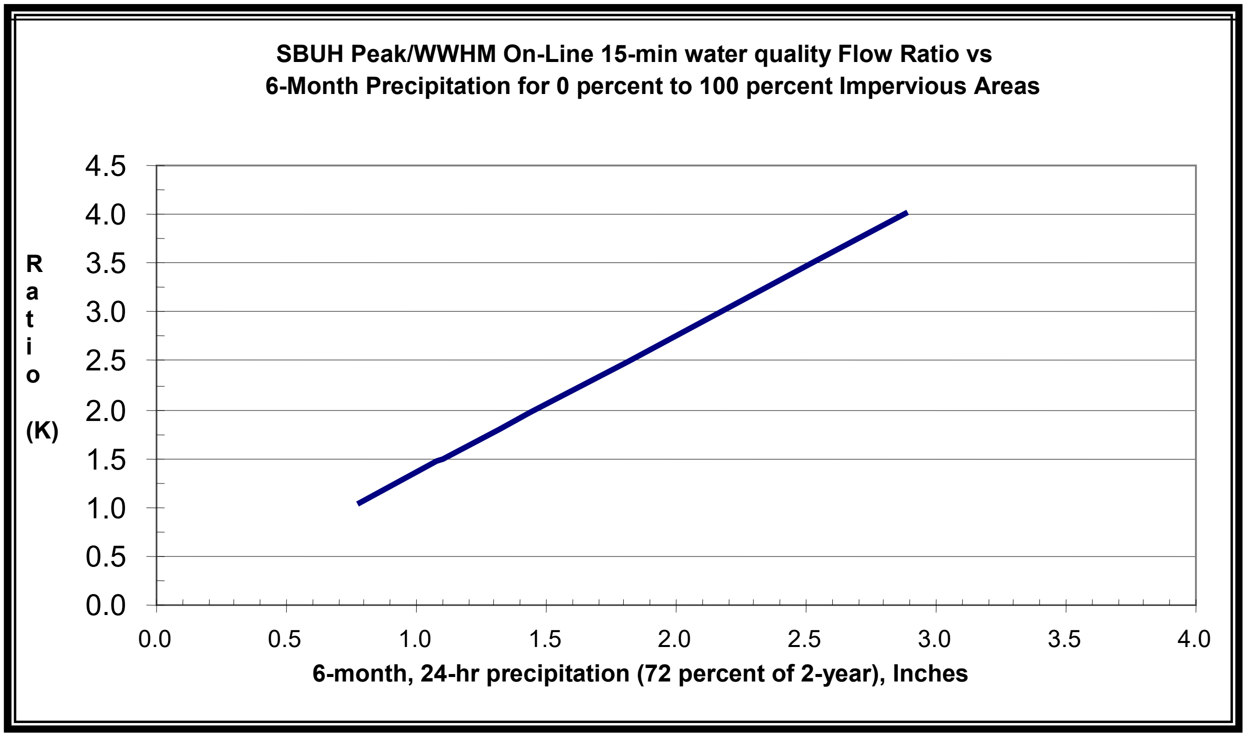


Figure 25.6a. Ratio of SBUH Peak/Water Quality Flow.

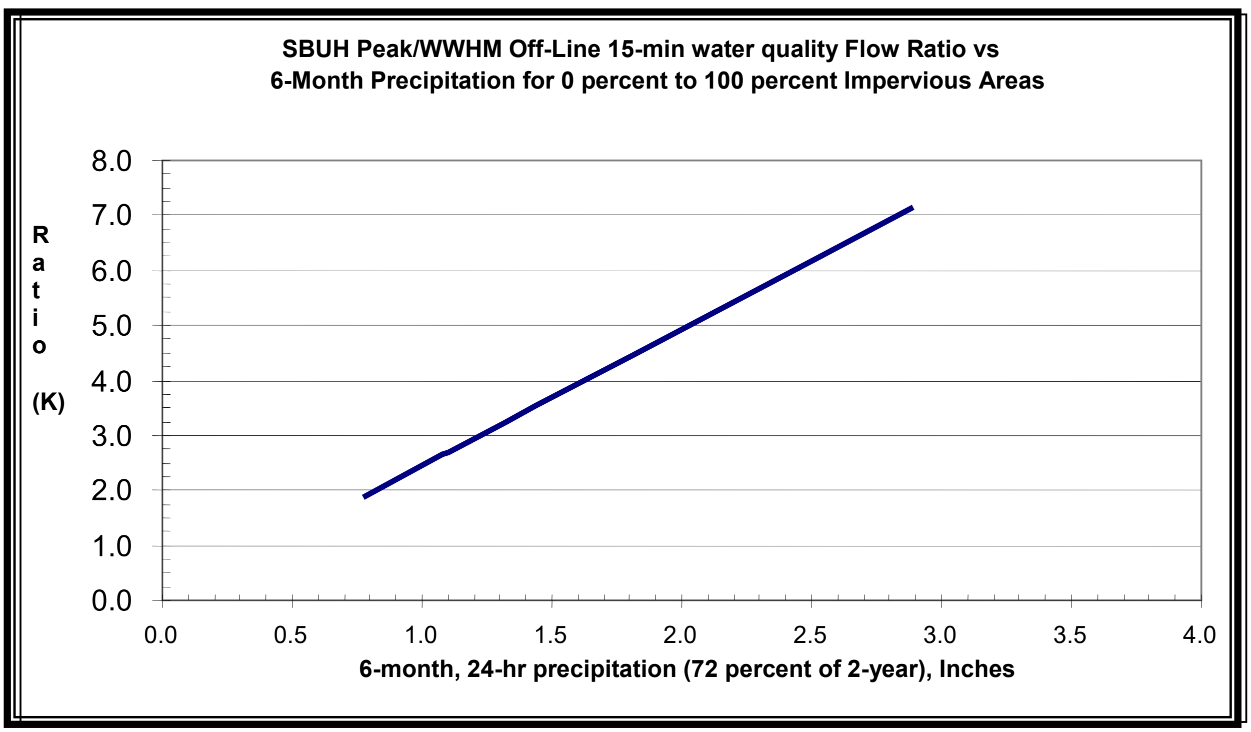


Figure 25.6b. Ratio of SBUH Peak/Water Quality Flow.

D-8. If there is still not sufficient space for the biofilter, the City of Tumwater and the project applicant should consider the following solutions (listed in order of preference):

- Divide the site drainage to flow to multiple biofilters.
- Use infiltration to provide lower discharge rates to the biofilter (only if the applicable infiltration requirements in Chapter 2 and 23 are met).
- Increase vegetation height and design depth of flow \
(**Note:** the design must ensure that vegetation remains standing during design flow).
- Reduce the developed surface area to gain space for biofiltration.
- Increase the longitudinal slope.
- Increase the side slopes.
- Nest the biofilter within or around another BMP.

25.2.2 Check for Stability (minimizing erosion)

The stability check must be performed for the combination of highest expected flow and least vegetation coverage and height. A check is not required for biofiltration swales that are located "off-line" from the primary conveyance/detention system. Maintain the same units as in the biofiltration capacity analysis.

SC-1. Perform the stability check for the 100-year recurrence interval flow using 15-minute time steps using an approved continuous runoff model. If 15-minute time steps are not available, the designer can use the 100-year hourly peak flows multiplied by an adjustment factor of 1.6 to approximate peak flows in 15-minute time steps.

SC-2. Estimate the vegetation coverage ("good" or "fair") and height on the first occasion that the biofilter will receive flow, or whenever the coverage and height will be least. Avoid flow introduction during the vegetation establishment period by timing planting or bypassing.

SC-3. Estimate the degree of retardance from Table 25.2. When uncertain, be conservative by selecting a relatively low degree.

The maximum permissible velocity for erosion prevention (Vmax) is 3 feet per second.

Table 25.2. Guide for Selecting Degree of Retardance.[a]

Coverage	Average Grass Height (inches)	Degree of Retardance
Good	<2	E. Very Low
	2–6	D. Low
	6–10	C. Moderate
	11–24	B. High
	>30	A. Very High
Fair	<2	E. Very Low
	2–6	D. Low
	6–10	D. Low
	11–24	C. Moderate
	>30	B. High

[a] See Chow (1959). In addition, Chow recommended selection of retardance C for a grass-legume mixture 6–8 inches high and D for a mixture 4–5 inches high. No retardance recommendations have appeared for emergent wetland species. Therefore, judgment must be used. Since these species generally grow less densely than grasses, using a “fair” coverage would be a reasonable approach.

25.2.1 Stability Check (SC) Steps

SC-4. Select a trial Manning’s n for the high flow condition. The minimum value for poor vegetation cover and low height (possibly, knocked from the vertical by high flow) is 0.033. A good initial choice under these conditions is 0.04.

SC-5. Refer to Figure 25.7 to obtain a first approximation for VR (i.e., the product of velocity and hydraulic radius) of 3 feet per second.

SC-6. Compute hydraulic radius, R, from VR in Figure 25.7 and a Vmax.

SC-7. Use Manning’s equation to solve for the actual VR.

SC-8. Compare the actual VR from Step SC-7 and first approximation from Step SC-5. If they do not agree within 5 percent, repeat Steps SC-4 to SC-8 until acceptable agreement is reached. If n < 0.033 is needed to get agreement, set n = 0.033, repeat Step SC-7, and then proceed to Step SC-9.

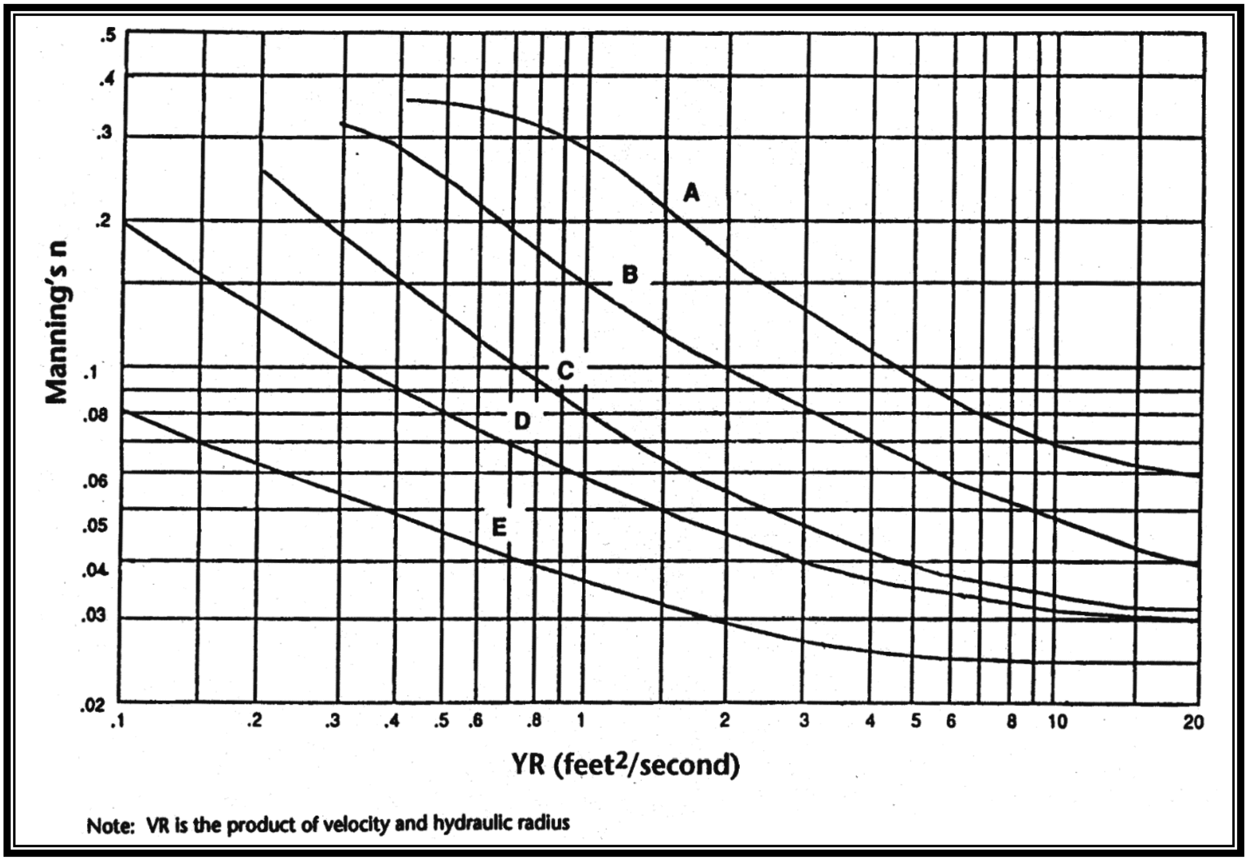
SC-9. Compute the actual V for the final design conditions:

Check to be sure $V < V_{max\ of\ 3\ ft/sec}$

SC-10. Compute the required swale cross-sectional area, A, for stability:

SC-11. Compare the A, computed in Step SC-10 of the stability analysis, with the A from the biofiltration capacity analysis (Step D-5).

If less area is required for stability than is provided for capacity, the capacity design is acceptable. If not, use A from Step SC-10 of the stability analysis and recalculate channel dimensions.



Source: Livingston, et al. 1984

Figure 25.7. The Relationship of Manning's n with VR for Various Degrees of Flow Retardance (A-E).

SC-12. Calculate the depth of flow at the stability check design flow rate condition for the final dimensions and use A from Step SC-10.

SC-13. Compare the depth from Step SC-12 to the depth used in the biofiltration capacity design (Step D-1). Use the larger of the two and add 0.5 feet of freeboard to obtain the total depth (yt) of the swale. Calculate the top width for the full depth using the appropriate equation.

SC-14. Recalculate the hydraulic radius: (use b from Step D-4 calculated previously for biofiltration capacity, or Step SC-11, as appropriate, and yt = total depth from Step SC-13).

SC-15. Make a final check for capacity based on the stability check design storm (this check will ensure that capacity is adequate if the largest expected event coincides with the greatest retardance). Use Equation 1, a Manning's n selected in Step D-2, and the calculated channel dimensions, including freeboard, to compute the flow capacity of the channel under these conditions. Use R from Step SC-14, above, and $A = b(yt) + Z(yt)^2$ using b from Step D-4, D-15, or SC-11 as appropriate.

If the flow capacity is less than the stability check design storm flow rate, increase the channel cross-sectional area as needed for this conveyance. Specify the new channel dimensions.

25.2.2 Completion Step (CO)

CO. Review all of the criteria and guidelines for biofilter planning, design, installation, and operation above and specify all of the appropriate features for the application.

25.2.3 Example of Design Calculations for Biofiltration Swales

Preliminary Steps

P-1. Assume that the continuous runoff model based water quality design flow rate in 15-minute time-steps, Q, is 0.2 cfs. Assume an on-line facility.

P-2. Assume the slope (s) is 2 percent.

P-3. Assume the vegetation will be a grass-legume mixture and it will be infrequently mowed.

Design for Biofiltration Swale Capacity

D-1. Set winter grass height at 5 inches and the design flow depth (y) at 3 inches.

D-2. Use $n = 0.20$ to $n_2 = 0.30$

D-3. Base the design on a trapezoidal shape, with a side slope $Z = 3$.

D-4a. Calculate the bottom width, b;

Where:

$n = 0.20$ $y = 0.25$ foot

$Q = 0.2$ cfs $s = 0.02$

$Z = 3$

$$b \approx \frac{2.5Qn}{1.49y^{1.67}s^{0.5}} - Zy$$

$b \approx 4.0$ ft

At n_2; $b_2 = 6.5$ feet

D-4b. Calculate the top width (T)

$$T = b + 2yZ = 4.0 + [2(0.25)(3)] = 5.5 \text{ feet}$$

D-5. Calculate the cross-sectional area (A)

$$A = by + Zy^2 = (4.0)(0.25) + (3)(0.25^2) = 1.19 \text{ ft}^2$$

D-6. Calculate the flow velocity (V)

$$V = K\frac{Q}{A} = 0.17 \text{ ft / sec}$$

for K = 1. Actual K is determined per Figure 25.6a

$0.17 < 1.0$ ft/sec $\therefore$ OK

D-7. Calculate the Length (L)

L = Vt (60 sec/min)

= 0.17 (9)(60)

For t = 9 min, L = 92 feet at n; expand to a minimum of 100-foot length per design criterion

At n_2; L = 100 feet

Note: Where b is less than the maximum value, it may be possible to reduce L by increasing b, so long as the minimum length (L) is never less than 100 ft.

25.2.4 Check for Channel Stability

SC-1. Base the check on passing the 100-year recurrence interval flow (using 15-minute time steps) through a swale with a mixture of Kentucky bluegrass and tall fescue on loose erodible soil.

SC-2. Base the check on a grass height of 3 inches with “fair” coverage (lowest mowed height and least cover, assuming flow bypasses or does not occur during grass establishment).

SC-3. From Table 25.2, Degree of Retardance = D (low)

Set V_{max} = 3 ft/sec

SC-4. Select trial Manning’s n = 0.04

SC-5. From Figure 25.7, VR_{appx} = 3 ft²/s

SC-6. Calculate R

$$R = \frac{VR_{appx}}{V_{max}} = 1.0 \text{ foot}$$

SC-7. Calculate VR_{actual}

$$VR_{actual} = \frac{1.49}{n} R^{1.67} s^{0.5} = 5.25 \text{ ft}^2 / \text{sec}$$

SC-8. VR_{actual} from Step SC-7 > VR_{appx} from Step SC-5 by > 5 percent.

Select new trial n = 0.0475

Figure 25.7: VR_{appx} = 1.7 ft²/s

R = 0.57 ft.

VR_{actual} = 1.73 ft²/s (within 5 percent of VR_{appx} = 1.7)

SC-9. Calculate V

$$V = \frac{VR_{actual}}{R} = \frac{1.73}{0.57} = 3 \text{ ft} / \text{sec}$$

V = 3 ft/sec ≤ 3 ft/sec, Vmax ∴ OK

SC-10. Calculate Stability Area

$$A_{Stability} = \frac{Q}{V} = \frac{1.92}{3} = 0.64 \text{ ft}^2$$

SC-11. Stability Check

$A_{Stability}$ = 0.64 ft² is less than $A_{Capacity}$ from Step D-5 ($A_{Capacity}$ = 1.19 ft²). ∴OK

If $A_{Stability} > A_{Capacity}$, it will be necessary to select new trial sizes for width and flow depth (based on space and other considerations), recalculate $A_{Capacity}$, and repeat steps SC-10 and SC-11.

SC-12. Calculate depth of flow at the stability design flow rate condition using the quadratic equation solution:

$$y = \frac{-b \pm \sqrt{b^2 - 4Z(-A)}}{2Z}$$

For b = 4, y = 0.14 foot (positive root)

SC-13. Use the greater value of y from SC-12 or that assumed in D-1. In this case, the greater depth is 0.25 foot, which was the basis for the biofiltration capacity design. Add 0.5 foot of freeboard to that depth.

Total channel depth = 0.75 foot

Top Width = b + 2yZ

= 4 + (2)(0.75)(3)

= 8.5 feet

SC-14. Recalculate hydraulic radius and flow rate

For b = 4 ft, y = 0.75 foot

Z = 3, s = 0.02, n = 0.2

$A = by + Zy^2 = 4.68\ ft^2$

$R = \{by + Zy^2\}/\{b + 2y(Z^2 + 1)^{0.5}\} = 0.53$ foot

SC-15. Calculate Flow Capacity at Greatest Resistance

$$Q = \frac{1.49AR^{0.67}s^{0.5}}{n} = 3.2 \text{ cfs}$$

$Q = 3.2 \text{ cfs} > 1.92 \text{ cfs} \therefore$ OK

Completion Step

CO-1. Assume 100 feet of swale length is available.

The final channel dimensions are:

Bottom width, b = 4 feet

Channel depth = 0.75 foot

Top width = b + 2yZ = 8.5 feet

No check dams are needed for a 2 percent slope.

25.2.5 Soil Criteria

- The following topsoil mix at least 8 inches deep:
  - Sandy loam 60–90 percent.
  - Clay 0–10 percent.
  - Composted organic matter 10–30 percent (excluding animal waste, toxics).

- Use compost-amended soil where practicable. Composted material shall meet the specifications for compost used in the bioretention soil mix (see Chapter 9). Note that this excludes the use of biosolids and manures.

- Till to a depth of at least 8 inches.

- For longitudinal slopes of less than 2 percent use more sand to obtain more infiltration.

- If groundwater contamination is a concern, seal the bed with a treatment liner (see Appendix V-E).

25.2.6 Vegetation Criteria

- See Tables 25.3, 25.4, and 25.5 for recommended grasses, wetland plants, and groundcovers. <u>The following invasive species shall not be used</u>: *Phalaris arundinacea* (reed canarygrass), *Lythrum salicaria* (purple loosestrife), *Phragmites* spp. (reeds), *Iris pseudacoru*s (yellow iris) and cattails (*Typha* spp.).

- Select fine, turf-forming, water-resistant grasses where vegetative growth and moisture will be adequate for growth.

- Irrigate if moisture is insufficient during dry weather season.

- Use sod with low clay content and where needed to initiate adequate vegetative growth. Preferably, sod should be laid to a minimum of 1-foot vertical depth above the swale bottom.

25.2.7 Recommended Grasses (see Tables 25.3 and 25.4 below)

- Consider sun/shade conditions for adequate vegetative growth and avoid prolonged shading of any portion not planted with shade tolerant vegetation.

- The seed mix in Table 25.3 is suitable for the bottom of the swale and the dry side slopes, and rates are provided as pounds of pure live seed per acre.

- Table 25.4 provides alternative groundcovers and grass species options for dry side slopes. The seed mix in Volume II, Table 3.3 is another low-growing grass option for side slopes.

- Stabilize soil areas upslope of the biofilter to prevent erosion.

  Fertilizing a biofilter should be avoided if at all possible in any application where nutrient control is an objective. Test the soil for nitrogen, phosphorous, and potassium and consult with a landscape professional about the need for fertilizer in relation to soil nutrition and vegetation requirements. If use of a fertilizer cannot be avoided, use a slow-release fertilizer formulation in the least amount needed.

Table 25.3. Bioswale Seed Mix.

Common Name	Species	Percent Species Composition	Desired Seeds Per Square Foot	Pounds Pure Live Seed per Acre
American sloughgrass	*Beckmannia syzigachne*	15	23	0.9
Tufted hairgrass	*Deschampsia cespitosa*	20	30	0.5
Blue wildrye	*Elymus glaucus*	18	27	10.7
Native red fescue	*Festuca rubra* var. *rubra*	20	30	2.6
Meadow barley	*Hordeum brachyantherum*	12	18	9.2
Northwestern mannagrass	*Glyceria occidentalis*	15	23	4.9
Total			**151**	**28.8**

Table 25.4. Groundcovers and Grasses Suitable for the Upper Side Slopes of a Biofiltration Swale in Western Washington.

Groundcovers	
Kinnikinnick	*Arctostaphylos uva-ursi*
Strawberry	*Fragaria chiloensis*
Broadleaf lupine	*Lupinus latifolius*
Grasses (drought-tolerant, minimum mowing)	
Dwarf tall fescues	*Festuca* spp. (e.g., Many Mustang, Silverado)
Hard fescue	*Festuca ovina duriuscula* (e.g., Reliant, Aurora)
Tufted fescue	*Festuca amethystine*
Buffalo grass	*Buchloe dactyloides*
Red fescue	*Festuca rubra*
Tall fescue grass	*Festuca arundinacea*
Blue oatgrass	*Helictotrichon sempervirens*

Table 25.6. Recommended Plants for Wet Biofiltration Swale.

Common Name	Scientific Name	Spacing (on center)
Shortawn foxtail	*Alopecuris aequalis*	seed
Water foxtail	*Alopecuris geniculatus*	seed
Spike rush	*Eleocharis* spp.	4 inches
Slough sedge[a]	*Carex obnupta*	6 inches or seed
Sawbeak sedge	*Carex stipata*	6 inches
Sedge	*Carex* spp.	6 inches
Western mannagrass	*Glyceria occidentalis*	seed
Velvetgrass	*Holcus mollis*	seed
Slender rush	*Juncus tenuis*	6 inches
Watercress[a]	*Rorippa nasturtium-aquaticum*	12 inches
Water parsley[a]	*Oenanthe sarmentosa*	6 inches
Hardstem bulrush	*Scirpus acutus*	6 inches
Small-fruited bulrush	*Scirpus microcarpus*	12 inches

[a] Good choices for swales with significant periods of flow, such as those downstream of a detention facility.

Note: Cattail (*Typha latifolia*) is not appropriate for most wet swales because of its very dense and clumping growth habit, which prevents water from filtering through the clump.

25.2.1 Construction Criteria

The biofiltration swale shall not be put 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 shall remain in place until the swale vegetation is established (see Volume II for erosion and sediment control BMPs). Avoid compaction during construction. Grade biofilters to attain uniform longitudinal and lateral slopes.

25.2.2 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

25.3 Wet Biofiltration Swale (Ecology BMP T9.20)

A *wet biofiltration swale* is a variation of a basic biofiltration swale for use where the longitudinal slope is slight, water tables are high, or continuous low base flow is likely to result in saturated soil conditions. Where saturation exceeds about 2 weeks, typical grasses will die. Thus, vegetation specifically adapted to saturated soil conditions is needed. Different vegetation in turn requires modification of several of the design parameters for the basic biofiltration swale.

25.3.1 Performance Objectives

To remove low concentrations of pollutants such as total suspended solids, heavy metals, nutrients, and petroleum hydrocarbons.

25.3.2 Applications and Limitations

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 or base flows on the site.
- Longitudinal slopes are slight (generally less than 2 percent).

25.3.3 Wet Biofiltration Swale Design Criteria

Use the same design approach as for basic biofiltration swales except to add the following:

Adjust for Extended Wet Season Flow

If the swale will be downstream of a detention pond providing flow control, multiply the treatment area (bottom width times length) of the swale by 2, and readjust the swale length, if desired. Maintain a 5:1 length to width ratio.

Intent**:** An increase in the treatment area of swales following detention ponds is required because of the differences in vegetation established in a constant flow environment. Flows following detention are much more prolonged. These prolonged flows result in more stream-like conditions than are typical for other wet biofilter situations. Since vegetation growing in streams is often less dense, this increase in treatment area is needed to ensure that equivalent pollutant removal is achieved in extended flow situations.

Swale Geometry

Same as specified for basic biofiltration swales except for the following modifications.

- ***Criterion 1:*** The bottom width may be increased to 25 feet maximum, but a minimum length-to-width ratio of 5:1 must be provided. No longitudinal dividing berm is needed. (**Note:** The minimum swale length is still 100 feet.)
- ***Criterion 2:*** If longitudinal slopes are greater than 2 percent, the wet swale must be stepped so that the slope within the stepped sections averages 2 percent. Steps may be made of retaining walls, log check dams, or short riprap sections. **No underdrain or low-flow drain is required.**

High-Flow Bypass

A high-flow bypass (i.e., an off-line design) is required for flows greater than the off-line water quality design flow that has been increased by the ratio indicated in Figure 25.6b. The bypass is necessary to protect wetland vegetation from damage. Unlike grass, wetland vegetation will not quickly regain an upright attitude after being laid down by high flows. New growth, usually from the base of the plant, often taking several weeks, is required to regain its upright form. The bypass may be an open channel parallel to the wet biofiltration swale.

Water Depth and Base Flow

Same as for basic biofiltration swales except the design water depth shall be 4 inches for all wetland vegetation selections, and **no underdrains or low-flow drains are required**.

Flow Velocity, Energy Dissipation, and Flow Spreading

Same as for basic biofiltration swales except no flow spreader is needed.

Access

Same as for basic biofiltration swales except access is only required to the inflow and the outflow of the swale; access along the length of the swale is not required. Also, wheel strips may not be used for access in the swale.

<u>Intent</u>**:** An access road is not required along the length of a wet swale because of infrequent access needs. Frequent mowing or harvesting is not desirable. In addition, wetland plants are fairly resilient to sediment-induced changes in water depth, so the need for access should be infrequent.

Soil Amendment

Same as for basic biofiltration swales.

Planting Requirements

Same as for basic biofiltration swales except for the following modifications:

- A list of acceptable plants and recommended spacing is shown in Table 25.5. In general, it is best to plant several species to increase the likelihood that at least some of the selected species will find growing conditions favorable.

- A wetland seed mix may be applied by hydroseeding, but if coverage is poor, planting of rootstock or nursery stock is required. Poor coverage is considered to be more than 30 percent bare area through the upper two-thirds of the swale after 4 weeks.

- Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the city through submittal of a pesticide-use plan.

Recommended Design Features

Same as for basic biofiltration swales.

Construction Criteria

Same as for basic biofiltration swales.

Operations and Maintenance Criteria

Same as for basic biofiltration swales.

25.4 Continuous Inflow Biofiltration Swale (Ecology BMP T9.30)

In situations where water enters a biofiltration swale continuously along the side slope rather than discretely at the head, a different design approach—the continuous inflow biofiltration swale—is needed. The basic swale design is modified by increasing swale length to achieve an equivalent average residence time.

25.4.1 Applications and Limitations

A continuous inflow biofiltration swale is to be **used when inflows are not concentrated**, such as locations along the shoulder of a road without curbs. This design may also be **used where frequent, small point flows enter a swale**, such as through curb inlet ports spaced at intervals along a road, or from a parking lot with frequent curb cuts. In general, no inlet port should carry more than about 10 percent of the flow.

A continuous inflow swale is not appropriate for a situation in which significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale width and length must be recalculated from the point of confluence to the swale outlet in order to provide adequate treatment for the increased flows.

25.4.2 Continuous Inflow Biofiltration Swale Design Criteria

Same as specified for **basic biofiltration swale** except for the following.

- The design flow for continuous inflow swales must include runoff from the pervious side slopes draining to the swale along the entire swale length. Therefore, they must be on-line facilities.

- If only a single design flow is used, the flow rate at the outlet shall be used. The goal is to achieve an average residence time through the swale of 9 minutes as calculated using the on-line water quality design flow rate multiplied by the ratio, K, in Figure 25.6a. Assuming an even distribution of inflow into the side of the swale double the hydraulic residence time to a minimum of 18 minutes.

- For continuous inflow biofiltration swales, interior side slopes above the water quality design treatment elevation shall be planted in grass. A typical lawn seed mix or the biofiltration seed mixes are acceptable. Landscape plants or groundcovers other than grass may not be used anywhere between the runoff inflow elevation and the bottom of the swale.

  Intent: The use of grass on interior side slopes reduces the chance of soil erosion and transfer of pollutants from landscape areas to the biofiltration treatment area.

25.4.3 Construction Criteria

Same as for basic biofiltration swales.

25.4.4 Operations and Maintenance Criteria

Same as for basic biofiltration swales.

25.5 Basic Filter Strip (Ecology BMP T9.40)

A basic filter strip is flat with no side slopes (Figure 25.8). Contaminated stormwater is distributed as sheet flow across the inlet width of a biofilter strip. Treatment is by passage of water over the surface, and through grass.

25.5.1 Applications and Limitations

The basic filter strip is typically used on-line and adjacent and parallel to a paved area such as parking lots, driveways, and roadways.

25.5.2 Filter Strip Design Criteria

- Use the design criteria specified in Table 24.3.
- If groundwater contamination is a concern, seal the bed with a treatment liner (see Appendix V-E).
- Filter strips must only receive sheet flow.
- For roadways with curbs, use curb cuts ≥ 12-inch wide and 1-inch above the filter strip inlet. Curb cuts shall be spaced at 10 feet, maximum.

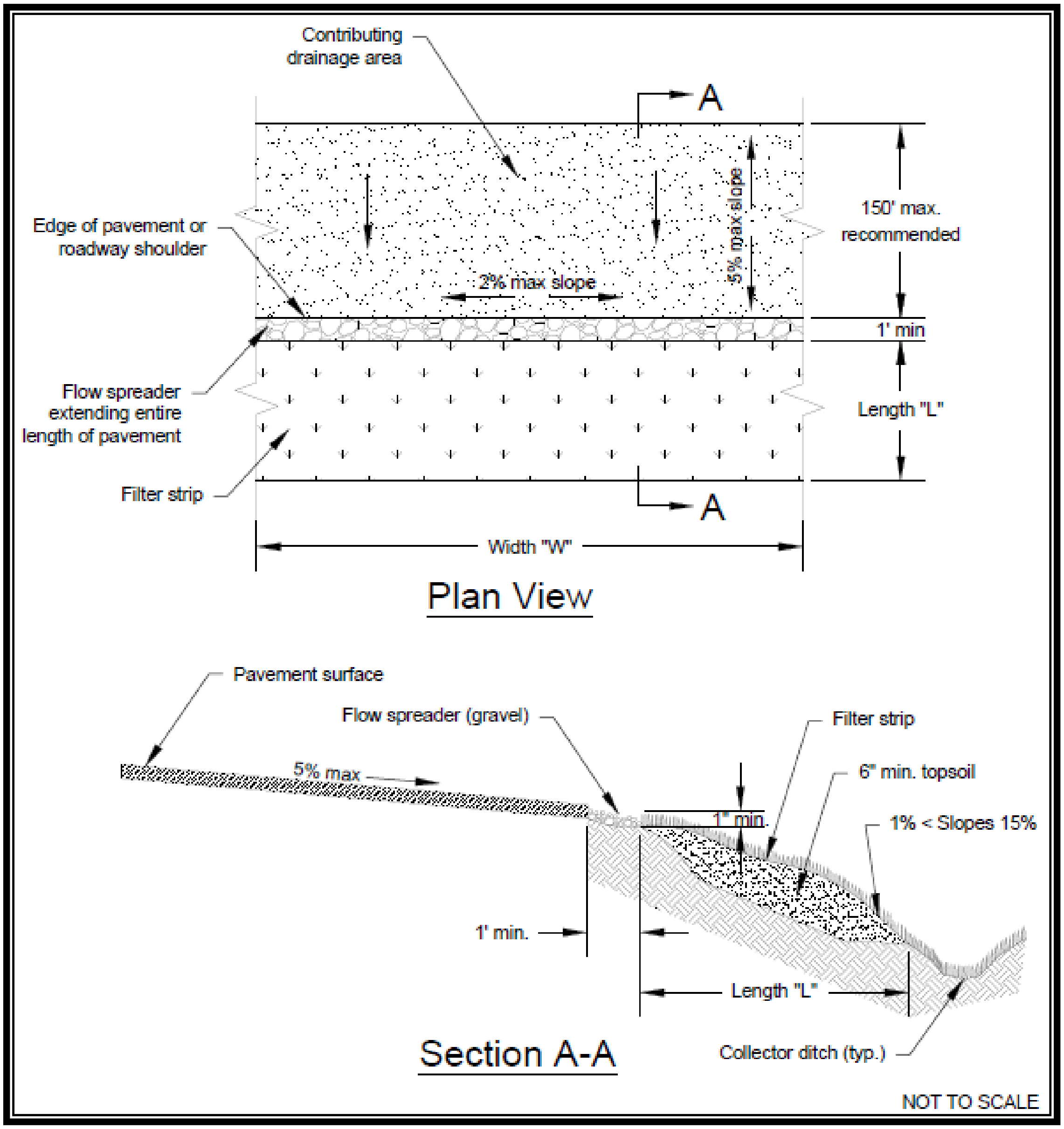


Figure 25.8. Typical Filter Strip.

Calculate the design flow depth using Manning's equation as follows:

$$KQ = (1.49AR^{0.67}\ s^{0.5})/n$$

Substituting for AR:

$$KQ = (1.49Ty^{1.67}\ s^{0.5})/n$$

Where:

$Ty = A_{rectangle,\ ft^2}$

$y \approx R_{rectangle}$, design depth of flow, feet. (1 inch maximum)

Q = peak water quality design flow rate based on an approved continuous runoff model, ft^3/sec

K = The ratio determined by using Figure 25.6a

n = Manning's roughness coefficient

s = Longitudinal slope of filter strip parallel to direction of flow

T = Width of filter strip perpendicular to the direction of flow, feet

A = Filter strip inlet cross-sectional flow area (rectangular), ft^2

R = hydraulic radius, feet

Rearranging for y:

$y = [KQn/1.49Ts^{0.5}]^{0.6}$

y must not exceed 1 inch

Note: As in swale design an adjustment factor of K accounts for the differential between the continuous runoff model water quality design flow rate and the SBUH design flow.

Calculate the design flow velocity V, ft/sec, through the filter strip:

$$V = KQ/Ty$$

V must not exceed 0.5 ft/sec

Calculate required length, in feet, of the filter strip at the minimum hydraulic residence time, t, of 9 minutes:

$$L = tV = 540V$$

25.5.3 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 2.4.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

Chapter 26 – Wet Pool Facilities

Note: Figures in Chapter 26 are from the King County Surface Water Management, Design Manual (2015).

26.1 Purpose

This section presents the methods, criteria, and details for analysis and design of wet ponds, wet vaults, and stormwater wetlands. These facilities have as a common element a permanent pool of water—the wet pool. Each of the wet pool facilities can be combined with a detention or flow control pond in a combined facility. This section addresses four BMPs that are classified as wet pool facilities:

- Wet Ponds, Basic and Large
- Wet Vaults
- Stormwater Treatment Wetlands
- Combined Detention and Wet Pool Facilities

26.2 Applications

The wet pool facility designs described for the four BMPs in this section will achieve the performance objectives cited in Volume I, Section 4.3 for specific treatment menus.

26.3 Best Management Practices for Wet Pool Facilities

26.3.1 Wet Ponds – Basic and Large (Ecology BMP T10.10)

A wet pond is a constructed stormwater pond that retains a permanent pool of water (“wet pool”) at least during the wet season. The volume of the wet pool is related to the effectiveness of the pond in settling particulate pollutants. 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 a “live storage” area above the permanent pool. Figures 26.1a and 26.1b illustrate a typical wet pond BMP.

The following design criteria cover two wet pond applications—the basic wet pond and the large wet pond. Large wet ponds are designed for higher levels of pollutant removal. As with other similar BMPs, wet ponds may be used as sedimentation ponds during construction. However, any sediment that has accumulated in the pond must be removed after construction is complete and before the pond is permanently on-line.

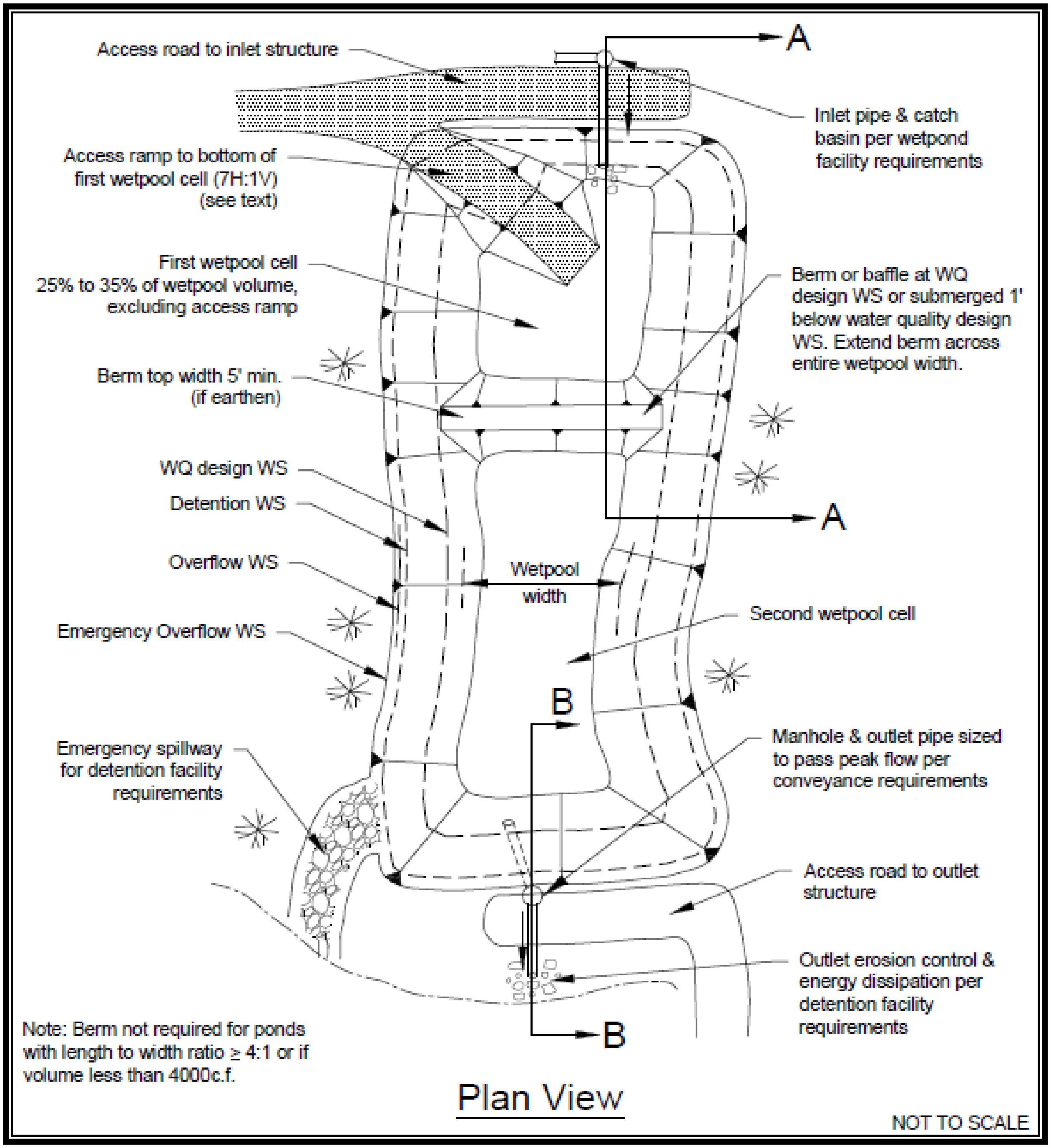


Figure 26.1a. Wet Pond.

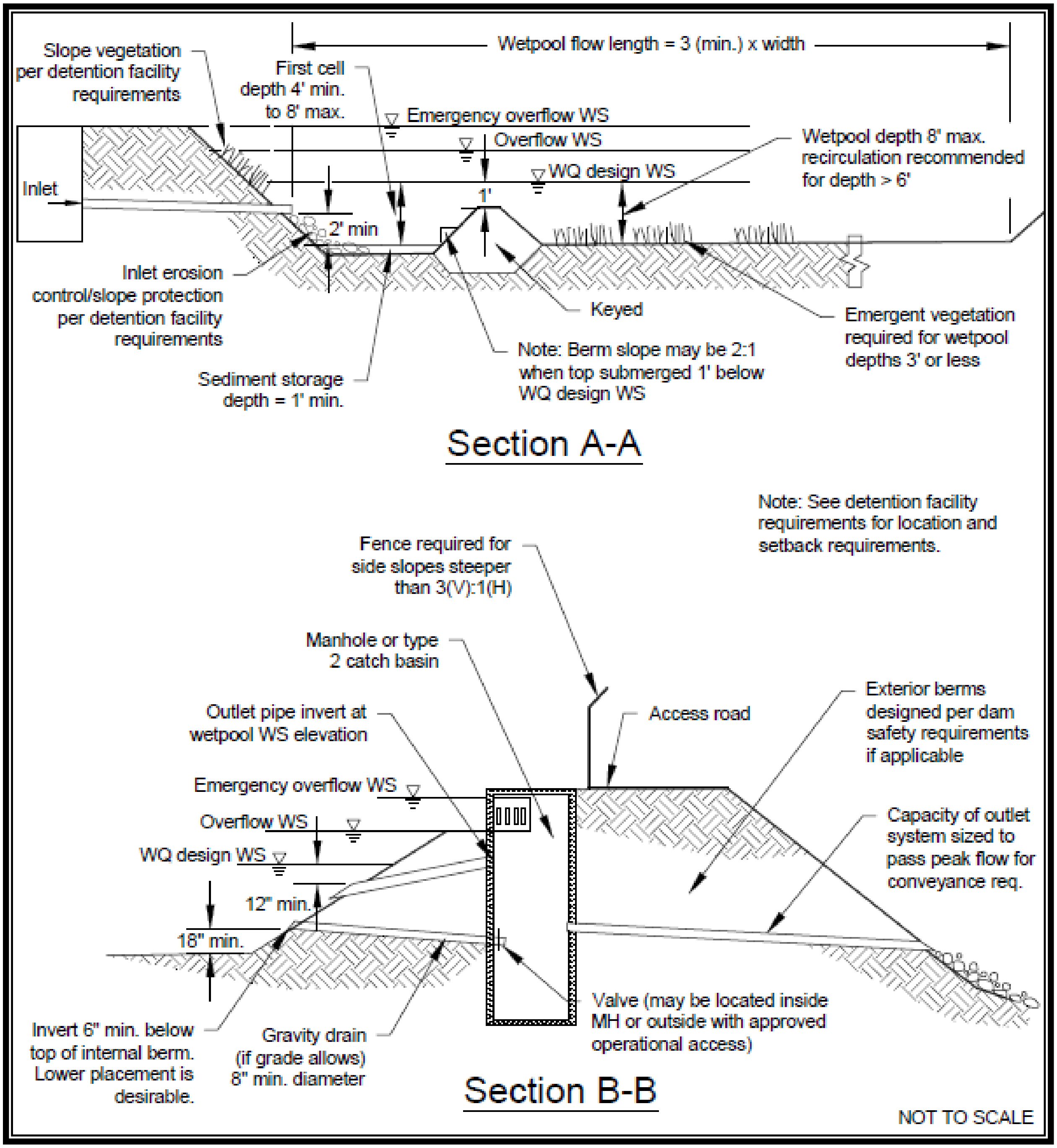


Figure 26.1b. Wet Pond

26.3.1 Applications and Limitations

A wet pond requires a larger area than a biofiltration swale, but it can be integrated to the contours of a site fairly easily. Wet ponds are designed to hold a permanent pool of water; therefore, the first cell of the wet pond must be lined with a treatment liner or low permeability liner (see Appendix V-E). Although high groundwater levels must be avoided for most stormwater facilities (due to buoyancy concerns), the standing water in a wet pond will neutralize any buoyancy effects from high groundwater. Thus, 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 known or seasonal high groundwater level.

Wet ponds may be single-purpose facilities, providing only runoff treatment, or they may be combined with a detention pond to also provide flow control. If combined, the wet pond can often be stacked under the detention pond with little further loss of development area. See Section 26.6, Combined Detention and Wet Pool Facilities (Ecology BMP T10.40), for a description of combined detention and wet pool facilities.

26.3.2 Wet Pond Design Criteria

The primary design factor that determines a wet pond's treatment efficiency is the volume of the wet pool. The larger the wet pool volume, the greater the potential for pollutant removal. For a basic wet pond, the wet pool volume provided shall be equal to or greater than the water quality design storm volume. **This volume is equal to the simulated daily volume that represents the upper limit of the range of daily volumes that accounts for 91 percent of the entire runoff volume over a multi-decade period of record.** WWHM identify this volume for the user.

A large wet pond requires a wet pool volume at least 1.5 times larger than the water quality design storm volume. Also important are the avoidance of short-circuiting and the promotion of plug flow. ***Plug flow*** describes the hypothetical condition of stormwater moving through the pond as a unit, displacing the "old" water in the pond with incoming flows. To prevent short-circuiting, water is forced to flow, to the extent practical, to all potentially available flow routes, avoiding "dead zones" and maximizing the time water stays in the pond during the active part of a storm.

Design features that encourage plug flow and avoid dead zones are:

- Dissipating energy at the inlet
- Providing a large length-to-width ratio
- Providing a broad surface for water exchange using a berm designed as a broad-crested weir to divide the wet pond into two cells rather than a constricted area such as a pipe
- Maximizing the flowpath between inlet and outlet, including the vertical path, also enhances treatment by increasing residence time.

Sizing Procedure

Procedures for determining a wet pond's dimensions and volume are outlined below.

Step 1: Identify required wet pool volume using an approved continuous runoff model (See water quality design storm volume calculation in Volume III). A large wet pond requires a volume at least 1.5 times the water quality design storm volume.

Step 2: Determine wet pool dimensions. Determine the wet pool dimensions satisfying the design criteria outlined below and illustrated in Figures 26.1a and 26.1b. A simple way to check the volume of each wet pool cell is to use the following equation:

$$V = \frac{h(A_1 + A_2)}{2}$$

Where V = wet pool volume (ft^3)

h = wet pool average depth (feet)

A_1 = water quality design surface area of wet pool (ft^2)

A_2 = bottom area of wet pool (ft^2)

Step 3: Design pond outlet pipe and determine primary overflow water surface. The pond outlet pipe shall be placed on a reverse grade from the pond's wet pool to the outlet structure. Use the following procedure to design the pond outlet pipe and determine the primary overflow water surface elevation:

- Use the nomographs in Appendix III-C, to select a trial size for the pond outlet pipe sufficient to pass the on-line water quality design flow, Q_{wq} indicated by an approved continuous runoff model.
- Use the nomographs in Appendix III-C, to determine the critical depth d_c at the outflow end of the pipe for Q_{wq}.
- Use the nomographs in Appendix III-C, to determine the flow area A_c at critical depth.
- Calculate the flow velocity at critical depth using continuity equation ($V_c = Q_{wq} / A_c$).
- Calculate the velocity head V_H ($V_H = V_c^2 / 2g$, where g is the gravitational constant, 32.2 ft/sec).
- Determine the primary overflow water surface elevation by adding the velocity head and critical depth to the invert elevation at the outflow end of the pond outlet pipe (i.e., overflow water surface elevation = outflow invert + d_c + V_H).
- Adjust outlet pipe diameter as needed and repeat steps (a) through (e).

Step 4: Determine wet pond dimensions. General wet pond design criteria and concepts are shown in Figures 26.1a and 26.1b.

Wet Pool Geometry

- The wet pool shall be divided into two cells separated by a baffle or berm. The first cell shall contain between 25 to 35 percent of the total wet pool volume. Both cells must have level pond bottoms.

- The baffle or berm volume shall not count as part of the total wet pool volume. The term baffle means 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.

  Intent: 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 of Tumwater.

- Sediment storage shall be provided in the first cell. The sediment storage shall have a minimum depth of 1 foot. A fixed sediment depth monitor should be installed in the first cell to gauge sediment accumulation unless an alternative gauging method is proposed.

- The minimum depth of the first cell shall be 4 feet, exclusive of sediment storage requirements. The depth of the first cell may be greater than the depth of the second cell.

- The maximum depth of each cell shall not exceed 8 feet (exclusive of sediment storage in the first cell). Pool depths of 3 feet or shallower (second cell) shall be planted with emergent wetland vegetation (see Planting requirements).

- Inlets and outlets shall be placed to maximize the flowpath through the facility. The ratio of flowpath length to width from the inlet to the outlet shall be at least 3:1. The ***flowpath length*** is defined as the distance from the inlet to the outlet, as measured at mid-depth. The ***width*** at mid-depth can be found 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 flowpath length be maximized. The ratio of flowpath length to width shall be at least 4:1 in single celled wet ponds, but should preferably be 5:1.

- All inlets shall enter the first cell. If there are multiple inlets, the length-to-width ratio shall be based on the average flowpath length for all inlets.

- The wet pool cells shall be lined per the liner requirements outlined in Appendix V-E.

Berms, Baffles, and Slopes

- A berm or baffle shall extend across the full width of the wet pool, and tie into the wet pond side slopes. If the berm embankments are greater than 4 feet in height, the berm must be constructed by excavating a key equal to 50 percent of the embankment cross-sectional height and width. This requirement may be waived if recommended by a geotechnical engineer for specific site conditions. The geotechnical analysis shall address situations in which one of the two cells is empty while the other remains full of water.

- The top of the berm may extend to the water quality design water surface or be 1 foot below the water quality design water surface. If at the water quality design water surface, berm side slopes should be 3H:1V. Berm side slopes may be steeper (up to 2:1) if the berm is submerged 1 foot.

  Intent: Submerging the berm is intended to enhance safety by discouraging pedestrian access when side slopes are steeper than 3H:1V. An alternative to the submerged berm design is the use of barrier planting to prevent easy access to the divider berm in an unfenced wet pond.

- If good vegetation cover is not established on the berm, erosion control measures must be used to prevent erosion of the berm back-slope when the pond is initially filled.

- The interior berm or baffle may be a retaining wall provided that the design is prepared and stamped by a licensed civil engineer. If a baffle or retaining wall is used, it should be submerged 1 foot below the design water surface to discourage access by pedestrians.

- Note that wet ponds can also be designed include oil containment booms at locations where oil control is required. Design guidelines for oil containment booms are not included in this chapter, but can be found in the 2014 WSDOT Highway Runoff Manual, Chapter 5, BMP RT.22.

- Requirements for wet pond side slopes are the same as for detention ponds (see Chapter 18).

Embankments

Embankments that impound water must comply with the Washington State Dam Safety Regulations (Chapter 173-175 WAC). If the impoundment has a storage capacity (including both water and sediment storage volumes) greater than 10 acre-feet (435,600 cubic feet or 3.26 million gallons) above natural ground level, then dam safety design and review are required by Ecology. See Chapter 18 for additional requirements.

Inlet and Outlet

See Figures 26.1a and 26.1b for details on the following requirements:

- The inlet to the wet pond shall be submerged with the inlet pipe invert a minimum of 2 feet from the pond bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible. Conveyance modeling for the stormwater system leading to the wet pond must be shown to include consideration of the backwater effects of the submerged inlet.

  Intent: The inlet is submerged to dissipate energy of the incoming flow. The distance from the bottom is set to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

- The runoff shall be discharged uniformly and at a velocity below 3 feet per second in Type A and B soils, and 5 feet per second in Type C and D soils or as necessary to prevent erosion and to ensure quiescent conditions within the BMP.

- An overflow structure shall be provided. Either a Type 2 catch basin with a grated opening (jailhouse window) or a manhole with a cone grate (birdcage) may be used (see Figure 18.3 for an illustration). The overflow structure receives flow from the pond outlet pipe. The grate or birdcage openings provide an overflow route should the pond outlet pipe become clogged. The overflow criteria provided below specifies the sizing and position of the grate opening.

- The pond outlet pipe (as opposed to the manhole or Type 2 catch basin outlet pipe) shall be back-sloped or have a turn-down elbow, and extend 1 foot below the water quality design water surface. **Note:** A floating outlet, set to draw water from 1 foot below the water surface, is also acceptable if vandalism concerns are adequately addressed.

  Intent: The inverted outlet pipe provides for trapping of oils and floatables in the wet pond.

- The pond outlet pipe shall be sized, at a minimum, to pass the on-line water quality design flow. **Note:** The highest invert of the outlet pipe sets the water quality design water surface elevation.

- The overflow criteria for single-purpose (treatment only, not combined with flow control) wet ponds are as follows.

  - The requirement for primary overflow is satisfied by either the grated inlet to the outlet structure or by a birdcage above the pond outlet structure.

  - The bottom of the grate opening in the outlet structure shall be set at or above the height needed to pass the water quality design flow through the pond outlet pipe. **Note:** The grate invert elevation sets the overflow water surface elevation.

  - The grated opening shall be sized to pass the 100-year recurrence interval design flow. The capacity of the outlet system shall be sized to pass the peak flow for the conveyance requirements.

- An emergency spillway shall be provided and designed according to the requirements for detention ponds (see Chapter 18).

- The city may require a bypass/shutoff valve to enable the pond to be taken off-line for maintenance purposes.

- A gravity drain for maintenance is required where feasible. The engineer must demonstrate why a drain is not feasible and show in the Maintenance and Source Control Manual how to drain the pond.

  Intent: It is anticipated that sediment removal will only be needed for the first cell in the majority of cases. The gravity drain is intended to allow water from the first cell to be drained to the second cell when the first cell is pumped dry for cleaning.

- The drain invert shall be at least 6 inches below the top elevation of the dividing berm or baffle. Deeper drains are encouraged where feasible, but must be no deeper than 18 inches above the pond bottom.

  Intent: To prevent highly sediment-laden water from escaping the pond when drained for maintenance.

- The drain shall be at least 8 inches (minimum) diameter and shall be controlled by a valve. Use of a shear gate is allowed only at the inlet end of a pipe located within an approved structure.

  Intent: Shear gates often leak if water pressure pushes on the side of the gate opposite the seal. The gate must be situated so that water pressure pushes toward the seal.

- Operational access to the valve shall be provided to the finished ground surface.

- The valve location shall be accessible and well-marked with 1 foot of paving placed around the box. It must also be protected from damage and unauthorized operation.

- A valve box is allowed to a maximum depth of 5 feet without an access manhole. If over 5 feet deep, an access manhole or vault is required.

- All metal parts shall be corrosion-resistant. Galvanized materials should not be used unless unavoidable.

  Intent: Galvanized metal contributes zinc to stormwater, sometimes in very high concentrations.

Access and Setbacks

- All facilities shall be a minimum of 20 feet from any structure, property line, and any vegetative buffer required by the City of Tumwater, and 100 feet from any septic tank/drainfield.

- All facilities shall be a minimum of 50 feet from any steep (greater than 15 percent) slope. A geotechnical assessment must address the potential impact of a wet pond on a steep slope.

- Access and maintenance roads shall be provided and designed according to the requirements for detention ponds (see Chapter 18). Access and maintenance roads shall extend to both the wet pond inlet and outlet structures. An access ramp shall be provided to the bottom of all cells, unless a trackhoe (maximum reach of 20 feet) can reach all portions of the cell and can load a truck parked at the pond edge or on the internal berm of a wet pond or combined pond.

- Fencing shall be provided where required based on slope or presence of walls (see Chapter 18) and designed according to the requirements for detention ponds (see Chapter 18).

- If the dividing berm is also used for access, it should be built to sustain loads of up to 80,000 pounds.

Signage

- See the signage requirements in Chapter 18 for wet pond sign requirements.

Planting Requirements

Planting requirements for detention ponds also apply to wet ponds.

- Large wet ponds intended for phosphorus control should not be planted within the cells, as the plants will release phosphorus in the winter when they die off.

- If the second cell of a basic wet pond is 3 feet or shallower, the bottom area shall be planted with emergent wetland vegetation. See Table 26.1 for recommended emergent wetland plant species for wet ponds.

  <u>Intent</u>: Planting of shallow pond areas helps to stabilize settled sediment and prevent resuspension.

- Cattails (*Typha latifolia*) are not recommended because they tend to crowd out other species and will typically establish themselves anyway.

- If the wet pond discharges to a lake or wetland, shrubs that form a dense cover should be planted on slopes above the water quality design water surface on at least three sides. For banks that are berms, no planting is allowed if the berm is regulated by dam safety requirements. The purpose of planting is to discourage waterfowl use of the pond and to provide shading. Some suitable trees and shrubs include vine maple (*Acer circinatum*), wild cherry (*Prunus emarginata*), red osier dogwood (*Cornus stolonifera*), California myrtle (*Myrica californica*), Indian plum (*Oemleria cerasiformis*), and Pacific yew (*Taxus brevifolia*) as well as numerous ornamental species.

Table 26.1. Emergent Wetland Plant Species Recommended for Wet Ponds.

Species	Common Name	Notes	Maximum Depth
Agrostis exarata[a]	Spike bent grass	Prairie to coast	to 2 feet
Carex stipata	Sawbeak sedge	Wet ground	
Eleocharis palustris	Spike rush	Margins of ponds, wet meadows	to 2 feet
Glyceria occidentalis	Western mannagrass	Marshes, pond margins	to 2 feet
Juncus tenuis	Slender rush	Wet soils, wetland margins	
Oenanthe sarmentosa	Water parsley	Shallow water along stream and pond margins; needs saturated soils all summer	
Scirpus atrocinctus (formerly *S. cyperinus*)	Woolgrass	Tolerates shallow water; tall clumps	
Scirpus microcarpus	Small-fruited bulrush	Wet ground to 18-inch depth	18 inches
Sagittaria latifolia	Arrowhead		
INUNDATION 1 FOOT TO 2 FEET			
Agrostis exarata[a]	Spike bent grass	Prairie to coast	
Alisma plantago-aquatica	Water plantain		
Eleocharis palustris	Spike rush	Margins of ponds, wet meadows	
Glyceria occidentalis	Western mannagrass	Marshes, pond margins	
Juncus effusus	Soft rush	Wet meadows, pastures, wetland margins	
Scirpus microcarpus	Small-fruited bulrush	Wet ground to 18-inch depth	18 inches
Sparganium emmersum	Burreed	Shallow standing water, saturated soils	
INUNDATION 1 FOOT TO 3 FEET			
Carex obnupta	Slough sedge	Wet ground or standing water	1.5 to 3 feet
Beckmannia syzigachne[a]	Western sloughgrass	Wet prairie to pond margins	
Scirpus acutus[b]	Hardstem bulrush	Single tall stems, not clumping	to 3 feet
Scirpus validus[b]	Softstem bulrush		
INUNDATION GREATER THAN 3 FEET			
Nuphar polysepalum	Spatterdock	Deep water	3 to 7.5 feet
Nymphaea odorata[a]	White waterlily	Shallow to deep ponds	to 6 feet

[a] Nonnative species. *Beckmannia syzigachne* is native to Oregon. Native species are preferred.

[b] Scirpus tubers must be planted shallower for establishment, and protected from foraging waterfowl until established. Emerging aerial stems should project above water surface to allow oxygen transport to the roots.

Primary sources: Municipality of Metropolitan Seattle 1990; Hortus Northwest 1991; Hitchcock and Cronquist 1973.

- Evergreen or columnar deciduous trees along the west and south sides of ponds are recommended to reduce thermal heating. In addition to shade, trees also help discourage waterfowl. Trees should be set back so that the branches will not extend over the pond.

- Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the Administrator through submittal of a pesticide-use plan (see Volume IV).

Note: The recommendations in Table 26.1 are for western Washington only. Local knowledge should be used to adapt this information if used in other areas.

Recommended Design Features

The following design features shall be incorporated into the wet pond design where site conditions allow. See also the landscaping requirements for detention ponds in Chapter 18.

- 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 or aerator, to prevent stagnation and low dissolved oxygen conditions.

- The access and maintenance road could be extended along the full length of the wet pond and could double as play courts or picnic areas. Placing finely ground bark or other natural material over the road surface would render it more pedestrian friendly.

- Provide pedestrian access to shallow pool areas enhanced with emergent wetland vegetation. This allows the pond to be more accessible without incurring safety risks.

- Provide side slopes that are sufficiently gentle to avoid the need for fencing (3:1 or flatter).

- Create flat areas overlooking or adjoining the pond for picnic tables or seating that can be used by residents. Walking or jogging trails around the pond are easily integrated into site design.

- Provide visual enhancement with clusters of trees and shrubs. On most pond sites, it is important to amend the soil before planting since ponds are typically placed well below the native soil horizon in poor soils. Make sure dam safety restrictions against planting do not apply.

- Orient the pond length along the direction of prevailing summer winds (typically west or southwest) to enhance wind mixing.

26.3.3 Construction Criteria

Sediment that has accumulated in the pond must be removed after construction in the drainage area is complete (unless used as part of a liner; see Appendix V-E).

26.3.4 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

26.4 Wet Vaults (Ecology BMP T10.20)

A wet vault is an underground structure similar in appearance to a detention vault, except that a wet vault has a permanent pool of water (wet pool) which dissipates energy and improves the settling of particulate pollutants (see the wet vault details in Figure 26.2). Being underground, the wet vault lacks the biological pollutant removal mechanisms, such as algae uptake, present in surface wet ponds.

26.4.1 Applications and Limitations

A wet vault may be used for commercial, industrial, or roadway projects if there are space limitations precluding the use of other treatment BMPs. The use of **wet vaults for residential development is highly discouraged.** Combined detention and wet vaults are allowed; see Section 26.3.

A wet vault is believed to be ineffective in removing dissolved pollutants such as soluble phosphorus or metals such as copper. There is also concern that oxygen levels will decline, especially in warm summer months, because of limited contact with air and wind. However, the extent to which this potential problem occurs has not been documented.

Below-ground structures like wet vaults are relatively difficult and expensive to maintain. The need for maintenance is often not visible without a deliberate inspection, and as a result routine maintenance often does not occur. Therefore, wet vaults **shall only be permitted after it has been demonstrated to the satisfaction of the city that more desirable BMPs are not practicable.**

If a wet vault/tank is designed to provide runoff treatment but not runoff quantity control it must be located "off-line" from the primary conveyance/detention system. Flows above the peak flow for the water quality design storm (see sizing procedure below) must bypass the facility in a separate conveyance to the point of discharge. A mechanism must also be provided at the bypass point to take the facility "off-line" for maintenance purposes. If oil control is required for a project, a wet vault may be combined with an API oil/water separator.

26.4.2 Wet Vault Design Criteria

Sizing Procedure

As with wet ponds, the primary design factor that determines the removal efficiency of a wet vault is the volume of the wet pool. 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 sizing procedure for a wet vault is identical to the sizing procedure for a wet pond. The wet pool volume for the wet vault **shall be equal to or greater than the water quality design storm volume estimated by an approved continuous runoff model**. In addition, because wet vaults are designed to be off-line, the facility must be designed with a flow splitter that can engage a bypass when the flow rate exceeds the water quality design flow rate.

Typical design details and concepts for the wet vault are shown in Figure 26.2.

Wet Pool Geometry

Same as specified for wet ponds (see previous section) except for the following two modifications:

- The sediment storage in the first cell shall be an average of 1 foot. Because of the V-shaped bottom, the depth of sediment storage needed above the bottom of the side wall is roughly proportional to vault width according to the schedule below:

Vault Width	Sediment Depth (from bottom of side wall)
15 feet	10 inches
20 feet	9 inches
40 feet	6 inches
60 feet	4 inches

- The second cell shall be a minimum of 3 feet deep since planting cannot be used to prevent resuspension of sediment in shallow water as it can in open ponds.

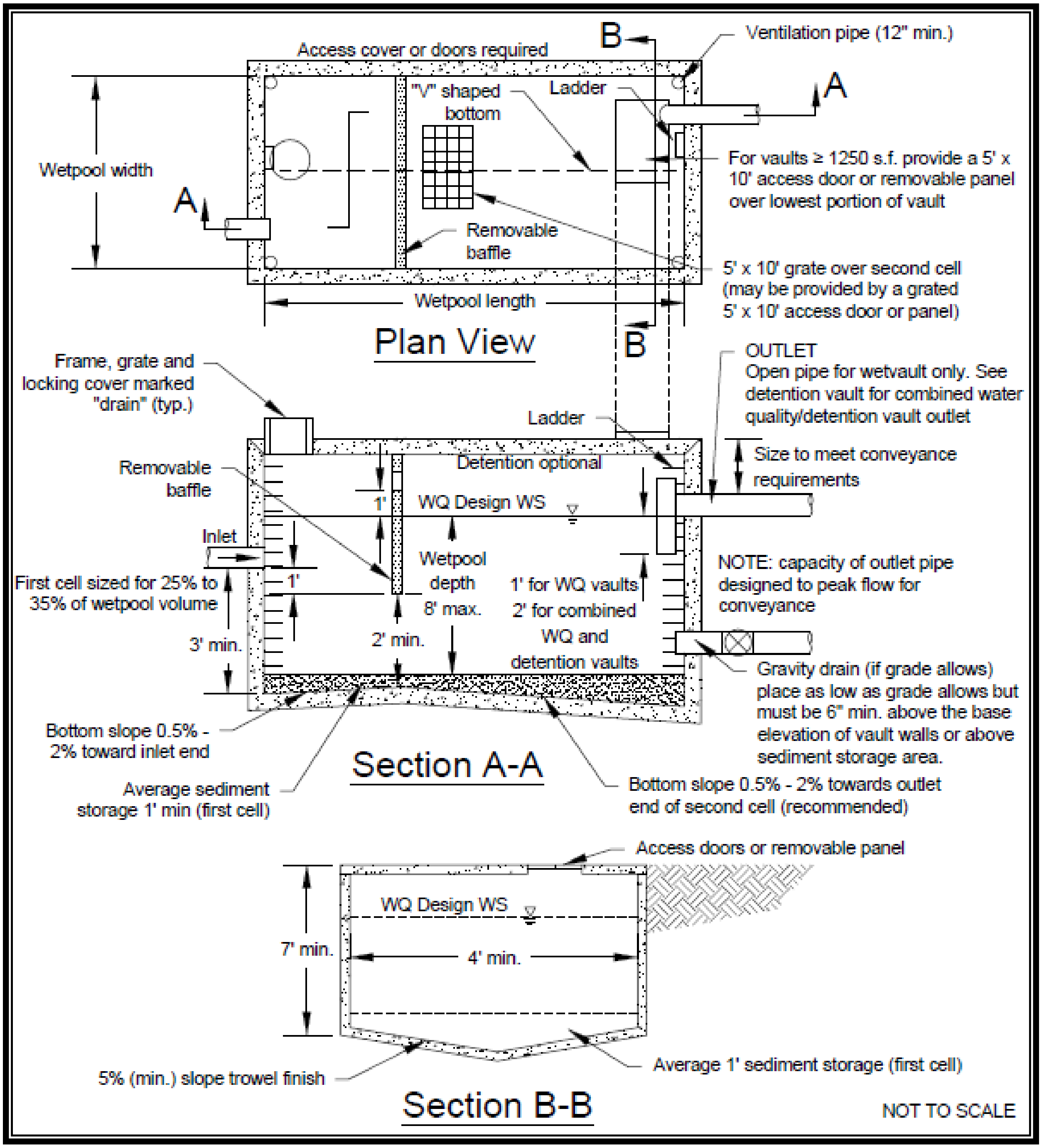


Figure 26.2. Wet Vault Geometry.

Vault Structure

- The vault shall be separated into two cells by a wall or a removable baffle. If a wall is used, a 5-foot by 10-foot removable maintenance access must be provided for both cells. If a removable baffle is used, the following criteria apply:
  - The baffle shall 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 shall be a minimum of 2 feet from the bottom of the vault, and greater if feasible.
- If the vault is less than 2,000 cubic feet (inside dimensions), or if the length-to-width ratio of the vault pool is 5:1 or greater, the baffle or wall may be omitted and the vault may be one-celled.
- The two cells of a wet vault should 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 flowpath.

  Intent: 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.
- The bottom of the first cell shall be sloped toward the access opening. Slope shall be between 0.5 percent (minimum) and 2 percent (maximum). The second cell may be level (longitudinally) sloped toward the outlet, with a high point between the first and second cells. The intent of sloping the bottom is to direct the sediment accumulation to the closest access point for maintenance purposes. Sloping the second cell towards the access opening for the first cell is also acceptable.
- The vault bottom shall slope laterally a minimum of 5 percent from each side towards the center, forming a broad "V" to facilitate sediment removal. **Note:** More than one "V" may be used to minimize vault depth.

  Exception: The City of Tumwater may allow the vault bottom to be flat if removable panels are provided over the entire vault. Removable panels should be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel.
- The highest point of a vault bottom must be at least 6 inches below the outlet elevation to provide for sediment storage over the entire bottom.

- Provision for passage of flows should the outlet plug shall be provided.

- Wet vaults may be constructed using arch culvert sections provided the top area at the water quality design water surface is, at a minimum, equal to that of a vault with vertical walls designed with an average depth of 6 feet.

  Intent: To prevent decreasing the surface area available for oxygen exchange.

- Wet vaults shall conform to the materials and structural stability criteria specified for detention vaults in Chapter 20.

- Where pipes enter and leave the vault below the water quality design water surface, they shall be sealed using a non-porous, non-shrinking grout.

Inlet and Outlet

- The inlet to the wet vault shall be submerged with the inlet pipe invert a minimum of 3 feet from the vault bottom. The top of the inlet pipe shall be submerged at least 1 foot.

  - The inlet pipe must also maintain a flow rate of 2 feet per second under the design water quality storm event to minimize sediment settling in the pipe.

  - Conveyance modeling for the stormwater system leading to the vault must be shown to include consideration of the backwater effects of the submerged vault inlet. Additional information on backwater analyses is provided in Volume III, Section 3.4.2

    Intent: 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.

- The capacity of the outlet pipe and available head above the outlet pipe shall be designed to convey the 100-year recurrence interval design flow for developed site conditions without overtopping the vault. The available head above the outlet pipe must be a minimum of 6 inches.

- The flowpath length must be maximized from inlet to outlet for all inlets to the vault.

- The outlet pipe shall be back-sloped or have tee section, the lower arm of which should extend 1 foot below the water quality design water surface to provide for trapping of oils and floatables in the vault.

- The City of Tumwater may require a bypass/shutoff valve to enable the vault to be taken off-line for maintenance.

Access Requirements

Same as for detention vaults (see Chapter 20) except for the following additional requirement for wet vaults:

- A minimum of 50 square feet of grate should be provided over the second cell. For vaults in which the surface area of the second cell is greater than 1,250 square feet, 4 percent of the top should 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.

Intent: 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.

Access Roads, Right-of-Way, and Setbacks

Same as for detention vaults (see Chapter 20).

26.4.3 Construction Criteria

Sediment that has accumulated in the vault must be removed after construction in the drainage area is complete.

26.4.4 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

26.4.5 Modifications for 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 runoff treatment requirements with one facility rather than two. Structural modifications and added design criteria are given below. However, the maintenance requirements for baffle oil/water separators must be adhered to, in addition to those for a wet vault. This will result in more frequent inspection and cleaning than for a wet vault used only for total suspended solids removal. See Section 8.10 for information on maintenance of baffle oil/water separators.

- The sizing procedures for the baffle oil/water separator (Chapter 27) should 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 shall be provided in the second cell 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.

- The vault shall have a minimum length-to-width ratio of 5:1.

- The vault shall have a design water depth-to-width ratio of between 1:3 and 1:2.
- The vault shall be watertight and shall be coated to protect from corrosion.
- Separator vaults shall 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 shall also be provided and accessible.
- Wet vaults used as oil/water separators must be off-line and must bypass flows greater than the off-line water quality design flow multiplied by the off-line ratio indicated in Figure 25.6b.

  Intent: This design minimizes the entrainment and/or emulsification of previously captured oil during very high flow events.

26.5 Stormwater Treatment Wetlands (Ecology BMP T10.30)

Stormwater treatment wetlands are shallow man-made ponds that are designed to treat stormwater through the biological processes associated with emergent aquatic plants (see the stormwater wetland details in Figures 26.3 and 26.4). Wetlands created to mitigate disturbance impacts, such as filling, may not also be used as stormwater treatment facilities.

In general, stormwater wetlands perform well to remove sediment, metals, and pollutants that bind to humic or organic acids. Phosphorus removal in stormwater wetlands is highly variable.

26.5.1 Applications and Limitations

This stormwater wetland design occupies about the same surface area as wet ponds, but has the potential to be better integrated aesthetically into a site because of the abundance of emergent aquatic vegetation. The most critical factor for a successful design is the provision of an adequate supply of water for most of the year. Careful planning is needed to be sure sufficient water will be retained to sustain good wetland plant growth. Since water depths are shallower than in wet ponds, water loss by evaporation is an important concern. Stormwater wetlands are a good water quality facility choice in areas with high winter groundwater levels.

26.5.2 Stormwater Treatment Wetland Design Criteria

When used for stormwater treatment, stormwater wetlands employ some of the same design features as wet ponds. However, instead of gravity settling being the dominant treatment process, pollutant removal mediated by aquatic vegetation and the microbiological community associated with that vegetation becomes the dominant treatment process. Thus, when designing wetlands, water volume is not the dominant design criteria. Rather, factors that affect plant vigor and biomass are the primary concerns.

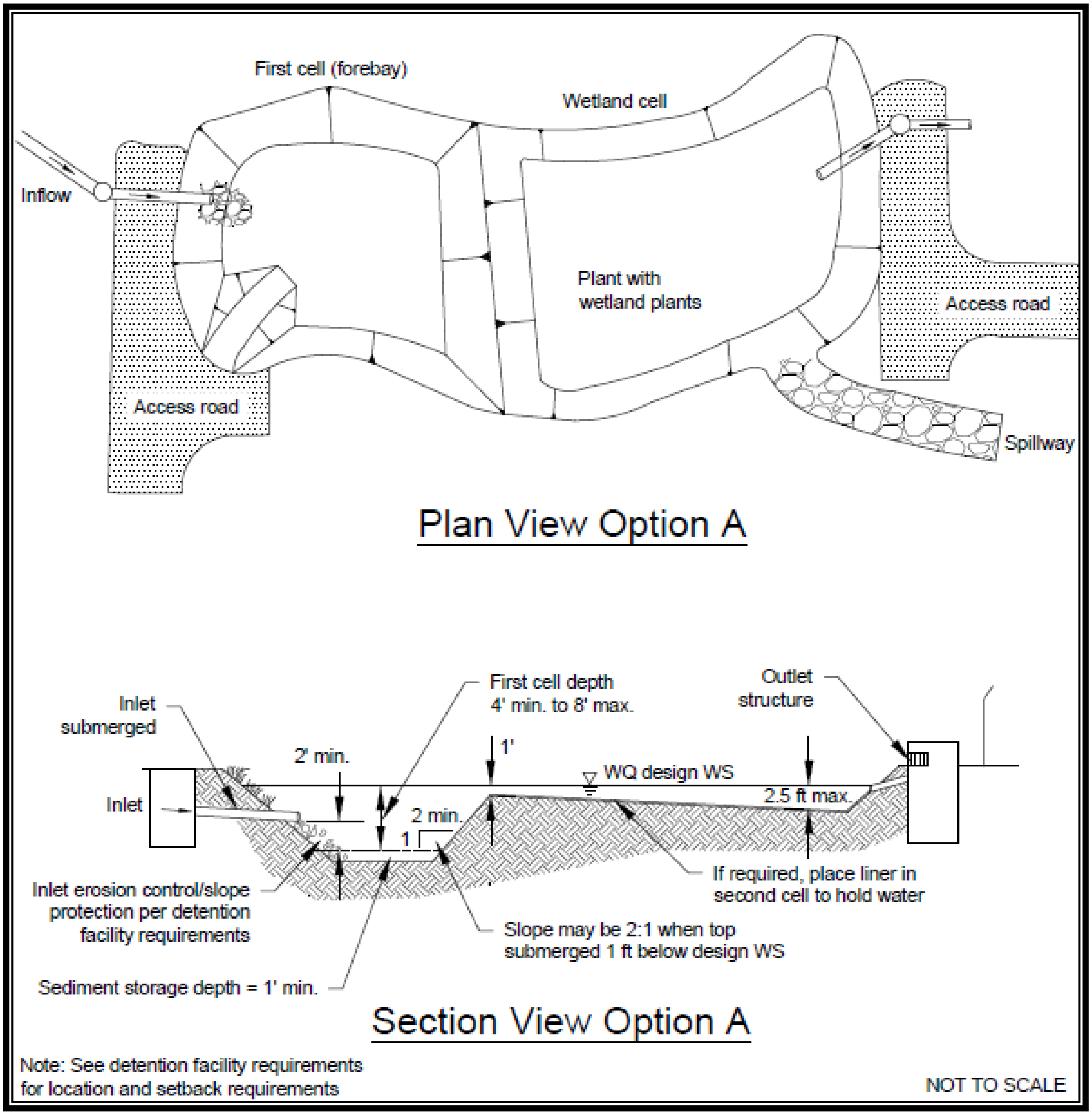


Figure 26.3. Stormwater Wetland – Option One.

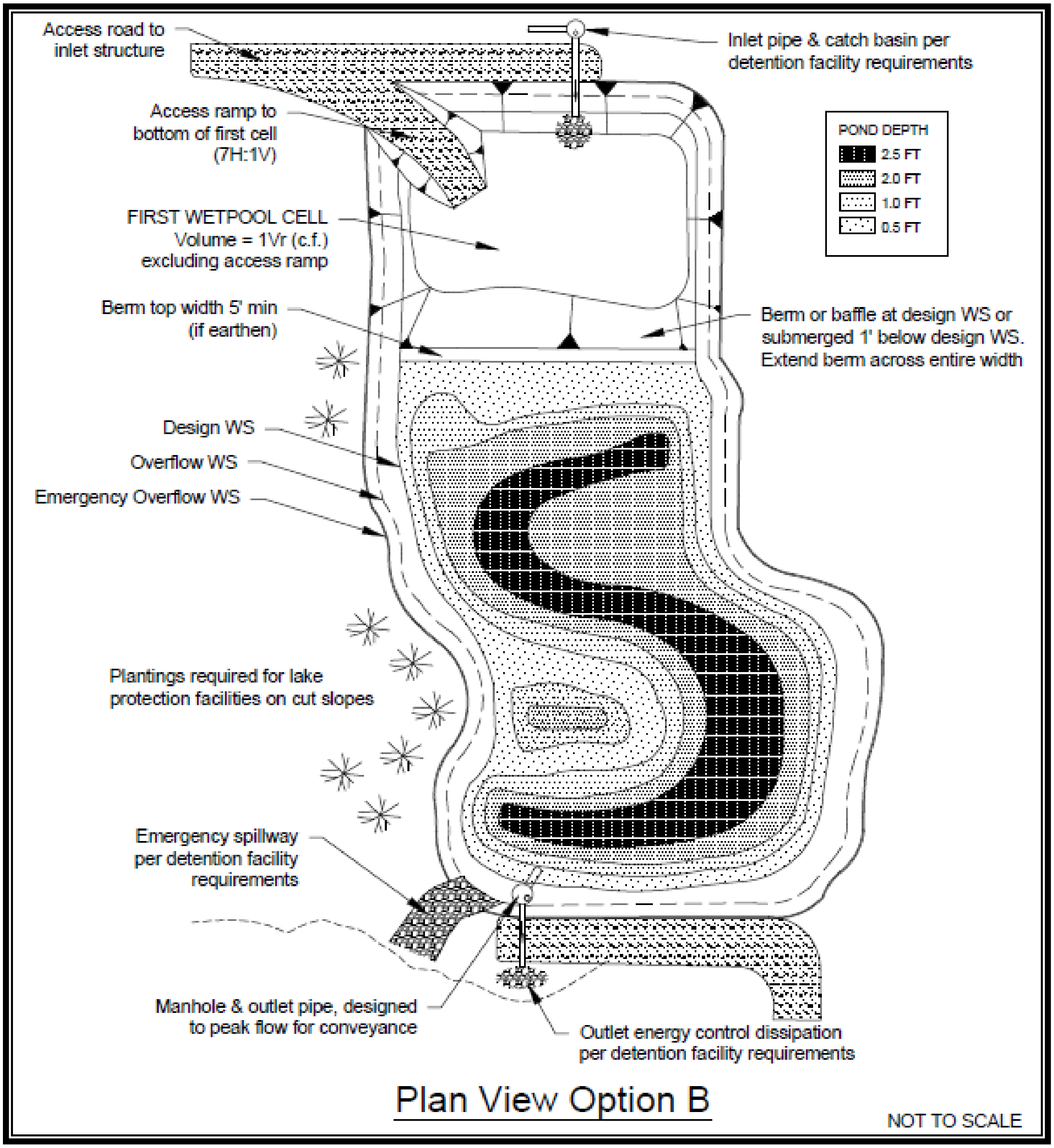


Figure 26.4. Stormwater Wetland – Option Two.

Sizing Procedure

Step 1: The volume of a basic wet pond is used as a template for sizing the stormwater wetland. The design volume is the water quality design storm volume estimated by an approved continuous runoff model.

Step 2: Calculate the surface area of the stormwater wetland. The surface area of the wetland shall be the same as the top area of a wet pond sized for the same site conditions. Calculate the surface area of the stormwater wetland by using the volume from Step 1 and dividing by the average water depth (use 3 feet).

Step 3: Determine the surface area of the first cell of the stormwater wetland. Use the volume determined from Criterion 2 under Wetland Geometry, below, and the actual depth of the first cell.

Step 4: Determine the surface area of the wetland cell. Subtract the surface area of the first cell (Step 3) from the total surface area (Step 2).

Step 5: Determine water depth distribution in the second cell. Decide if the top of the dividing berm will be at the surface or submerged (designer's choice). Adjust the distribution of water depths in the second cell according to Criterion 9 under Wetland Geometry, below. **Note:** This will result in a facility that holds less volume than that determined in Step 1 above. This is acceptable.

Intent: The surface area of the stormwater wetland is set to be roughly equivalent to that of a wet pond designed for the same site so as not to discourage use of this option.

Step 6: Choose plants. See Table 26.1 for a list of plants recommended for wet pond water depth zones, or consult a wetland scientist.

Wetland Geometry

- Stormwater wetlands shall consist of two cells, a presettling cell and a wetland cell.
- The presettling cell shall contain approximately 33 percent of the wet pool volume calculated in Step 1 above.
- The depth of the presettling cell shall be between 4 feet (minimum) and 8 feet (maximum), excluding sediment storage.
- One foot of sediment storage shall be provided in the presettling cell.
- The presettling cell must include a gravity drain for maintenance.
- The wetland cell shall have an average water depth of about 1.5 feet (plus or minus 3 inches).

- The berm separating the two cells shall be shaped such that its downstream side gradually slopes to form the second shallow wetland cell (see the section view in Figure 26.3). Alternatively, the second cell may be graded naturalistically from the top of the dividing berm (see Criterion 9 below).

- The top of berm shall be either at the water quality design water surface or submerged 1 foot below the water quality design water surface, as with wet ponds. Correspondingly, the side slopes of the berm must meet the following criteria.

    - If the top of berm is at the water quality design water surface, the berm side slopes shall be no steeper than 3H:1V.

    - If the top of berm is submerged 1 foot, the upstream side slope may be up to 2H:1V. If the berm is at the water surface, then for safety reasons, its slope should be not greater than 3:1, just as the pond banks should not be greater than 3:1 if the pond is not fenced. A steeper slope (2:1 rather than 3:1) is allowable if the berm is submerged in 1 foot of water. If submerged, the berm is not considered accessible, and the steeper slope is allowable.

- Two examples are provided for grading the bottom of the wetland cell. One example is a shallow, evenly graded slope from the upstream to the downstream edge of the wetland cell (see Figure 26.3). The second example is a “naturalistic” alternative, with the specified range of depths intermixed throughout the second cell (see Figure 26.4). A distribution of depths shall be provided in the wetland cell depending on whether the dividing berm is at the water surface or submerged (see Table 26.2). The maximum depth is 2.5 feet in either configuration. Other configurations within the wetland geometry constraints listed above may be approved by the City of Tumwater.

- Construction of the naturalistic alternative (example 2 above) can be easily accomplished by first excavating the entire area to the 1.5-foot average depth. Then soil subsequently excavated to form deeper areas can be deposited to raise other areas until the distribution of depths indicated in the design is achieved.

- To the extent possible create a complex microtopography within the wetland.

- Design the flowpath to maximize sinuous flow between wetland cells.

Table 26.2. Distribution of Depths in Wetland Cell.

Dividing Berm at Water Quality Design Water Surface		Dividing Berm Submerged 1 Foot	
Depth Range (feet)	**Percent**	**Depth Range (feet)**	**Percent**
0.1 to 1	25	1 to 1.5	40
1 to 2	55	1.5 to 2	40
2 to 2.5	20	2 to 2.5	20

Lining Requirements

Constructed wetlands are not intended to infiltrate. Many wetland plants can adapt to periods of summer drought, however the stormwater wetland design should maximize the duration of wet conditions to the extent possible. Therefore, both cells of the stormwater wetland shall be lined with a low-permeability liner. The criteria for liners given in Appendix V-E must be observed. A minimum of 18 inches of native soil amended with good topsoil or compost (one part compost mixed with three parts native soil) must be placed over the liner. For geomembrane liners, a soil depth of 3 feet is recommended to prevent damage to the liner during planting. A liner is not required in hydric soils.

Inlet and Outlet

Inlets and outlets shall be configured in accordance with the requirements of wet ponds, see Ecology BMP T9.10.

Access and Setbacks

- Location of the stormwater wetland relative to site constraints (e.g., buildings, property lines, etc.) shall be the same as for detention ponds (see Chapter 18).

- Access and maintenance roads shall be provided and designed according to the requirements for detention ponds (see Chapter 18). Access and maintenance roads shall extend to both the wetland inlet and outlet structures. An access ramp shall be provided to the bottom of the first cell unless all portions of the cell can be reached and sediment loaded from the top of the wetland side slopes.

- Fencing shall be provided where required based on slope or presence of walls (see Chapter 18) and designed according to the requirements for detention ponds (see Chapter 18).

Planting Requirements

The wetland cell shall be planted with emergent wetland plants following the guidance given in Table 26.1 or the recommendations of a wetland specialist. **Note:** Cattails (*Typha latifolia*) are not recommended. They tend to escape to natural wetlands and crowd out other species. In addition, the shoots die back each fall and will result in oxygen depletion in the wet pool unless they are removed.

Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the city through submittal of a pesticide-use plan.

26.5.3 Construction Criteria

Sediment that has accumulated in the pond must be removed after construction in the drainage area is complete (unless used as part of a liner; see Appendix V-E).

26.5.4 Operations and Maintenance Criteria

See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

26.6 Combined Detention and Wet Pool Facilities (Ecology BMP T10.40)

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. The following combined facilities are addressed.

- 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. See Volume I, Section 4.3 for more information about treatment performance goals.

26.6.1 Applications and Limitations

Combined detention and water quality facilities can be efficient uses of space for sites that also have detention requirements. The water quality facility may often be placed beneath the detention facility without increasing the facility surface area. However, the fluctuating water surface of the live storage will create unique challenges for plant growth and for aesthetics alike.

The basis for pollutant removal in combined facilities is the same as in the stand-alone water quality facilities. However, in the combined facility, the detention function creates fluctuating water levels and added turbulence. For simplicity, the positive effect of the extra live storage volume and the negative effect of increased turbulence are assumed to balance, and are thus ignored when sizing the wet pool volume. For the combined detention/stormwater wetland, criteria that limit the extent of water level fluctuation are specified to better ensure survival of the wetland plants.

Unlike the wet pool volume, the live storage component of the facility must be provided above the known or seasonal high water table.

26.6.2 Construction, and Operations and Maintenance Criteria

Construction, and operations and maintenance criteria for combined facilities are the same as those outlined for each individual detention and treatment facility (i.e., as outlined in Chapters 6 through 25 and in the previous sections of this chapter).

26.6.3 Combined Detention and Wet Pond (basic and large)

Typical design details and concepts for a combined detention and wet pond are shown in Figures 26.5a and 26.5b. The detention portion of the facility shall meet the design criteria and sizing procedures set forth in Chapters 6 through 22.

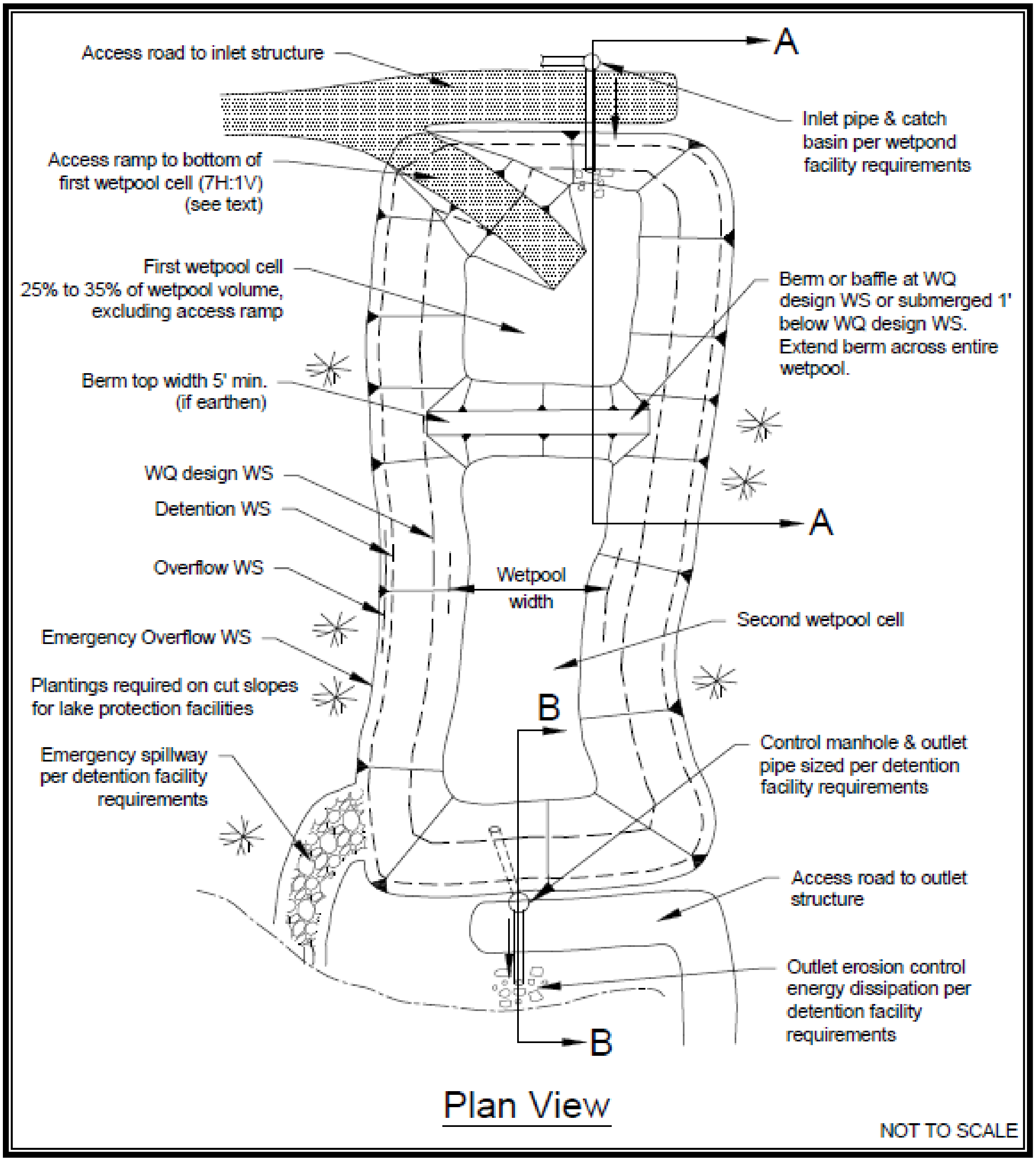


Figure 26.5a. Combined Detention and Wet Pond.

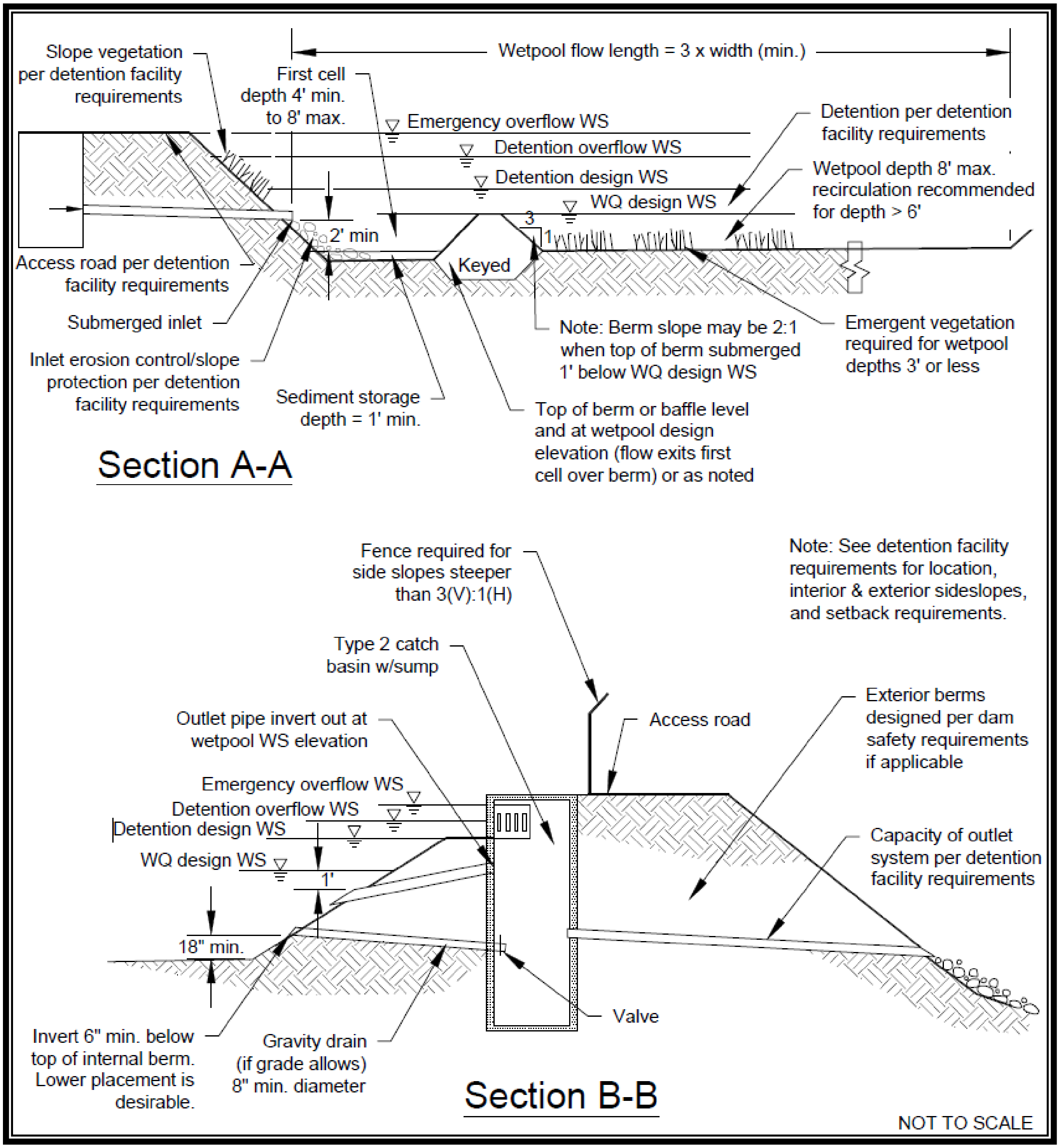


Figure 26.5b. Combined Detention and Wet Pond (continued).

Sizing Procedure

The sizing procedure for combined detention and wet ponds are identical to those outlined for wet ponds and for detention facilities. The wet pool volume for a combined facility shall be equal to or greater than the water quality design storm volume estimated by an approved continuous runoff model. Follow the standard procedure specified in Chapters 6 through 22 and guidance documents for use of an approved continuous runoff model to size the detention portion of the pond.

Detention and Wet Pond Geometry

- The wet pool and sediment storage volumes shall not be included in the required detention volume.

- The wet pool geometry criteria in the Wet Ponds – Basic and Large (Ecology BMP T10.10) section above shall apply, with the following modifications/clarifications.

    - Criterion 1: The permanent pool may be made shallower to take up most of the pond bottom, or deeper and positioned to take up only a limited portion of the bottom. Note, however, that having the first wet pool cell at the inlet allows for more efficient sediment management than if the cell is moved away from the inlet. Wet pond criteria governing water depth must, however, still be met. See Figure 26.6 for two possibilities for wet pool cell placement.

      Intent: This flexibility in positioning cells is provided to allow for multiple use options, such as volleyball courts in live storage areas in the drier months.

    - Criterion 2: The minimum sediment storage depth in the first cell is 1 foot. The 6 inches of sediment storage required for detention ponds do not need to be added to this, but 6 inches of sediment storage must be added to the second cell to comply with the detention sediment storage requirement.

Berms, Baffles, and Slopes

Same as for wet ponds.

Inlet and Outlet

The inlet and outlet criteria in the Wet Ponds – Basic and Large (Ecology BMP T10.10) section above shall apply, with the following modifications.

- A sump must be provided in the outlet structure of combined ponds.

- The detention flow restrictor and its outlet pipe shall be designed according to the requirements for detention ponds (see Chapter 18).

Access and Setbacks

Same as for wet ponds.

Planting Requirements

Same as for wet ponds.

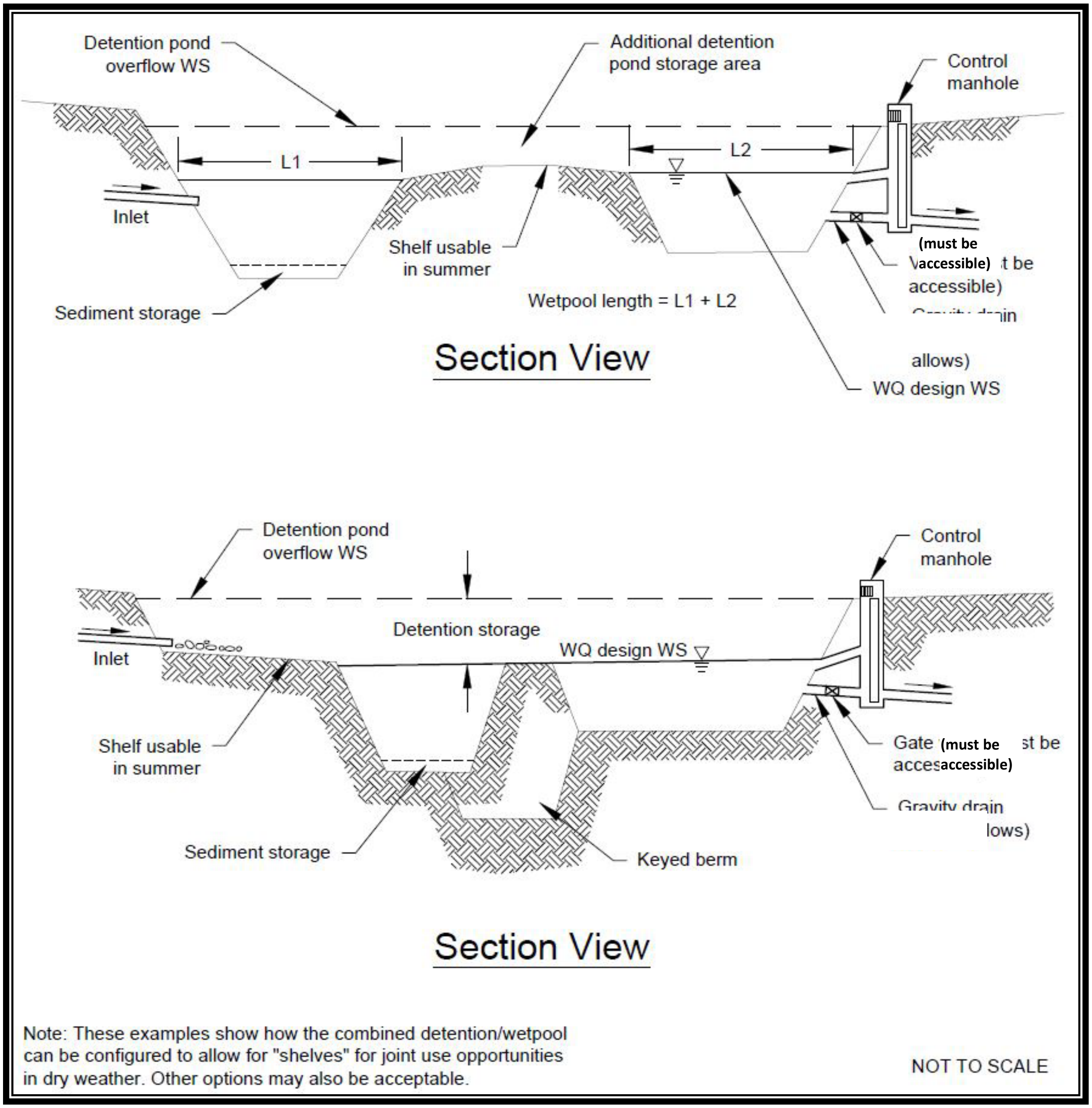


Figure 26.6. Alternative Configurations of Detention and Wet Pool Areas.

26.6.1 Combined Detention and Wet Vault

Sizing Procedure

The sizing procedure for combined detention and wet vaults is identical to those outlined for wet vaults and for detention facilities. The wet vault volume for a combined facility shall be equal to or greater than the water quality design storm volume estimated by an approved continuous runoff model. Follow the standard procedure specified in Chapter 20 to size the detention portion of the vault.

Detention and Wet Vault Geometry

The design criteria for detention vaults and wet vaults must both be met, except for the following modifications:

- The minimum sediment storage depth in the first cell shall average 1 foot. The 6 inches of sediment storage required for detention vaults does not need to be added to this, but 6 inches of sediment storage must be added to the second cell to comply with detention vault sediment storage requirements.

Berms, Baffles, and Slopes

The design criteria for detention vaults and wet vaults must both be met, except for the following modifications.

- The oil retaining baffle shall extend a minimum of 2 feet below the water quality design water surface.

  Intent: The greater depth of the baffle in relation to the water quality design water surface compensates for the greater water level fluctuations experienced in the combined vault.

Note: If a vault is used for detention as well as water quality control, the facility may not be modified to function as a baffle oil/water separator as allowed for wet vaults. This is because the added pool fluctuation in the combined vault does not allow for the quiescent conditions needed for oil separation.

Inlet and Outlet

Same as for wet vaults.

Access and Setbacks

Same as for wet vaults.

26.6.2 Combined Detention and Stormwater Wetland

Sizing Procedure

The sizing procedure for combined detention and stormwater wetlands is identical to those outlined for stormwater wetlands and for detention facilities. Follow the procedure specified for stormwater treatment wetlands in the previous section to determine the stormwater wetland size. Follow the standard procedure specified in Chapters 18 and 22 to size the detention portion of the wetland.

Detention and Wetland Geometry

The design criteria for detention ponds and stormwater wetlands must both be met, except for the following modifications.

- Water Level Fluctuation Restrictions: The difference between the water quality design water surface and the maximum water surface associated with the 2-year recurrence interval runoff shall not be greater than 3 feet. If this restriction cannot be met, the size of the stormwater wetland must be increased. The additional area may be placed in the first cell, second cell, or both. If placed in the second cell, the additional area need not be planted with wetland vegetation or counted in calculating the average depth.

  Intent: This criterion is designed to dampen the most extreme water level fluctuations expected in combined facilities to better ensure that fluctuation-tolerant wetland plants will be able to survive in the facility. It is not intended to protect native wetland plant communities and is not to be applied to natural wetlands.

- The wetland geometry criteria in the Stormwater Treatment Wetlands (Ecology BMP T10.30) section must be modified such that the minimum sediment storage depth in the first cell is 1 foot. The 6 inches of sediment storage required for detention ponds does not need to be added to this, nor does the 6 inches of sediment storage in the second cell of detention pond.

  Intent: Since emergent plants are limited to shallower water depths, the deeper water created before sediments accumulate is considered detrimental to robust emergent growth. Therefore, sediment storage is confined to the first cell, which functions as a presettling cell.

The inlet and outlet criteria in Section 26.3.1, Wet Ponds – Basic and Large (Ecology BMP T10.10), shall apply, with the following modifications.

- A sump must be provided in the outlet structure of combined facilities.

- The detention flow restrictor and its outlet pipe shall be designed according to the requirements for detention ponds (see Chapter 18).

The “Planting Requirements” for stormwater wetlands are modified to use the following plants, which are better adapted to water level fluctuations.

- *Scirpus acutus* (hardstem bulrush) 2- to 6-foot depth
- *Scirpus microcarpus* (small-fruited bulrush) 1- to 2.5-foot depth
- *Sparganium emersum* (burreed) 1- to 2-foot depth
- *Sparganium eurycarpum* (burreed) 1- to 2-foot depth
- *Veronica* spp. (marsh speedwell) 0- to 1-foot depth

In addition, the shrub Douglas spirea (*Spiraea douglasii*) may be used in combined facilities.

Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the city through submittal of a pesticide-use plan.

Chapter 27 – Oil and Water Separators

27.1 Purpose

This section provides a discussion of oil and water separators, including their application and design criteria. Oil and water separators remove oil and other water-insoluble hydrocarbons, and settleable solids from stormwater runoff.

BMPs are described for baffle type and coalescing plate separators. In addition to the oil and water separators outlined in this chapter, the City of Tumwater may also permit the use of oil control booms for oil control in some situations when designed in accordance with the requirements outlined in the 2019 WSDOT Highway Runoff Manual, Chapter 5, BMP RT.22 (or subsequent updates as approved by Ecology and the City of Tumwater).

27.2 Description

Oil and water separators are typically the API, also called baffle type (American Petroleum Institute 1990) or the coalescing plate type using a gravity mechanism for separation. See Figures 27.1 and 27.2. Oil removal separators typically consist of three bays; forebay, separator section, and the afterbay. The coalescing plate separators need considerably less space for separation of the floating oil due to the shorter travel distances between parallel plates. A spill control separator (Figure 27.3) is a simple catch basin with a T-inlet for temporarily trapping small volumes of oil. The spill control separator is included here for comparison only and is not designed for, or to be used for, treatment purposes.

27.3 Performance Objectives

Oil and water separators are expected to remove oil and total petroleum hydrocarbons (TPH) down to 15 mg/L at any time and 10 mg/L on a 24-hour average, and produce a discharge that does not cause an ongoing or recurring visible sheen in the stormwater discharge, or in the receiving water (see also Volume I, Section 4.3).

Without intense maintenance, oil/water separators may not be sufficiently effective in achieving oil and TPH removal down to required levels. See Minimum Requirement #9 in Volume I, Section 4.2.10; and the Stormwater Facility Maintenance Standards on the city web site, for information on maintenance requirements.

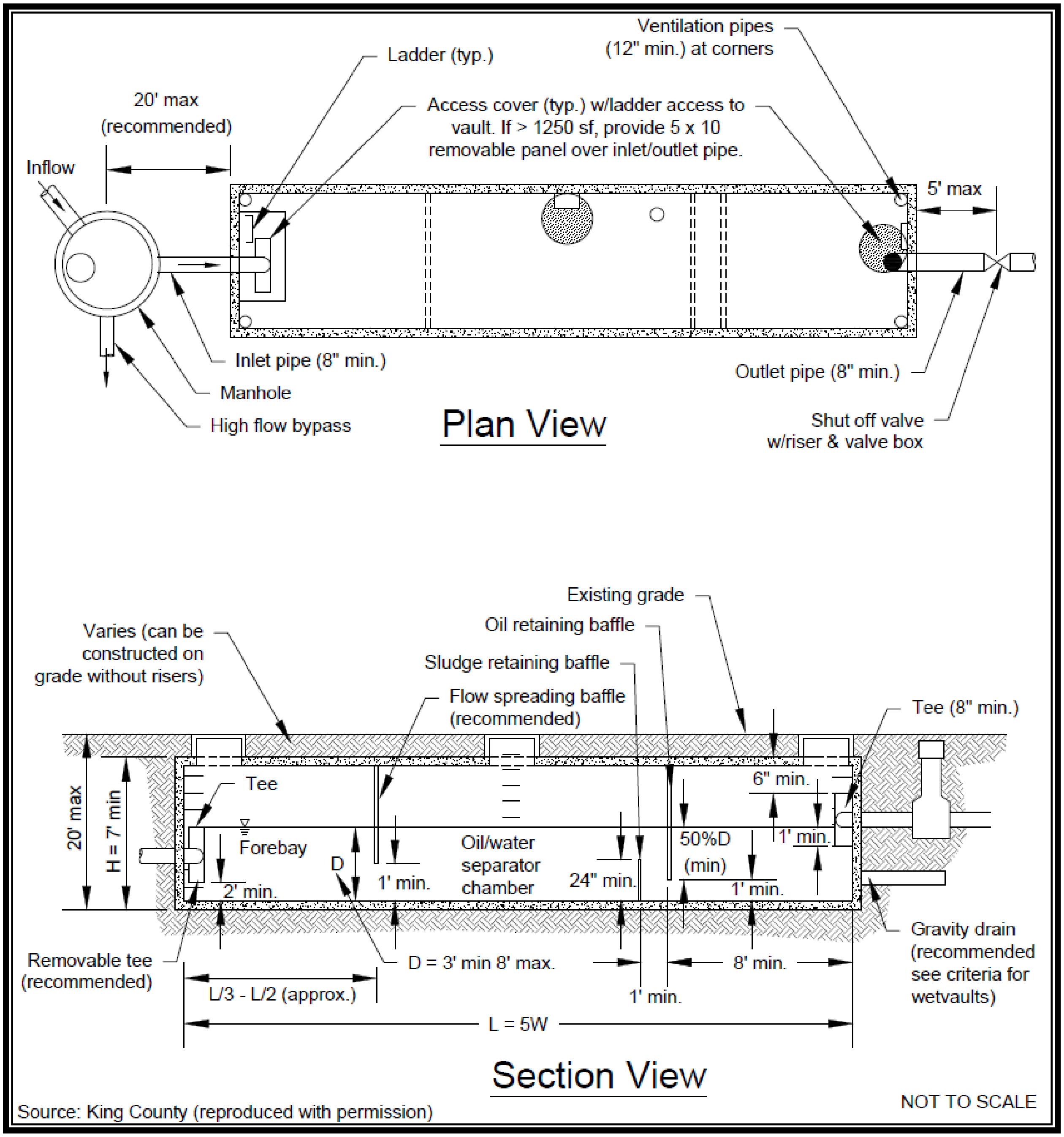


Figure 27.1. API (Baffle Type) Separator.

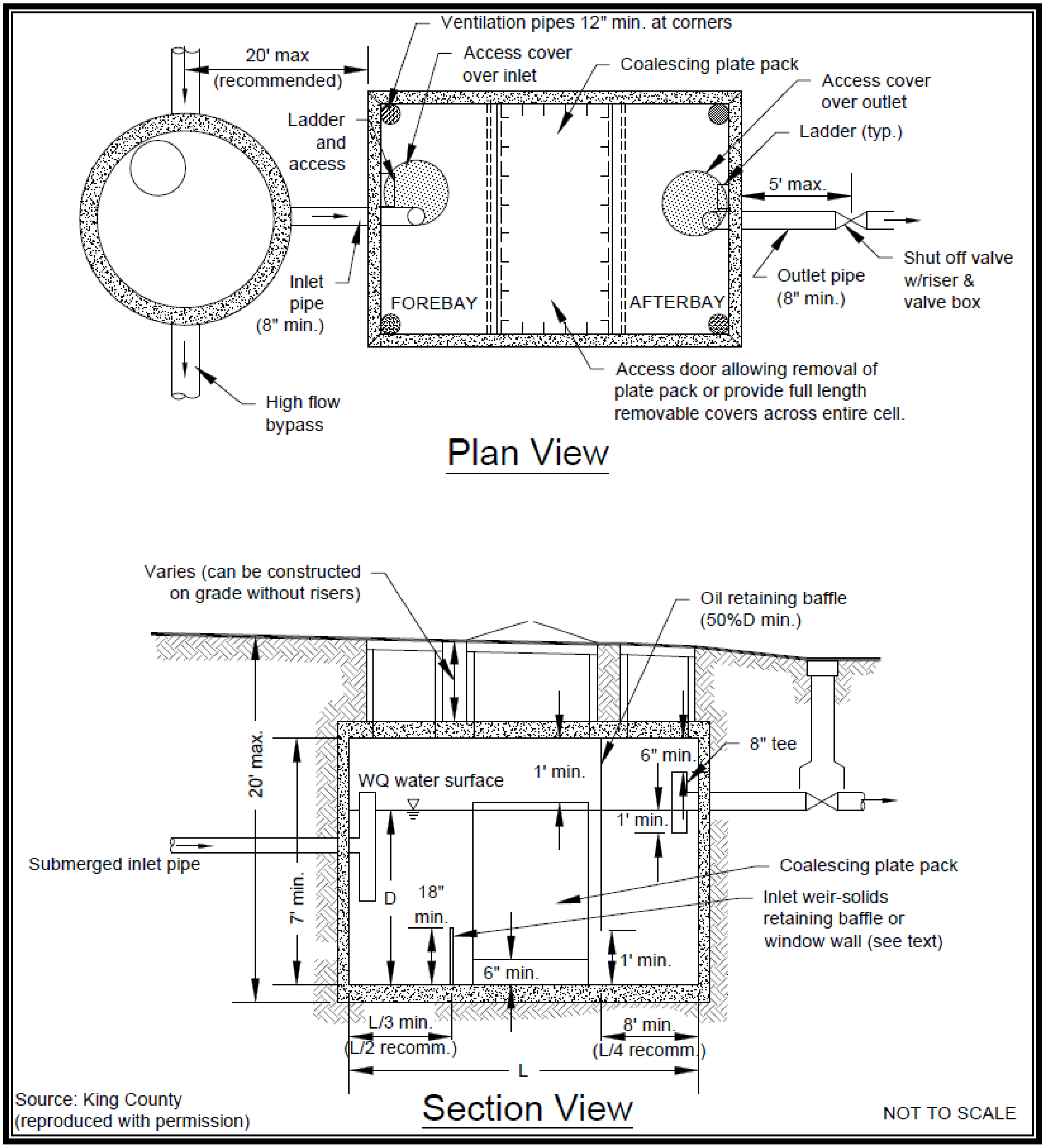
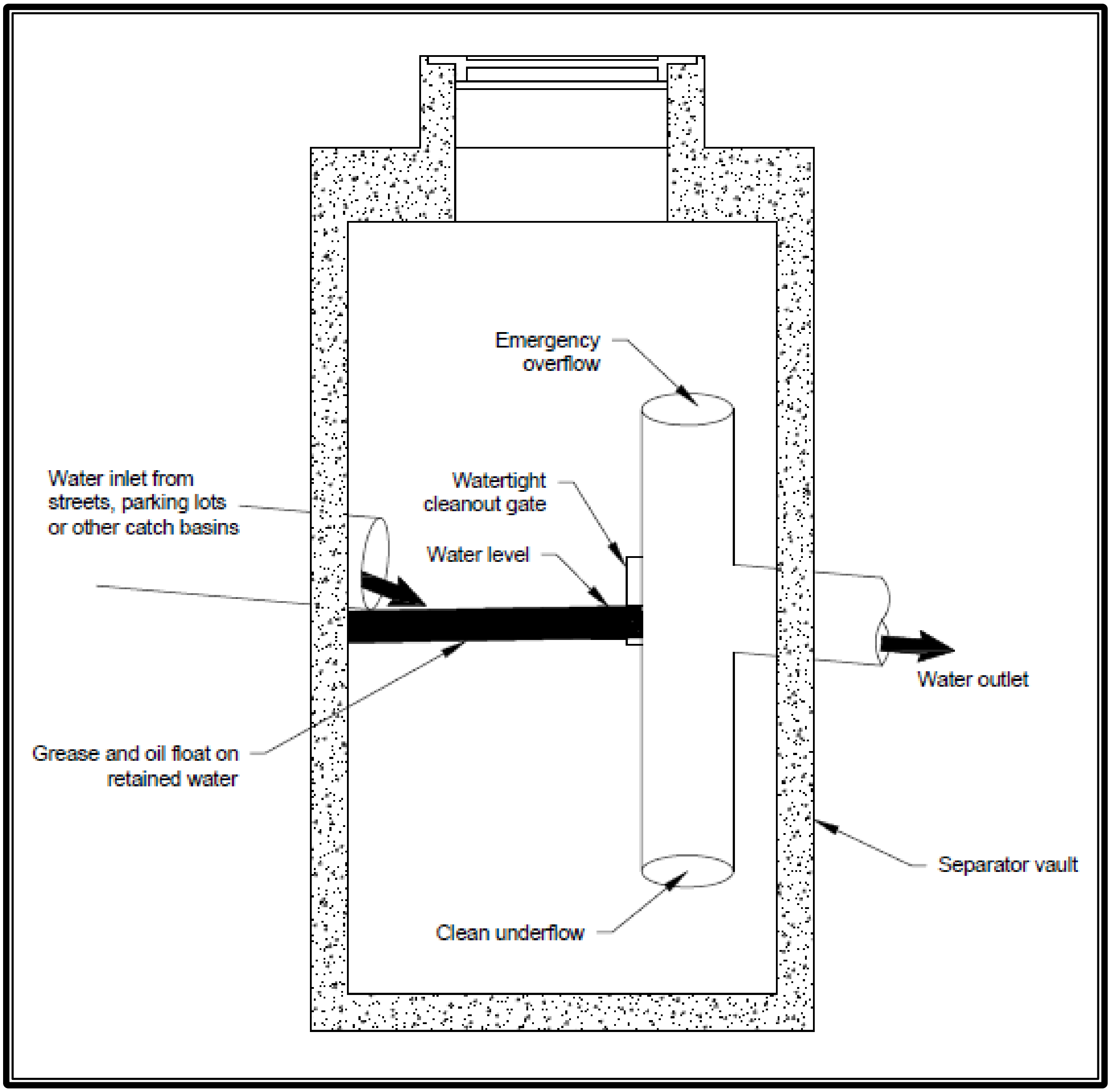


Figure 27.2. Coalescing Plate Separator.



Source: 2014 Ecology Manual

Figure 27.3. Spill Control Separator (not for oil treatment).

27.4 Site Suitability

Consider the following site characteristics.

- Sufficient land area
- Adequate total suspended solids control or pretreatment capability
- Compliance with environmental objectives
- Adequate influent flow attenuation and/or bypass capability
- Sufficient access for operation and maintenance.

27.5 Design Criteria – General Considerations

There is concern that oil/water separators used for stormwater treatment have not performed to expectations (Schueler et al. 1992; Schueler 1994). Therefore, emphasis should be given to proper application, design, operation and maintenance, (particularly sludge and oil removal), and prevention of coalescing plate fouling and plugging (U.S. Army Corps of Engineers 1994). Other treatment systems, such as emerging technologies, should be considered for the removal of insoluble oil and TPH.

The following are design criteria applicable to API and coalescing plate oil/water separators:

- Locate the separator off-line and bypass the incremental portion of flows that exceed the off-line 15-minute, water quality design flow rate multiplied by the ratio indicated in Figure 25.6b of this chapter. If it is necessary to locate the separator on line, try to minimize the size of the area needing oil control, and use the on-line water quality design flow rate multiplied by the ratio indicated in Figure 25.6b.
- Use only impervious conveyances for oil contaminated stormwater.
- Add pretreatment for total suspended solids that could cause clogging of the coalescing plate separator, or otherwise impair the long-term effectiveness of the separator.
- Include roughing screens for the forebay or upstream of the separator to remove debris. Screen openings should be about 3/4 inch.

27.6 Criteria for Separator Bays

- Size the separator bay for the water quality design flow rate (15-minute time step) multiplied by the correction factor ratio indicated in Figure 25.6b of this chapter (assuming an off-line facility). (See Volume I, Section 2.4.7 for a definition of the water quality design flow rate.)
- To collect floatables and settleable solids, design the surface area of the forebay at ≥ 20 ft² per 10,000 ft² of area draining to the separator. The length of the forebay should be 1/3 to 1/2 of the length of the entire separator.
- Include a submerged inlet pipe with a turn-down elbow in the first bay at least 2 feet from the bottom. The outlet pipe should be a Tee, sized to pass the design peak flow and placed at least 12 inches below the water surface.
- Include a shutoff valve at the separator outlet pipe.

27.7 Criteria for Baffles

- Oil retaining baffles (top baffles) must be located at least at one-quarter of the total separator length from the outlet and must extend down at least 50 percent of the water depth and at least 1 foot from the separator bottom.
- Baffle height to water depth ratios shall be 0.85 for top baffles and 0.15 for bottom baffles.

27.8 Oil and Water Separator BMPs

Two BMPs are described in this section: API baffle type separators, and coalescing plate separators.

27.9 API (Baffle type) Separator Bay (Ecology BMP T11.10)

API separators are composed of three bays separated by baffles. The efficiency of API separators is dependent on detention time in the center bay and on droplet size. API type separators rarely treat stormwater to reduce oil levels below 10 mg/l. The use of API separators should be limited to protection from large oil spills and not for small amounts of oil on the pavement surfaces. However, Ecology also requires each developer to perform detailed performance verification during at least one wet season when using their modified design. Given this requirement, the City of Tumwater has elected not to allow the use of API separators on sites smaller than 2 acres. The following approach only applies to contributing drainage areas larger than 2 acres:

27.10 API Design Criteria

The API design criteria is based on the horizontal velocity of the bulk fluid (V_h), the oil rise rate (V_t), the residence time (t_m), width, depth, and length considerations.

The following is the API sizing procedure:

- Determine the oil rise rate, V_t, in centimeters per second, using Stokes' Law (Water Pollution Control Federation 1985) or empirical determination.

- Stokes Law equation for rise rate, V_t (ft/min):

$$V_t = 1.97g(\sigma_w - \sigma_o)D^2 / 18\eta_w$$

Where: 1.97 = conversion factor (centimeters per second/ft per minute)

g = gravitational constant (981 centimeters per second squared)

D = diameter of the oil particle (centimeters).

Use

oil particle size diameter, D = 60 microns (0.006 centimeters)

σ_w = water density = 0.999 grams per cubic centimeter (gm/cc) at 32°F

σ_o: Select conservatively high oil density,

For example, if diesel oil @ σ_o = 0.85 gm/cc and motor oil @ σ_o = 0.90 gm/cc can be present then use σ_o = 0.90 gm/cc

η_w = dynamic viscosity of water = 0.017921 poise (gm/cm-sec) at water temperature of 32°F (see API publication 421, February 1990)

For Stormwater Inflow from Drainages More Than 2 Acres

- Determine V_t based on above criteria

- Determine Q

  Q = the 15-minute water quality design flow rate in ft^3/min multiplied by the ratio indicated in Figure 25.6a (for on-line facilities) or Figure 25.6b (for off-line facilities) for the site location (k). Note that the continuous runoff models likely report 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.

- Calculate horizontal velocity of the bulk fluid, V_h (in ft/min), and depth (d), feet.

  Vh = 15Vt

$d = (Q/2Vh)^{1/2}$, with

Separator water depth, $3 \leq d \leq 8$ feet (to minimize turbulence). 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 (American Petroleum Institute 1990; U.S. Army Corps of Engineers 1994).

- Calculate the minimum residence time (t_m), in minutes, of the separator at depth d:

  $t_m = d/V_t$

- Calculate the minimum length of the separator section, l(s), using:

  $F = 1.65$

  Depth/width (d/w) of 0.5 (American Petroleum Institute 1990),

  $l(s) = FQt_m/wd = F(V_h/V_t)d$

  For other dimensions, including the length of the forebay, the length of the afterbay, and the overall length, L; refer to Figure 27.1.

- Calculate $V = l(s)wd = FQt_m$, and $A_h = wl(s)$

  V = minimum hydraulic design volume, in cubic feet.

  A_h = minimum horizontal area of the separator, in square feet.

27.11 Coalescing Plate Separator Bay (Ecology BMP T11.11)

27.11.1 Coalescing Plate Design Criteria

Calculate the projected (horizontal) surface area of plates needed using the following equation:

$$A_h = Q/V_t = Q/[0.00386* ((S_w - S_o)/(\mu_w))]$$

Where:

Q = design flow rate (ft^3/min)

V_t = Rise rate of the oil droplet

A_h = horizontal surface area of the plates (ft^2; 0.00386 is unit conversion constant)

S_w = specific gravity of water at the design temperature

S_o = specific gravity of oil at the design temperature

μ_w = absolute viscosity of the water (poise).

The above equation is based on an oil droplet diameter of 60 microns.

- Plate spacing should be a minimum of 3/4 inch (perpendicular distance between plates) or as determined by the manufacturer. (ASCE & WEF 1998; U.S. Army Corps of Engineers 1994; U.S. Air Force 1991; Jaisinghani et al. 1979).
- Select a plate angle between 45 to 60 degrees from the horizontal.
- Locate plate pack at least 6 inches from the bottom of the separator for sediment storage.
- Add 12 inches minimum head space from the top of the plate pack and the bottom of the vault cover.
- Design inlet flow distribution and baffles in the separator bay to minimize turbulence, short-circuiting, and channeling of the inflow especially through and around the plate packs of the coalescing plate separator. The Reynolds Number through the separator bay should be less than 500 (laminar flow).
- Include forebay for floatables and afterbay for collection of effluent (ASCE and WEF 1998).
- The sediment-retaining baffle must be upstream of the plate pack at a minimum height of 18 inches.
- Design plates for ease of removal, and cleaning with high-pressure rinse or equivalent.

Chapter 28 – Emerging Technologies

28.1 Background

This section addresses emerging (new) technologies that have not been evaluated in sufficient detail to be acceptable for general usage in new development or redevelopment situations.

As a Phase II NPDES stormwater permit holder, the City of Tumwater is required to adopt the 2019 Ecology Manual or an equivalent manual. BMPs listed in the 2019 Ecology Manual are presumed to provide adequate treatment (see Volume I, Section 1.5.4), but in many situations traditional BMPs such as wet ponds and biofiltration swales may not be appropriate or optimal (due to size and space restraints, or inability to remove target pollutants). Because of this, the stormwater treatment industry emerged to develop new stormwater treatment devices.

Emerging technologies are stormwater treatment devices that are new to the stormwater treatment marketplace. These devices include both permanent and construction site treatment technologies. Many of these devices have not undergone complete performance testing so their performance claims cannot be verified.

28.2 Evaluation of Emerging Technologies

Ecology currently participates in a process to evaluate emerging technologies for permanent and construction site stormwater runoff applications and to convey judgments made by local jurisdictions and others on their acceptance. Based on recommendations from Ecology's Stormwater Technical Advisory Committee, Ecology has implemented the following process:

- In order to properly evaluate new technologies, performance data must be obtained using the Ecology-approved TAPE and the Chemical TAPE (C-TAPE) or other accepted protocols. More information on these protocols can be found at <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies>.Other acceptable protocols may also be available at Ecology's web site.

- Ecology participates in all Technical Review Committee and Chemical Technical Review Committee activities, which include reviewing manufacturer performance data and providing recommendations on use level designations.

- Based on performance and other pertinent data from vendors and manufacturers and recommendations by the review committees, Ecology assesses levels of developments of emerging technologies and posts relevant decisions and supporting documentation at its stormwater web site.

- Ecology provides oversight and analysis of all submittals to ensure consistency with this manual.

28.3 Applicability and Restrictions

The City of Tumwater has chosen to allow application of new technologies to be used to meet the requirements of this manual when they reach the GULD. The Administrator has the authority to add additional requirements or conditions to these technologies, beyond those required by Ecology. **Note that the City of Tumwater will not accept ownership of GULD facilities without prior approval.**

Additional general guidelines regarding the applicability and restrictions of emerging technologies are as follows:

- In most retrofit situations where the requirements of this manual are not triggered, emerging BMPs may be used, with prior approval by the city. The assumption is that an experimental BMP is better than nothing.

- The city may, in some circumstances, allow use of technologies receiving Conditional Use Level Designation (CULD). Any application of CULD technologies will be required to sign a maintenance agreement with the city, stating that they will be responsible for maintaining these structures at all times, in accordance with the manufacturer's requirements or as outlined for the specific CULD BMP by the city. This includes single-family residential applications. In addition, all property owners using these technologies will be responsible for upgrade/replacement of their systems in perpetuity. This includes upgrading or replacing these systems when problems arise, standards change, or the technology is ultimately rejected by the Technical Review Committee or the city.

- The City of Tumwater may allow pilot level applications of new technologies in order for manufacturers to obtain data to help fulfill the requirements of the testing protocol of the Technical Review Committee. These projects must be approved in advance by the Administrator, have an approved monitoring plan from the Technical Review Committee or Ecology, and provide a financial bond to provide cleanup and replacement in the event of failure.

Volume V References and Information Sources

API. 1990. *Design and Operation of Oil-Water Separators*. Publication 421. American Petroleum Institute. Washington D.C. February 1990.

ASCE & WEF. 1998. *Urban Runoff Quality Management*. American Society of Civil Engineers, Reston, VA. 1998.

Brater, Ernest F., and Horace.W. King. 1996. *Handbook of Hydraulics for the Solution of Hydraulic Engineering Problems*, 7th ed. McGraw-Hill, Boston, Massachusetts.

Caraco, Deborah and Richard Claytor. 1997. *Stormwater BMP Design Supplement for Cold Climates.* Center for Watershed Protection, Inc. Ellicott City, Maryland.

Center for Watershed Protection. 1998. *Better Site Design.* Center for Watershed Protection, Inc. Ellicott City, Maryland.

Chow, Ven Te. 1959. *Open Channel Hydraulics*. McGraw Hill Book Co., New York, New York.

Portland, City of. 2016. Avoiding Impacts on Nesting Birds: Best Management Practices for Vegetation and Construction Projects. City of Portland, Bureau of Environmental Services. <https://www.portlandoregon.gov/bes/index.cfm?a=322164>.

Ecology. 2006. *Guidance for UIC Wells that Manage Stormwater*. Publication Number 05-10-067. Washington State Department of Ecology, Olympia, Washington. December. Available online at: <https://apps.ecology.wa.gov/publications/documents/0510067.pdf >.

Ecology. 2019. *2019 Stormwater Management Manual for Western Washington*. Publication No. 19-10-021. Washington State Department of Ecology, Olympia, Washington.

FHWA. 1995. *Geosynthetic Design and Construction Guidelines*, Publication No. FHWA HI 95 038. Federal Highway Administration. May 1995.

WSU. 2013. *Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance*. Washington State University Extension.

Hitchcock, C. Leo, and Arthur Cronquist. 1973. *Flora of the Pacific Northwest.* University of Washington Press, Seattle, Washington.

Horner, W.R. 2000. Conservation Design: Managing Stormwater Through Maximizing Preventive Nonstructural Practices. In: *National Conference on Tools for Urban Water Resource Management and Protection*, Chicago, IL, pp. 147-157. U.S. Environmental Protection Agency.

Hortus Northwest. 1991. *Wetland Plants for Western Oregon*. Issue 2. 1991.

Jaisinghani, R.A., and G.S. Sprenger. 1979. A Study of Oil/Water Separation in Corrugated Plate Separators. *Journal of Engineering for Industry*. 101(4), pp. 441-448. November 1979.

Koerner, Robert M. and George R. Koerner. 1994. *NCHRP Report 367: Long-Term Performance of Geosynthetics in Drainage Applications*. National Academy Press. January 1, 1994.

Massman, Joel W. 2003. *A Design Manual for Sizing Infiltration Ponds*. Washington State Department of Transportation. October 2003.

Municipality of Metropolitan Seattle. 1990. *Water Pollution Control Aspects of Aquatic Plants: Implications for Stormwater Quality Management*. Office of Water Quality.

Pierce County. 2021. *Pierce County Stormwater and Site Development Manual*, December. Available online at: <https://www.piercecountywa.gov/DocumentCenter/View/106293/Stormwater-Management-and-Site-Development-Manual20210701%20target=>.

SCS. 1990. *Soil Survey of Thurston County, Washington.* U.S. Department of Agriculture, Soil Conservation Service, in cooperation with Washington State Department of Natural Resources and Washington State University, Agricultural Research Center. Issued June.

Seattle, City of. 2021. *City of Seattle Stormwater Manual*. January. Available online at: <http://www.seattle.gov/dpd/codesrules/codes/stormwater/>.

Schueler, Thomas R., Peter A. Kumble, and Maureen A. Heraty. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone*. Metropolitan Washington Council of Governments. 1992.

Schueler, Thomas R. 1994. Hydrocarbon Hotspots in the Urban Landscape: Can They be Controlled? *Watershed Protection Techniques*. 1(1), 3-5 February 1994.

Singh, Vijay P. 2016. *Handbook of Applied Hydrology*, 2nd ed. McGraw-Hill Education.

Stenn, H., C. Cogger, J. Girven, and D. McDonald. 2012. *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13*. Available online at: <https://www.soilsforsalmon.org/>.

U.S. Air Force. 1991. Gravity Oil and Water Separator Design Criteria.

U.S. Army Corps. of Engineers. 1994. *Selection and Design of Oil and Water Separators at Army Facilities*. Corps of Engineers Engineering Technical Letter (ETL) 1110-3-466. August 1994.

Water Pollution Control Federation. 1985. *Clarifier Design*. Manual of Practice FD-8. Water Pollution Control Federation. Task force on Clarifier Design. Washington, D.C. 1985.

WSU and PSP. 2012. *Low Impact Development: Technical Guidance Manual for Puget Sound*. Publication No. PSP 2012-3. Washington State University Extension and Puget Sound Partnership. December

Appendix V-A – Methods for Determining Design Infiltration Rates

V-A.1 Determining Design Infiltration Rates

There are two acceptable methods for estimating initial infiltration rates. Each is described in detail in Sections A.2 and A.3 of this appendix. A safety/correction factor is applied to the initial rate to determine the design infiltration rate. Note that the subgrade safety/correction factors in this appendix may not apply to bioretention, permeable pavement, and rain gardens. Refer to Chapters 9 through 11 for additional guidance on infiltration testing methods and application of appropriate safety/correction factors specific to bioretention, rain gardens, and permeable pavement.

- Method 1. Field Testing Procedures (must incorporate safety factor):
    - Large-Scale Pilot Infiltration Test (PIT). This test applies to infiltration facilities with drainage areas greater than 1 acre and may be used to demonstrate infeasibility of bioretention, rain gardens, or permeable pavement in meeting Minimum Requirement #5.
    - Small-Scale PIT. This test applies to infiltration facilities with drainage areas less than 1 acre and may be used to demonstrate infeasibility of bioretention, rain gardens, or permeable pavement in meeting Minimum Requirement #5.
- Method 2. Soil Grain Size Analysis: This method applies to project sites that are that are underlain by Type A soils (refer to the NRCS Web Soil Survey at the following web site: <http://websoilsurvey.sc.egov.usda.gov>), and may not be used to demonstrate infeasibility of bioretention, rain gardens, or permeable pavement in meeting Minimum Requirement #5.

Section A.4 of this appendix describes the recommended modifications to ASTM D2434 (standard test method for permeability of granular soils) for measuring hydraulic conductivity of bioretention soil mixes. These modifications were developed by the City of Seattle in cooperation with local soils laboratories specifically for bioretention soil mixes.

V-A.2 Method 1 – Field Infiltration Testing Procedures

- Excavate to the bottom elevation of the proposed infiltration facility. Measure the infiltration rate of the underlying soil using the Ecology large- and small-scale PIT described below and presented in the 2014 Ecology Manual.
- Fill test hole or apparatus with water and maintain at depths above the test elevation for the saturation periods specific for the appropriate test.

- Following the saturation period, the infiltration rate shall be determined in accordance with the specified test procedures.

- See the individual BMP descriptions for requirements related to the number and location of tests required.

  Note: The certified soils professional or engineer can exercise discretion concerning infiltration testing if in their judgment information exists confirming that the site is unconsolidated outwash material (high infiltration rates) and there is adequate depth to groundwater.

- If the general site assessment cannot confirm that the seasonal high groundwater or hydraulic restricting layer will be greater than 1 or 3 feet below the bottom of the bioretention facility (depending on contributing area, see Chapter 9) and 1 foot below the bottom of the lowest gravel base course of permeable pavement (subgrade surface), monitoring wells or excavated pits must be placed strategically to assess depth to groundwater.

- For all field testing procedures, apply safety factor to obtain design infiltration rate (see next section).

V-A.2.1 Safety Factor for Field Measurements

The following equation incorporates safety factors to adjust for uncertainties related to testing, depth to the water table or impervious strata, infiltration receptor geometry, and long-term reductions in permeability due to biological activity and accumulation of fines. Note that the safety factors below may not apply to the infiltration testing conducted for bioretention, permeable pavement and/or rain gardens (see Chapters 9 through 11 for additional information). This equation estimates the maximum design infiltration rate, I_{design}. Additional reduction of the design infiltration rate may be appropriate depending on-site conditions. **In no case shall the design infiltration rate exceed 20 inches per hour**.

$$I_{design} = I_{measured} \times F_{testing} \times F_{geometry} \times F_{plugging}$$

$F_{testing}$ accounts for uncertainties in the testing methods. For the full-scale PIT method, $F_{testing} = 0.75$; for the small-scale PIT and falling head percolation test method, $F_{testing} = 0.50$; for grain size analysis, $F_{testing} = 0.40$. These values are intended to represent the difference in each test's ability to estimate the actual saturated hydraulic conductivity. The assumption is the larger the scale of the test, the more reliable the result.

$F_{geometry}$ accounts for the influence of facility geometry and depth to the water table or impervious strata on the actual infiltration rate. A shallow water table or impervious layer will reduce the effective infiltration rate of a large pond, but this would not be reflected in a small-scale test. $F_{geometry}$ must be between 0.25 and 1.0 as determined by the following equation:

$$F_{geometry} = 4\ D/W + 0.05$$

Where:

D = depth from the bottom of the proposed facility to the maximum winter season water table or nearest impervious layer, whichever is less.

W = width of facility

$F_{plugging}$ accounts for reductions in infiltration rates over the long term due to plugging of soils. This factor is:

- 0.7 for loams and sandy loams
- 0.8 for fine sands and loamy sands
- 0.9 for medium sands
- 1.0 for coarse sands or cobbles

V-A.2.2 Washington Department of Ecology PIT Methods

Large-Scale Pilot Infiltration Test (PIT)

Large-scale in-situ infiltration measurements, using the PIT described below is the preferred method for estimating the measured (initial) saturated hydraulic conductivity (K_{sat}) of the soil profile beneath the proposed infiltration facility. The PIT reduces some of the potential scale errors associated with relatively small-scale tests such as the Modified Falling Head Percolation Test, double ring infiltrometer, or “stove-pipe” infiltration tests. It is not a standard test but rather a practical field procedure recommended by Ecology’s Technical Advisory Committee.

Infiltration Test:

- Excavate the test pit to the depth of the bottom of the proposed infiltration facility. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be approximately 100 square feet.
- Accurately document the size and geometry of the test pit.

- Install a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom.

- Use a rigid 6-inch-diameter pipe with a splash plate on the bottom to convey water to the pit and reduce side wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates.

- Add water to the pit at a rate that will maintain a water level between 6 and 12 inches above the bottom of the pit. A rotameter can be used to measure the flow rate into the pit.

Note: For infiltration facilities serving large drainage areas, designs with multiple feet of standing water can have infiltration tests with greater than 1 foot of standing water. The depth must not exceed the proposed maximum depth of water expected in the completed facility.

Every 15 to 30 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point on the measuring rod.

Add water to the pit until 1 hour after the flow rate into the pit has stabilized (constant flow rate; a goal of 5 percent variation or less variation in the total flow) while maintaining the same pond water level (usually 6 hours). The total of the pre-soak time plus 1 hour after the flow rate has stabilized should be no less than 6 hours.

After the flow rate has stabilized for at least 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty. Consider running this falling head phase of the test several times to estimate the dependency of infiltration rate with head.

Data Analysis:

Calculate and record the infiltration rate in inches per hour in 30 minutes or 1-hour increments until 1 hour after the flow has stabilized.

Note: Use statistical/trend analysis to obtain the hourly flow rate when the flow stabilizes. This would be the lowest hourly flow rate.

To compute the design infiltration rate (I_{design}), apply appropriate safety factors outlined previously.

Example:

The area of the bottom of the test pit is 8.5 feet by 11.5 feet.

Water flow rate was measured and recorded at intervals ranging from 15 to 30 minutes throughout the test. Between 400 minutes and 1,000 minutes, the flow rate stabilized between 10 and 12.5 gallons per minute or 600 to 750 gallons per hour, or an average of (9.8 + 12.3) / 2 = 11.1 inches per hour.

To compute the design infiltration rate (I_{design}), the infiltration rate must then be adjusted by the appropriate safety factors outlined previously.

Small-Scale Pilot Infiltration Test

A smaller-scale PIT can be used in any of the following instances.

- The drainage area to the infiltration site is less than 1 acre.
- The testing is for bioretention areas or permeable pavement surfaces that either serve small drainage areas (refer to Chapter 9 through 11 for specific applications to bioretention, rain garden, and permeable pavements) and/or are widely dispersed throughout a project site.
- The site has a high infiltration rate, making a large-scale PIT difficult, and the site geotechnical investigation suggests uniform subsurface characteristics.
- Verification of performance testing of permeable pavement or bioretention subgrade prior to placement of the material.

Infiltration Test

- Excavate the test pit to the estimated surface elevation of the proposed infiltration facility. In the case of bioretention, excavate to the estimated elevation at which the imported soil mix will lie on top of the underlying native soil. For permeable pavement, excavate to the elevation at which the imported subgrade materials, or the pavement itself, will contact the underlying native soil. If the native soils (road subgrade) will have to meet a minimum subgrade compaction requirement, compact the native soil to that requirement prior to testing. Note that the permeable pavement design guidance recommends compaction not exceed 90 to 92 percent. Finally, lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be 12 to 32 square feet. It may be circular or rectangular, but accurately document the size and geometry of the test pit.
- For verification of performance testing of permeable pavement or bioretention subgrade a 4-foot to 7-foot diameter ring (e.g., manhole riser section, pipe segment) may be embedded into the subgrade (without disturbing the material in the center of the ring). Care must be taken to backfill around the ring to minimize water loss around the bottom edge of the ring. Depending on soil conditions, you may have to pack low-permeability soil or mix a very small amount of ready-mix concrete into the soil, around the inside edge of the ring, to make a seal.

- Install a vertical measuring rod adequate to measure the ponded water depth and that is marked in half-inch increments in the center of the pit bottom.
- Use a rigid pipe with a splash plate on the bottom to convey water to the pit and reduce side wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates. Use a 3-inch-diameter pipe for pits on the smaller end of the recommended surface area, and a 4-inch pipe for pits on the larger end of the recommended surface area.
- Pre-soak period: Add water to the pit so that there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
- At the end of the pre-soak period, add water to the pit at a rate that will maintain a 6- to 12-inch water level above the bottom of the pit over a full hour. The depth must not exceed the proposed maximum depth of water expected in the completed facility.
- Every 15 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point (between 6 to 12 inches) on the measuring rod. The specific depth should be the same as the maximum designed ponding depth (usually 6 to 12 inches).
- After 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty.
- A self-logging pressure sensor may also be used to determine water depth and drain-down.

Data Analysis

See the explanation under the guidance for large-scale PIT.

V-A.3 Method 2 – Soil Grain Size Analysis Method

For each defined layer below the infiltration basin to a depth below the pond bottom of 2.5 times the maximum depth of water in the pond, but not less than 10 feet, estimate the initial saturated hydraulic conductivity (K_{sat}) in cm/sec using the following relationship (see Massman 2003). This method may only be applied to project sites that are underlain by Type A soils. Refer to the NRCS Web Soil Survey at the following web site: <http://websoilsurvey.sc.egov.usda.gov>.

For large infiltration facilities serving drainage areas of 10 acres or more, soil grain size analyses should be performed on layers up to 50 feet deep (or no more than 10 feet below the water table).

$$\log_{10}(K_{sat}) = -1.57 + 1.90D_{10} + 0.015D_{60} - 0.013D_{90} - 2.08\mathrm{f}_{\mathrm{fines}}$$

Where, D_{10}, D_{60}, and D_{90} are the grain sizes in mm for which 10 percent, 60 percent, and 90 percent of the sample is more fine and f_{fines} is the fraction of the soil (by weight) that passes the U.S. #200 sieve (K_{sat} is in cm/s).

For bioretention areas, analyze each defined layer below the top of the final bioretention area subgrade to a depth of at least 3 times the maximum ponding depth, but not less than 3 feet (1 meter). For permeable pavement, analyze for each defined layer below the top of the final subgrade to a depth of at least 3 times the maximum ponding depth within the base (reservoir) course, but not less than 3 feet (1 meter).

If the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, soil layers at greater depths must be considered when assessing the site's hydraulic conductivity characteristics. Massman (2003) indicates that where the water table is deep, soil or rock strata up to 100 feet below an infiltration facility can influence the rate of infiltration. Note that only the layers near and above the water table or low permeability zone (e.g., a clay, dense glacial till, or rock layer) need to be considered, as the layers below the groundwater table or low permeability zone do not significantly influence the rate of infiltration. Also note that this equation for estimating K_{sat} assumes minimal compaction consistent with the use of tracked (i.e., low to moderate ground pressure) excavation equipment.

If the soil layer being characterized has been exposed to heavy compaction (e.g., due to heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires) the hydraulic conductivity for the layer could be approximately an order of magnitude less than what would be estimated based on grain size characteristics alone (Pitt 2003). In such cases, compaction effects must be taken into account when estimating hydraulic conductivity.

For clean, uniformly graded sands and gravels, the reduction in K_{sat} due to compaction will be much less than an order of magnitude. For well-graded sands and gravels with moderate to high silt content, the reduction in K_{sat} will be close to an order of magnitude. For soils that contain clay, the reduction in K_{sat} could be greater than an order of magnitude.

If greater certainty is desired, the in-situ saturated conductivity of a specific layer can be obtained through the use of a PIT. Note that these field tests generally provide a K_{sat} combined with a hydraulic gradient. In some of these tests, the hydraulic gradient may be close to 1.0; therefore, in effect, the test infiltration rate result is the same as the hydraulic conductivity. In other cases, the hydraulic gradient may be close to the gradient that is likely to occur in the full-scale infiltration facility. The hydraulic gradient will need to be evaluated on a case-by-case basis when interpreting the results of field tests. It is important to recognize that the gradient in the test may not be the same as the gradient likely to occur in the full-scale infiltration facility in the long-term (i.e., when groundwater mounding is fully developed).

Once the K_{sat} for each layer has been identified, determine the effective average K_{sat} below the pond. K_{sat} estimates from different layers can be combined using the harmonic mean:

$$K_{equiv} = \frac{d}{\sum \frac{d_i}{K_i}}$$

Where, d is the total depth of the soil column, d_i is the thickness of layer "*i*" in the soil column, and K_i is the saturated hydraulic conductivity of layer "*i*" in the soil column. The depth of the soil column, d, typically would include all layers between the pond bottom and the water table. However, for sites with very deep water tables (>100 feet) where groundwater mounding to the base of the pond is not likely to occur, it is recommended that the total depth of the soil column in Equation 2 be limited to approximately 20 times the depth of pond, but not more than 50 feet. This is to ensure that the most important and relevant layers are included in the hydraulic conductivity calculations. Deep layers that are not likely to affect the infiltration rate near the pond bottom need not be included in Equation 2.

Equation 2 may over-estimate the effective K_{sat} value at sites with low conductivity layers immediately beneath the infiltration basin. For sites where the lowest conductivity layer is within 5 feet of the base of the pond, it is suggested that this lowest K_{sat} value be used as the equivalent hydraulic conductivity rather than the value from Equation 2. Using the layer with the lowest K_{sat} is advised for designing bioretention areas or permeable pavement surfaces. The harmonic mean given by Equation 2 is the appropriate effective hydraulic conductivity for flow that is perpendicular to stratigraphic layers, and will produce conservative results when flow has a significant horizontal component such as could occur due to groundwater mounding.

V-A.4 Recommended Modifications to ASTM D2434 When Measuring Hydraulic Conductivity for Bioretention Soil Mixes

Developed by the City of Seattle in cooperation with local soils laboratories.

Proctor method ASTM D1557 Method C (6-inch mold) and ASTM D2434 shall be used to determine the hydraulic conductivity of bioretention soil samples with a compaction rate of 85 percent. Sample preparation for the Proctor test (ASTM D1557 Method C) shall be amended in the following ways:

1. Maximum grain size within the sample shall be no more than 0.5 inches in size.

2. Snip larger organic particles (if present) into 0.5-inch-long pieces.

3. When adding water to the sample during the Proctor test, allow the sample to pre-soak for at least 48 hours to allow the organics to fully saturate before compacting the sample. This pre-soak ensures the organics have been fully saturated at the time of the test.

ASTM D2434 shall be used and amended in the following ways:

1. Apparatus:
    a. 6-inch mold size shall be used for the test
    b. If using porous stone disks for the testing, the permeability of the stone disk shall be measured before and after the soil tests to ensure clogging or decreased permeability has not occurred during testing
    c. Use the confined testing method, with 5- to 10-pound force spring
    d. Use de-aired water.
2. Sample:
    a. Maximum grain size within the sample shall not be more than 0.5 inch in size.
    b. Snip larger organic particles (if present) into 0.5-inch-long pieces.
    c. Pre-soak the sample for at least 48 hours prior to loading it into the mold. During the pre-soak, the moisture content shall be higher than optimum moisture but less than full saturation (i.e., there shall be no free water). This pre-soak ensures the organics have been fully saturated at the time of the test.
3. Preparation of Sample:
    a. Place soil in cylinder via a scoop.
    b. Place soil in 1-inch lifts and compact using a 2-inch-diameter round tamper. Pre-weigh how much soil is necessary to fill 1-inch lift at 85 percent of maximum dry density, then tamp to 1-inch thickness. Once mold is full, verify that density is at 85 percent of maximum dry density (+ or -0.5 percent). Apply vacuum (20 inches Hg) for 15 minutes before inundation.
    c. Inundate sample slowly under a vacuum of 20 inches Hg over a period of 60 to 75 minutes.
    d. Slowly remove vacuum (>15 seconds).
    e. Sample shall be soaked in the mold for 24 to 72 hours before starting test.

4. Procedure:

   a. The permeability test shall be conducted over a range of hydraulic gradients between 0.1 and 2

   b. Steady state flow rates shall be documented for four consecutive measurements before increasing the head

   c. The permeability test shall be completed within 1 day (1-day test duration).

Appendix V-B – On-Site Stormwater Management BMP Infeasibility Criteria

The following tables present infeasibility criteria that can be used to justify not using various on-site stormwater management BMPs for consideration in the List #1 or List #2 option of Minimum Requirement #5. This information is also included under the detailed descriptions of each BMP, but is provided here in this appendix for additional clarity and efficiency. Where any inconsistencies or lack of clarity exists, the requirements in the main text of each volume shall be applied. If a project is limited by one or more of the infeasibility criteria specified below, but still wishes to use the given BMP, they may propose a functionally equivalent design to the City of Tumwater for review and approval.

Lawn and Landscaped Areas	
BMP	**Infeasibility Criteria**
Postconstruction Soil Quality and Depth	• Siting and design criteria provided in Chapter 6 cannot be achieved.
Roofs	
BMP	**Infeasibility Criteria**
Full Dispersion	• Site setbacks and design criteria provided in Chapter 7 (under Full Dispersion) cannot be achieved. • A 65 to 10 ratio of forested or native vegetation area to impervious area cannot be achieved. • A minimum forested or native vegetation flowpath length of 100 feet (25 feet for sheet flow from a nonnative pervious surface) cannot be achieved.
Downspout Infiltration Systems	• Site setbacks and design criteria provided in Chapter 15 (Downspout Infiltration Systems) cannot be achieved. • The lot(s) or site does not have outwash or loam soils. • There is not at least 12 inches or more of permeable soil from the proposed bottom (final grade) of the infiltration system to the known or seasonal high groundwater table or other impermeable layer.
Downspout Dispersion Systems	• Site setbacks and design criteria provided in Chapter 15 (Downspout Dispersion) cannot be achieved. • For splashblocks, a vegetated flowpath at least 50 feet in length from the downspout to the downstream property line, structure, stream, wetland, or other impervious surface is not feasible. • For trenches, a vegetated flowpath of at least 25 feet in between the outlet of the trench and any property line, structure, stream, wetland, or impervious surface is not feasible.

Roofs (continued)	
BMP	**Infeasibility Criteria**
Bioretention or Rain Gardens	Note: criteria with setback distances are as measured from the bottom edge of the bioretention soil mix. Citation of any of the following infeasibility criteria must be based on an evaluation of site-specific conditions and a written recommendation from an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist): • Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or downgradient flooding. • Where the only area available for siting would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, pre-existing structures, or pre-existing road or parking lot surfaces. • Where the only area available for siting does not allow for a safe overflow pathway to stormwater drainage system or private storm sewer system. • Where there is a lack of usable space for bioretention areas at re-development sites, or where there is insufficient space within the existing public right-of-way on public road projects. • Where infiltrating water would threaten existing below grade basements. • Where infiltrating water would threaten shoreline structures such as bulkheads. The following criteria can be cited as reasons for infeasibility without further justification (though some require professional services to make the observation): • Within setbacks provided in Chapter 9, Section 9.6.1, Setbacks and Site Constraints. • Where they are not compatible with surrounding drainage system as determined by the city (e.g., project drains to an existing stormwater collection system whose elevation or location precludes connection to a properly functioning bioretention area). • Where land for bioretention is within an erosion hazard, or landslide hazard area (as defined by Title 16.20 TMC). • Where the site cannot be reasonably designed to locate bioretention areas on slopes less than 8 percent. • For properties with known soil or groundwater contamination (typically federal Superfund sites or state cleanup sites under the Model Toxics Control Act [MTCA]): - Within 100 feet of an area known to have deep soil contamination. - Where groundwater modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the groundwater. - Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area. - Any area where these facilities are prohibited by an approved cleanup plan under the state Model Toxics Control Act or Federal Superfund Law, or an environmental covenant under Chapter 64.70 RCW.

Roofs (continued)	
BMP	**Infeasibility Criteria**
Bioretention or Rain Gardens (continued)	• Within 100 feet of a closed or active landfill. • Within 10 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is 1,100 gallons or less. (As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10 percent or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface. • Within 100 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is greater than 1,100 gallons. • Where field testing indicates potential bioretention/rain garden sites have a measured (a.k.a., initial) native soil saturated hydraulic conductivity less than 0.30 inches per hour. A small-scale or large-scale PIT in accordance with Appendix V-A shall be used to demonstrate infeasibility of bioretention areas. If the measured native soil infiltration rate is less than 0.30 in/hour, bioretention/rain garden BMPs are not required to be evaluated as an option in List #1 or List #2. In these slow draining soils, a bioretention area with an underdrain may be used to treat pollution-generating surfaces to help meet Minimum Requirement #6, Runoff Treatment. If the underdrain is elevated within a base course of gravel, it will also provide some modest flow reduction benefit that will help achieve Minimum Requirement #7.
Bioretention or Rain Gardens (continued)	• Where the minimum vertical separation of 3 feet to the known or seasonal high groundwater elevation or other impermeable layer would not be achieved below bioretention that would serve a drainage area that exceeds the following thresholds: - 5,000 square feet of pollution-generating impervious surface (PGIS) - 10,000 square feet of impervious area - 0.75 acre of lawn and landscape. • Where the minimum vertical separation of 1 foot to the known or seasonal high groundwater or other impermeable layer would not be achieved below bioretention that would serve a drainage area less than the above thresholds.
Perforated Stub-Out Connections	• Site setbacks and design criteria provided in Chapter 15, Section 15.5, Perforated Stub-Out Connections, cannot be achieved. • There is not at least 1 foot of permeable soil from the proposed bottom (final grade) of the perforated stub-out connection trench to the highest estimated groundwater table or other impermeable layer. • The only location available for the perforated stub-out connection is under impervious or heavily compacted soils. • For sites with septic systems, the only location available for the perforated portion of the pipe is located upgradient of the drainfield primary and reserve areas. This requirement can be waived if site topography will clearly prohibit flows from intersecting the drainfield or where site conditions (soil permeability, distance between systems, etc.) indicate that this is unnecessary. • The connecting pipe discharges to a stormwater facility designed to meet Minimum Requirement #7.
Full Dispersion	• See Full Dispersion in “Roofs” section of this table, above.

<table>
<tr><th colspan="2">Other Hard Surfaces</th></tr>
<tr><th>BMP</th><th>Infeasibility Criteria</th></tr>
<tr><td>Permeable Pavement</td><td>Citation of any of the following infeasibility criteria must be based on an evaluation of site-specific conditions and a written recommendation from an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist):
• Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or downgradient flooding.
• Where infiltrating and ponded water below the new permeable pavement area would compromise adjacent impervious pavements.
• Where infiltrating water below a new permeable pavement area would threaten existing below grade basements.
• Where infiltrating water would threaten shoreline structures such as bulkheads.
• Down slope of steep, erosion prone areas that are likely to deliver sediment.
• Where fill soils are used that can become unstable when saturated.
• Excessively steep slopes where water within the aggregate base layer or at the subgrade surface cannot be controlled by detention structures and may cause erosion and structural failure, or where surface runoff velocities may preclude adequate infiltration at the pavement surface.
• Where permeable pavements cannot provide sufficient strength to support heavy loads at industrial facilities such as ports.
• Where installation of permeable pavement would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, or pre-existing road subgrades.
The following criteria can be cited as reasons for infeasibility without further justification (though some require professional services to make the observation):
• Within setbacks provided in Chapter 11, Section 11.6.1, Setbacks and Site Constraints.
• For properties with known soil or groundwater contamination (typically federal Superfund sites or state cleanup sites under the Model Toxics Control Act [MTCA]):
- Within 100 feet of an area known to have deep soil contamination.
- Where groundwater modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the groundwater.
- Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area.
• Any area where these facilities are prohibited by an approved cleanup plan under the state Model Toxics Control Act or Federal Superfund Law, or an environmental covenant under Chapter 64.70 RCW.
• Within 100 feet of a closed or active landfill.
• Within 10 feet of any underground storage tank and connecting underground pipes, regardless of tank size. As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10 percent or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface.
• At multi-level parking garages, and over culverts and bridges.
• Where the site design cannot avoid putting pavement in areas likely to have long-term excessive sediment deposition after construction (e.g., construction and landscaping material yards).</td></tr>
</table>

Other Hard Surfaces (continued)	
BMP	**Infeasibility Criteria**
Permeable Pavement (continued)	• Where the site cannot reasonably be designed to have a porous asphalt surface at less than 5 percent slope, or a pervious concrete surface at less than 10 percent slope, or a permeable interlocking concrete pavement surface (where appropriate) at less than 12 percent slope. Grid systems upper slope limit can range from 6 to 12 percent; check with manufacturer and local supplier. • Where the subgrade soils below a pollution-generating permeable pavement (e.g., road or parking lot) do not meet the soil suitability criteria for providing treatment. See soil suitability criteria for treatment in Chapter 23. Note: In these instances, the city may approve installation of a 6-inch sand filter layer meeting city specifications for treatment as a condition of construction. • Where underlying soils are unsuitable for supporting traffic loads when saturated. Soils meeting a California Bearing Ratio of 5 percent are considered suitable for residential access roads. • Where appropriate field testing indicates soils have a measured (a.k.a., initial) subgrade soil saturated hydraulic conductivity less than 0.3 inches per hour. Only small-scale PIT or large-scale PIT methods in accordance with Appendix V-A shall be used to evaluate infeasibility of permeable pavement areas. (Note: In these instances, unless other infeasibility restrictions apply, roads and parking lots may be built with an underdrain, preferably elevated within the base course, if flow control benefits are desired.) • Roads that receive more than very low traffic volumes, and areas having more than very low truck traffic. Roads with a projected average daily traffic volume of 400 vehicles or less are very low volume roads (AASHTO 2001; U.S. Department of Transportation 2013). Areas with very low truck traffic volumes are roads and other areas not subject to through truck traffic but may receive up to weekly use by utility trucks (e.g., garbage, recycling), daily school bus use, and multiple daily use by pick-up trucks, mail/parcel delivery trucks, and maintenance vehicles. Note: This infeasibility criterion does not extend to sidewalks and other non-traffic bearing surfaces associated with the collector or arterial. • Where replacing existing impervious surfaces unless the existing surface is a non-pollution generating surface over an outwash soil with a saturated hydraulic conductivity of 4 inches per hour or greater. • At sites defined as “high-use sites.” For more information on high-use sites, refer to the Glossary in Appendix I-A. • In areas with “industrial activity” as defined in the Glossary (located in Appendix I-A). • Where the risk of concentrated pollutant spills is more likely such as gas stations, truck stops, and industrial chemical storage sites. • Where routine, heavy applications of sand occur in frequent snow zones to maintain traction during weeks of snow and ice accumulation. • Where the known or seasonal high groundwater or an underlying impermeable/low permeable layer would create saturated conditions within 1 foot of the bottom of the lowest gravel base course.

Other Hard Surfaces (continued)	
BMP	**Infeasibility Criteria**
Bioretention or Rain Gardens	• See Bioretention in "Roofs" section of this table, above.
Sheet Flow Dispersion	• Site setbacks and design criteria provided in Chapter 7 (Sheet Flow Dispersion) cannot be achieved. • Positive drainage for sheet flow runoff cannot be achieved. • Area to be dispersed (e.g., driveway, patio) cannot be graded to have less than a 15 percent slope. • For flat to moderately sloped areas, at least a 10-foot-wide vegetation buffer for dispersion of the adjacent 20 feet of contributing surface cannot be achieved. For variably sloped areas, at least a 25-foot vegetated flowpath between berms cannot be achieved.
Concentrated Flow Dispersion	• Site setbacks and design criteria provided in Chapter 7, Section 7.4, Concentrated Flow Dispersion, cannot be achieved. • A minimum 3-foot length of rock pad and 50-foot flowpath OR a dispersion trench and 25-foot flowpath for every 700 square feet of drainage area followed with applicable setbacks cannot be achieved. • More than 700 square feet of drainage area drains to any dispersion device.

Appendix V-C – Geotextile Specifications

Table C.1. Geotextile Property Requirements for Underground Drainage.[a]

Geotextile Property	Test Method	Low Survivability Woven/Nonwoven	Moderate Survivability Woven/Nonwoven
Grab Tensile Strength, in machine and x-machine direction	ASTM D4632	180 lbs/115 lbs min.	250 lbs/160 lbs min.
Grab Failure Strain, in machine and x-machine direction	ASTM D4632	< 50%/ >= 50%	< 50%/ >= 50%
Seam Breaking Strength (if seams are present) with seam located in the center of 8-inch long specimen oriented parallel to grip faces	ASTM D4632	160 lbs/100 lbs min.	220 lbs/140 lbs min.
Puncture Resistance	ASTM D6241	730 lbs/220 lbs min.	495 lbs/310 lbs min.
Tear Strength, in machine and x-machine direction	ASTM D4533	67 lbs/40 lbs min.	80 lbs/50 lbs min.
Ultraviolet (UV) Radiation stability	ASTM D4355	50% strength retained min., after 500 hrs. in a xenon arc device	50% strength retained min., after 500 hrs. in a xenon arc device

[a] All geotextile properties are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table).

Table C.2. Geotextile Property Requirements for Underground Drainage Filtration.[a]

Geotextile Property	Test Method	Class A	Class B	Class C
AOS[b]	ASTM D4751	No. 40 max.	No. 60 max.	No. 80 max.
Water Permittivity	ASTM D4491	0.5 sec $^{-1}$ min.	0.4 sec $^{-1}$ min.	0.3 sec $^{-1}$ min.

[a] All geotextile properties are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table).

[b] Apparent Opening Size (measure of diameter of the pores in the geotextile).

Table C.3. Geotextile Strength Property Requirements for Impermeable Liner Protection.

Geotextile Property	Test Method	Geotextile Property Requirementsa
Grab Tensile Strength, min. in machine and x-machine direction	ASTM D4632	250 lbs min.
Grab Failure Strain, in machine and x-machine direction	ASTM D4632	> 50%
Seam Breaking Strength (if seams are present)	ASTM D4632 and ASTM D4884 (adapted for grab test)	220 lbs min.
Puncture Resistance	ASTM D4833	125 lbs min.
Tear Strength, min. in machine and x-machine direction	ASTM D4533	90 lbs min.
Ultraviolet (UV) Radiation	ASTM D4355	50% strength stability retained min., after 500 hrs. in xenon arc device

[a] All geotextile properties are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table).

Applications

- For an infiltration drain specify Geotextile for Underground Drainage, low survivability, Class C, from Tables C.1 and C.2 in the Geotextile Specifications.

- For a sand bed cover a geotextile fabric is placed exposed on top of the sand layer to trap debris brought in by the stormwater and to protect the sand, facilitating easy cleaning of the surface of the sand layer. However, a geotextile is not the best product for this application. A polyethylene or polypropylene geonet would be better. The geonet material should have high UV resistance (90 percent or more strength retained after 500 hours in the weatherometer, ASTM D4355), and high permittivity (ASTM D4491, 0.8 sec. -1 or more) and percent open area (CWO-22125, 10 percent or more). Tensile strength should be on the order of 200 lbs grab (ASTM D4632) or more.

Courtesy of Tony Allen, Geotechnical Engineer—WSDOT.

Reference for Tables C.1 and C.2: Section 9-33.2 "Geotextile Properties," 2014 *Standard Specifications for Road, Bridge, and Municipal Construction*.

Appendix V-D – Structures

Control structures are catch basins or manholes with a restrictor device that controls outflow from a facility to meet the desired performance. Riser-type restrictor devices ("tees" or "FROP-Ts") also provide some incidental oil and water separation, temporarily detaining oil or other floatable pollutants entering runoff due to accidental spill or illegal dumping.

Bypass and diversion structures are used to isolate flows when only part of the contributing flows are being directed to water quality.

V-D.1 Control Structures

Control structures are used when there is a need to control outflow flow rates from a BMP facility.

V-D.1.1 Applicability

The structures included in this appendix apply to the following BMPs:

- Detention Ponds
- Detention Tanks
- Detention Vaults
- Wet Ponds.

Bypass and diversion structures apply to any BMPs that are designed to be "off-line," where only part of the contributing stormwater flow is routed to the treatment BMP.

V-D.1.2 Hydrologic and Hydraulic Design Considerations

Control structure restrictor devices usually consist of two or more orifices and/or a weir section sized to meet performance requirements. Several publicly available and proprietary stormwater modeling programs are capable of designing control structures.

Methods of Analysis

This section presents methods and equations for design of *control structure restrictor devices*. Included are details for the design of orifices, rectangular sharp-crested weirs, v-notch weirs, sutro weirs, and overflow risers.

Rectangular notched weirs are typically most efficient and will result in the optimal detention system design using WWHM.

Orifices

Flow-through orifice plates in the standard tee section or turn-down elbow may be approximated by the general equation:

$$Q = C\,A\sqrt{2gh} \qquad \text{(equation 4)}$$

where: Q = flow (cfs)
C = coefficient of discharge (0.62 for plate orifice)
A = area of orifice (ft^2)
h = hydraulic head (ft)
g = acceleration of gravity (32.2 ft/sec^2)

Figure D.1 illustrates this simplified application of the orifice equation.

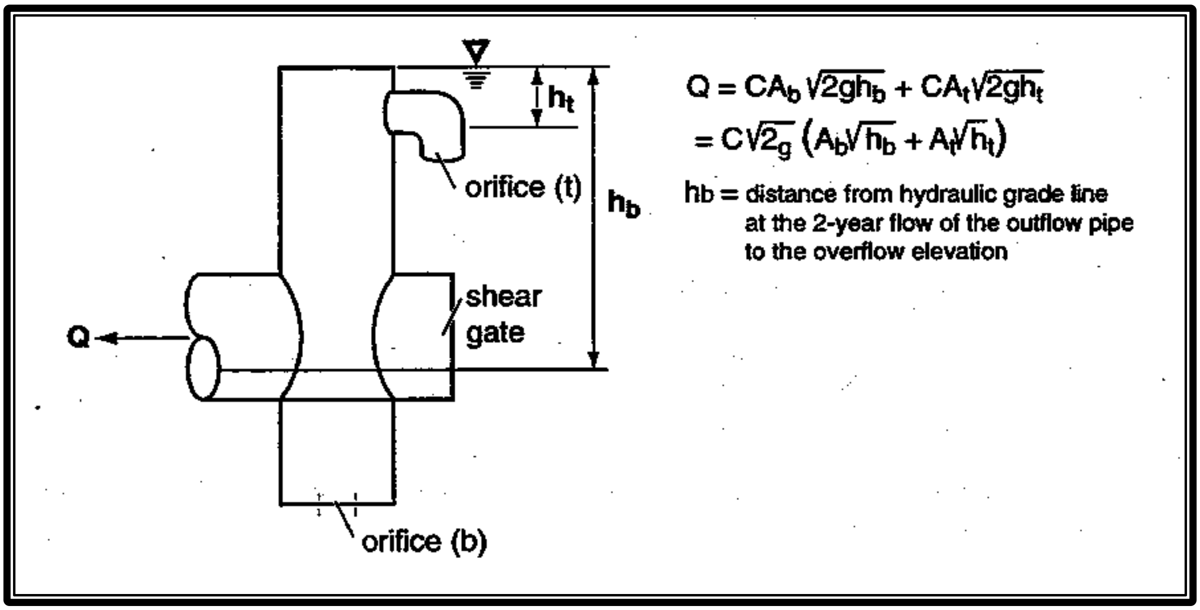


Figure D.1. Simple Orifice.

The diameter of the orifice is calculated from the flow. The orifice equation is often useful when expressed as the orifice diameter in inches:

$$d = \sqrt{\frac{36.88Q}{\sqrt{h}}} \qquad \text{(equation 5)}$$

where *d* = orifice diameter (inches)
Q = flow (cfs)
h = hydraulic head (ft)

Rectangular Sharp-Crested Weir

The rectangular, sharp-crested weir design shown in Figure D.2 may be analyzed using standard weir equations for the fully contracted condition.

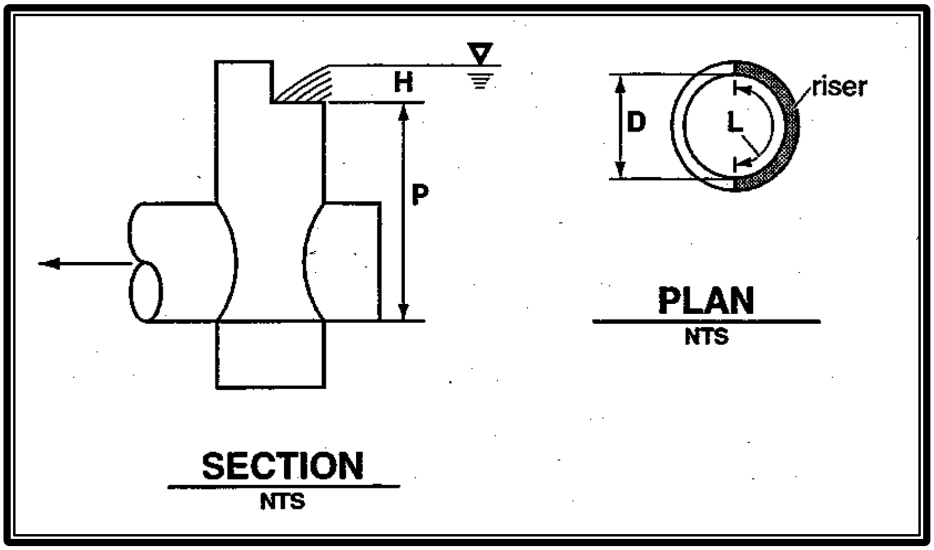


Figure D.2. Rectangular, Sharp-Crested Weir.

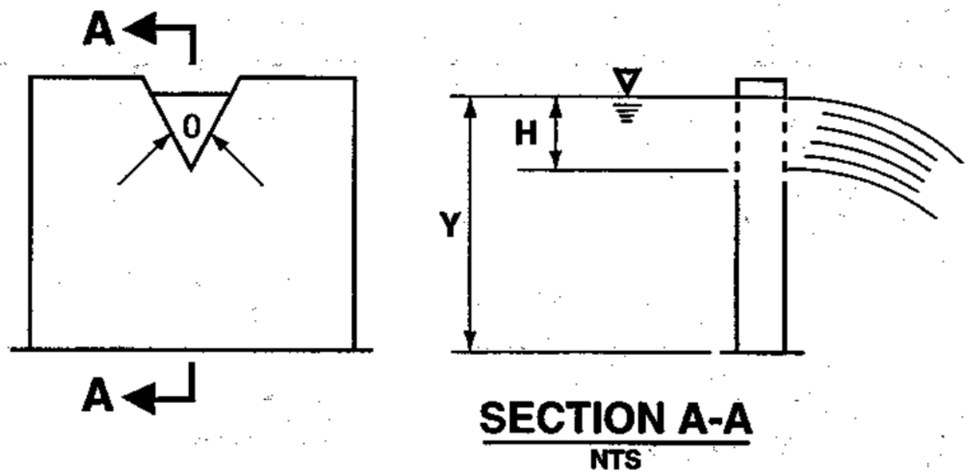
$$Q=C\,(L - 0.2H)H^{3/2} \qquad \text{(equation 6)}$$

where Q = flow (cfs)
C = 3.27 + 0.40 H/P (ft)
H, P are as shown above
L = length (ft) of the portion of the riser circumference as necessary not to exceed 50 percent of the circumference
D = inside riser diameter (ft)

Note that this equation accounts for side contractions by subtracting 0.1H from L for each side of the notch weir.

V-Notch, Sharp-Crested Weir

V-notch weirs as shown in Figure D.3 may be analyzed using standard equations for the fully contracted condition.



$$Q = C_d(\tan \Theta/2)H^{5/2}\text{, in cfs}$$

Where values of C_d may be taken from the following chart:

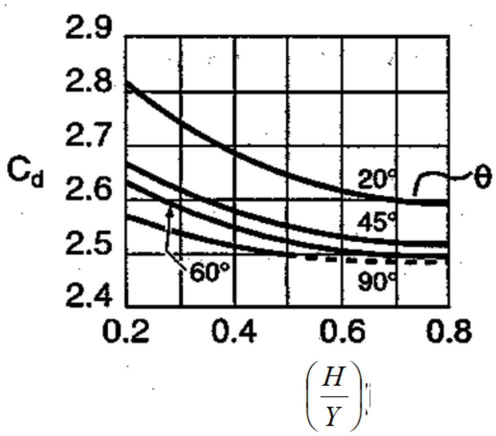


Figure D.3. V-Notch, Sharp-Crested Weir.

Proportional or Sutro Weir

Sutro weirs are designed so that the discharge is proportional to the total head. This design may be useful in some cases to meet performance requirements.

The sutro weir consists of a rectangular section joined to a curved portion that provides proportionality for all heads above the line A-B (see Figure D.4). The weir may be symmetrical or non-symmetrical.

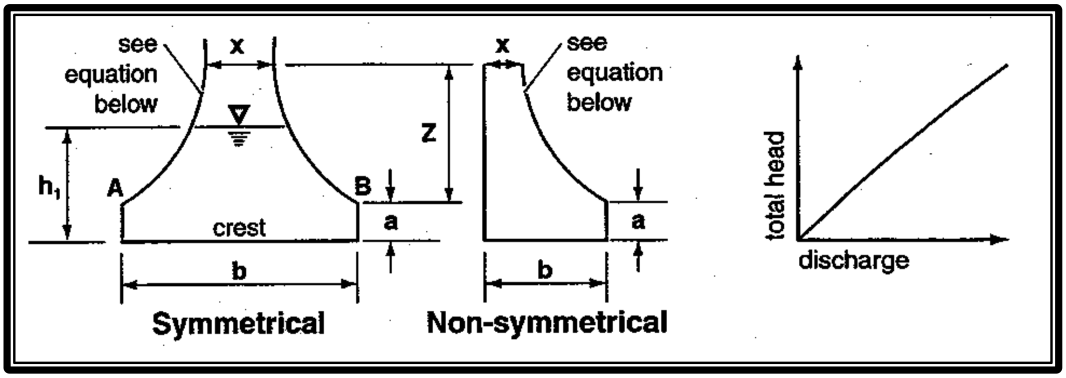


Figure D.4. Sutro Weir.

For this type of weir, the curved portion is defined by the following equation (calculated in radians):

$$\frac{x}{b} = 1 - \frac{2}{\pi} Tan^{-1} \sqrt{\frac{Z}{a}} \qquad \text{(equation 7)}$$

where a, b, x and Z are as shown in Figure D.4. The head-discharge relationship is:

$$Q = C_d \, b \sqrt{2ga(h_1 - \frac{a}{3})} \qquad \text{(equation 8)}$$

Values of *Cd* for both symmetrical and non-symmetrical sutro weirs are summarized in Table D.1.

Note: When b > 1.50 or a > 0.30, use Cd=0.6.

Table D.1. Values of C_d for Sutro Weirs.					
Cd Values, Symmetrical b (feet)					
a (feet)	0.50	0.75	1.0	1.25	1.50
0.02	0.608	0.613	0.617	0.6185	0.619
0.05	0.606	0.611	0.615	0.617	0.6175
0.10	0.603	0.608	0.612	0.6135	0.614
0.15	0.601	0.6055	0.610	0.6115	0.612
0.20	0.599	0.604	0.608	0.6095	0.610
0.25	0.598	0.6025	0.6065	0.608	0.6085
0.30	0.597	0.602	0.606	0.6075	0.608
Cd Values, Non-Symmetrical b (feet)					
a (feet)	0.50	0.75	1.0	1.25	1.50
0.02	0.614	0.619	0.623	0.6245	0.625
0.05	0.612	0.617	0.621	0.623	0.6235
0.10	0.609	0.614	0.618	0.6195	0.620
0.15	0.607	0.6115	0.616	0.6175	0.618
0.20	0.605	0.610	0.614	0.6155	0.616
0.25	0.604	0.6085	0.6125	0.614	0.6145
0.30	0.603	0.608	0.612	0.6135	0.614

Broad-Crested Weir

The equation for flow through a broad-crested weir that is used as a spillway section would be:

$$Q_{100} = C\,(2g)^{1/2}\left[\frac{2}{3}LH^{3/2} + \frac{8}{15}(\tan\theta)\,H^{5/2}\right] \text{ (equation 1)}$$

Where:

- Q_{100} = Peak flow for the 100-year runoff event (cfs)
- C = Discharge coefficient (0.6)
- g = Acceleration due to gravity (32.2 ft/sec^2)
- L = Length of weir (ft)
- H = Height of water over weir (ft)
- θ = Angle of side slopes

Q_{100} is either the 100-year, 1-hour flow, indicated by an approved continuous runoff model, multiplied by a factor of 1.6, or the peak 10-minute flow computed from the 100-year, 24-hour storm and a Type 1A distribution.

Assuming C = 0.6 and Tan θ = 3 (for 3:1 slopes), the equation becomes:

$$Q_{100} = 3.21[LH^{3/2} + 2.4\ H^{5/2}] \qquad \text{(equation 2)}$$

To find width *L* for the weir section, the equation is rearranged to use the computed Q_{100} and trial values of H (0.2 feet minimum):

$$L = [Q_{100}/(3.21H^{3/2})] - 2.4\ H \quad \text{or} \quad \text{6 feet minimum} \qquad \text{(equation 3)}$$

Riser Overflow

The nomograph in Figure D.5 can be used to determine the head (in feet) above a riser of given diameter and for a given flow (usually the 100-year peak flow for developed conditions).

Standard control structure details are shown in Figures D.6 through D.8.

Multiple Orifice Restrictor

In most cases, control structures need only two orifices: one at the bottom and one near the top of the riser, although additional orifices may best utilize detention storage volume. Several orifices may be located at the same elevation if necessary to meet performance requirements.

- Minimum orifice diameter is 0.5 inches. In some instances, a 0.5-inch bottom orifice will be too large to meet target release rates, even with minimal head. In these cases, the live storage depth shall not be reduced to less than 3 feet in an attempt to meet the performance standards. Also, under such circumstances, flow-throttling devices may be a feasible option. These devices will throttle flows while maintaining a plug-resistant opening.

- Orifices may be constructed on a tee section as shown in Figure D.6 or on a baffle as shown in Figure D.7.

- In some cases, performance requirements may require the top orifice/elbow to be located too high on the riser to be physically constructed (e.g., a 13-inch diameter orifice positioned 0.5 feet from the top of the riser). In these cases, a notch weir in the riser pipe may be used to meet performance requirements (see Figure D.8).

- Consideration must be given to the backwater effect of water surface elevations in the downstream conveyance system. High tailwater elevations may affect performance of the restrictor system and reduce live storage volumes.

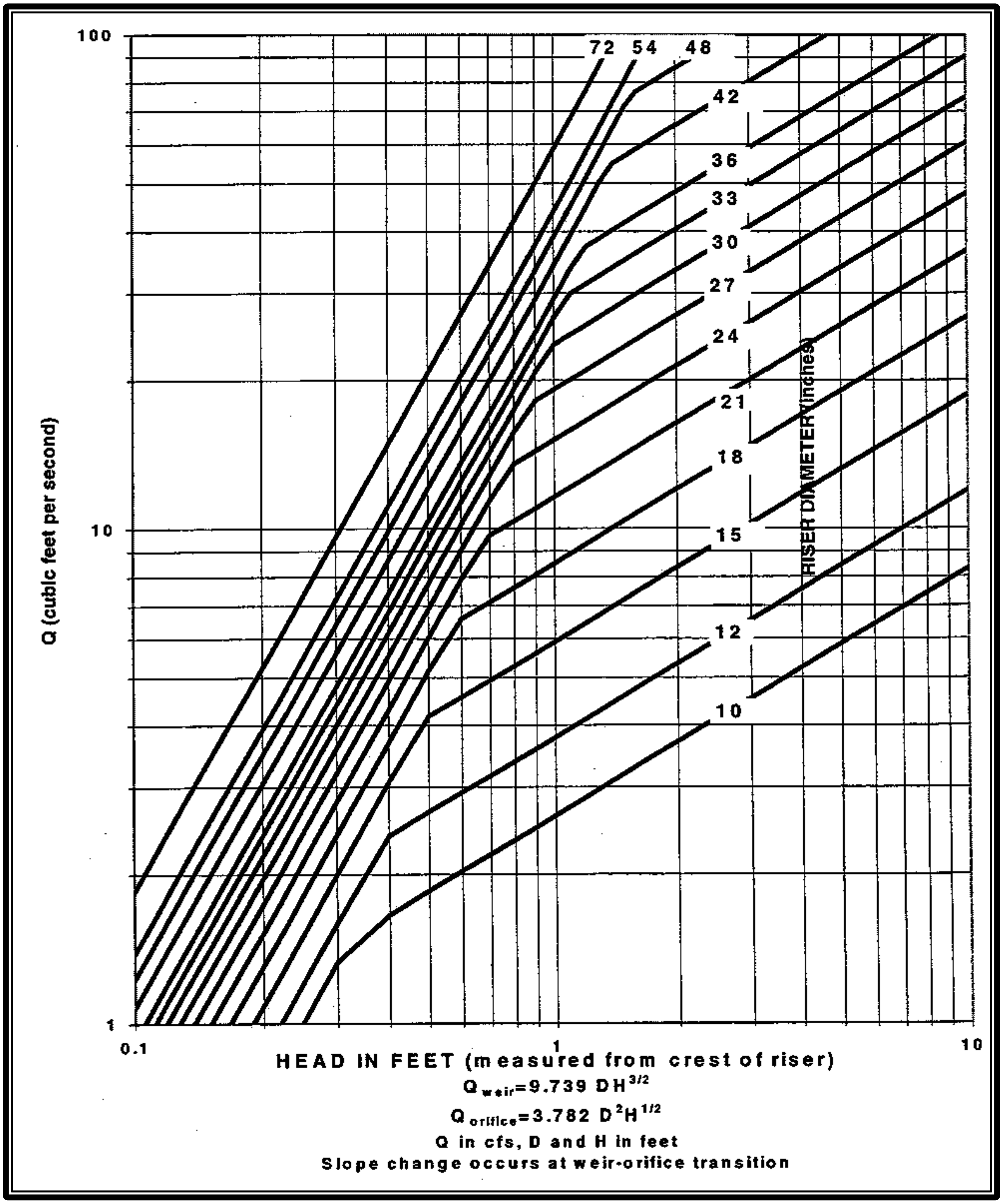
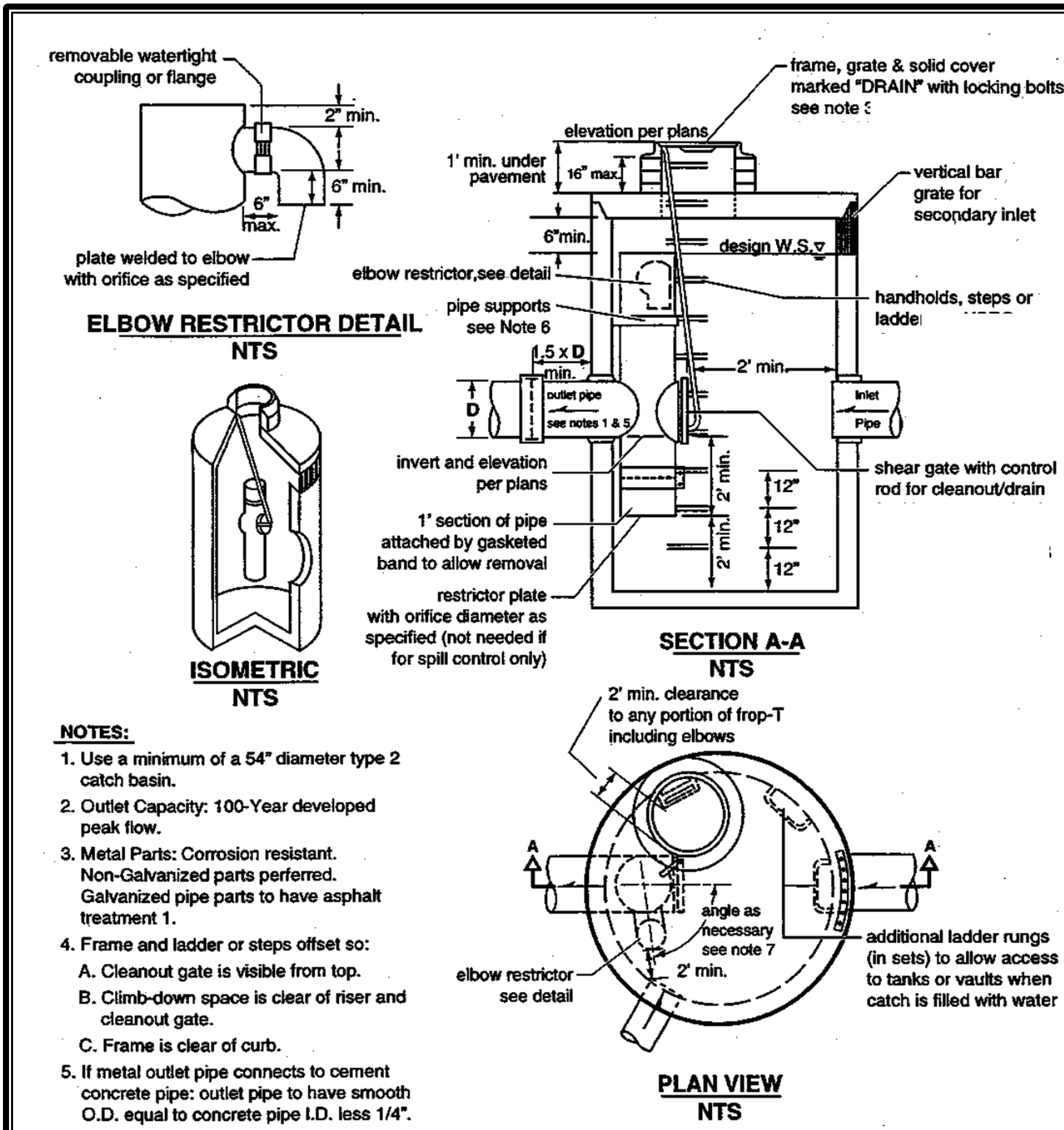


Figure D.5. Riser Inflow Curves.



NOTES:

1. Use a minimum of a 54" diameter type 2 catch basin.
2. Outlet Capacity: 100-Year developed peak flow.
3. Metal Parts: Corrosion resistant. Non-Galvanized parts perferred. Galvanized pipe parts to have asphalt treatment 1.
4. Frame and ladder or steps offset so:
   A. Cleanout gate is visible from top.
   B. Climb-down space is clear of riser and cleanout gate.
   C. Frame is clear of curb.
5. If metal outlet pipe connects to cement concrete pipe: outlet pipe to have smooth O.D. equal to concrete pipe I.D. less 1/4".
6. Provide at least one 3" X .090 inches support bracket anchored to concrete wall. (maximum 3'-0" vertical spacing)
7. Locate elbow restrictor(s) as necessary to provide minimum clearance as shown.
8. Locate additional ladder rungs in structures used as access to tanks or vaults to allow access when catch basin is filled with water.

Figure D.6. Flow Restrictor (TEE).

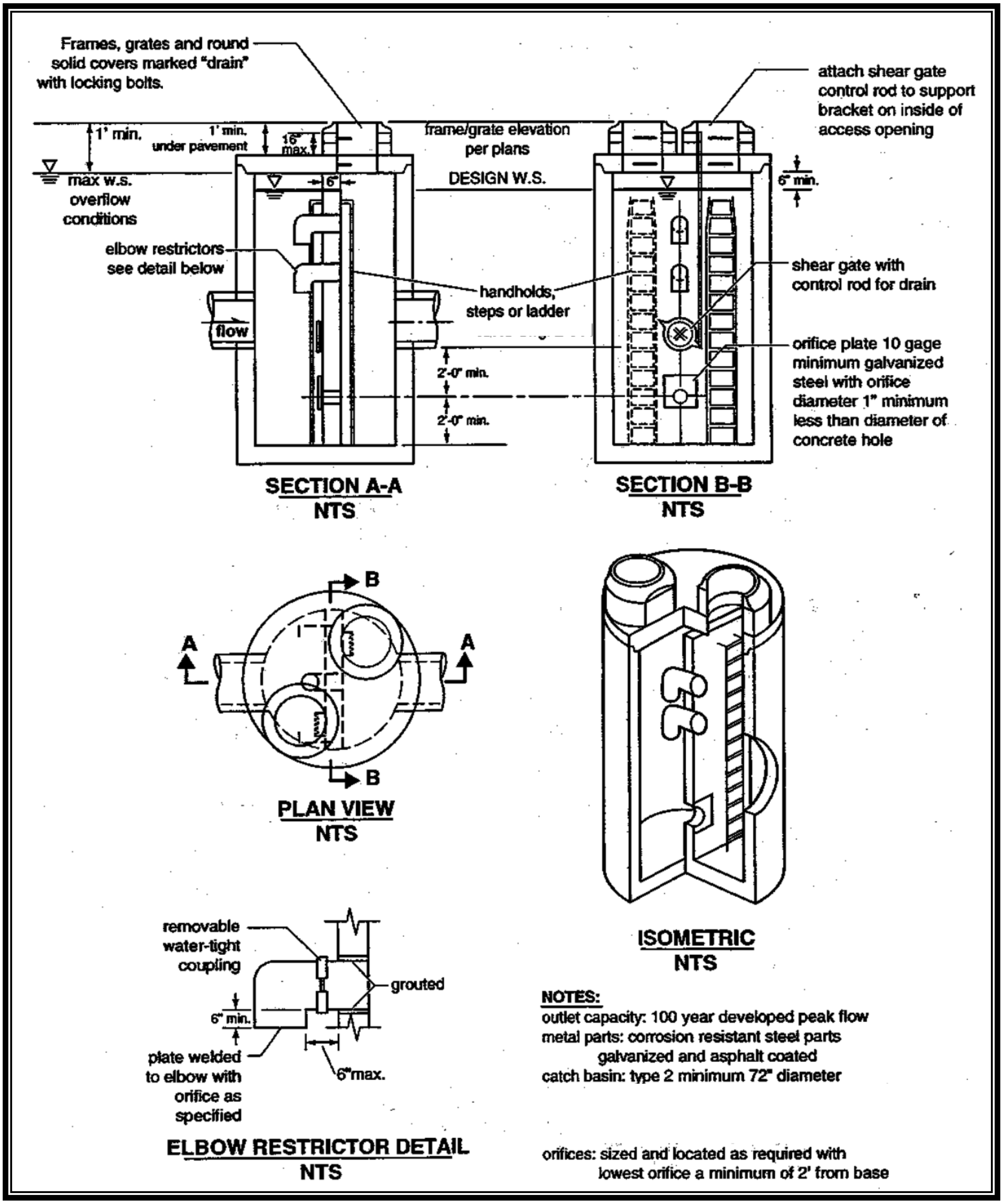
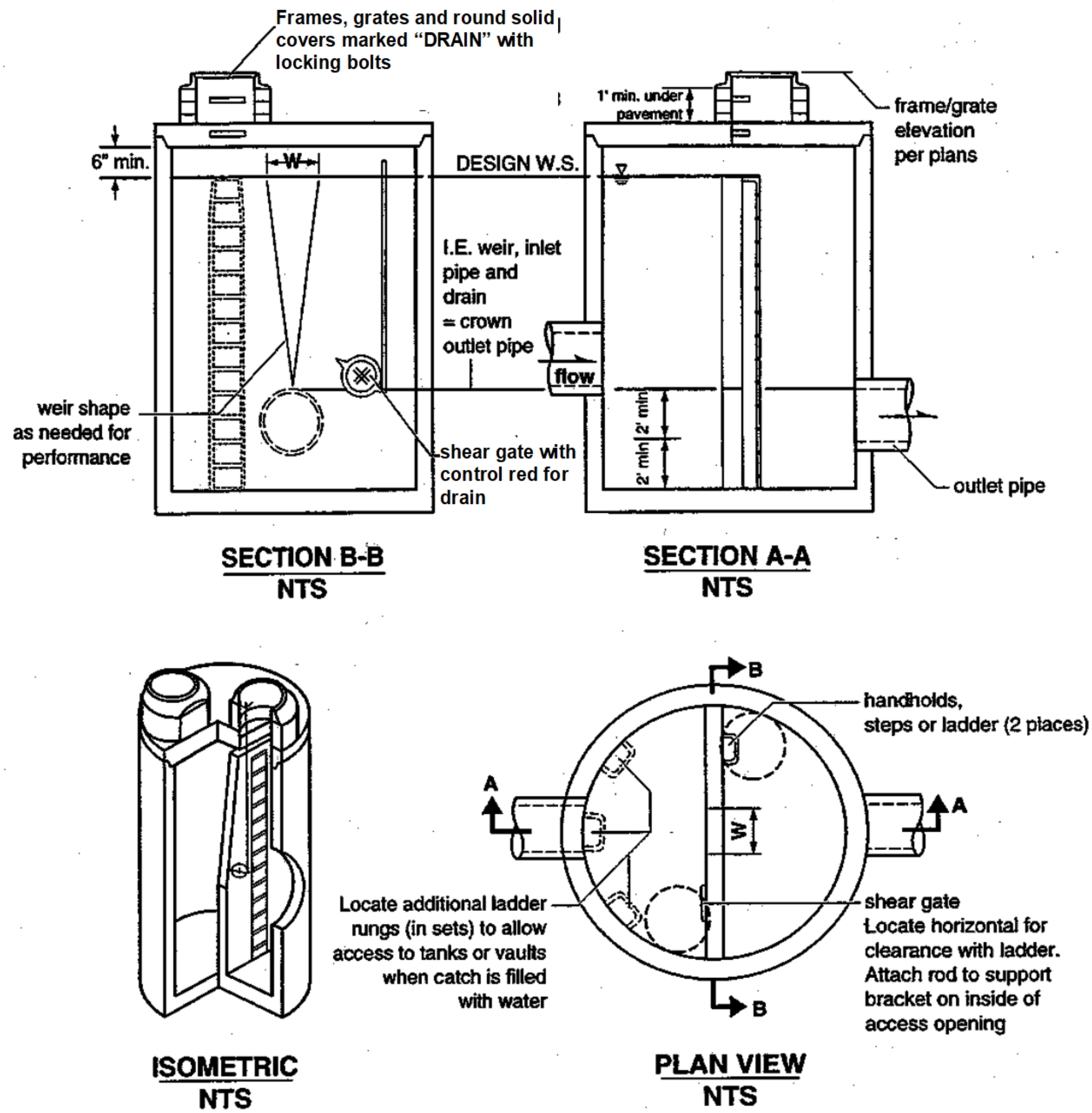


Figure D.7. Flow Restrictor (Baffle).



NOTES:
Outlet Capacity: 100-year developed peak flow.
Metal Parts: corrosion resistant steel parts galvanized and asphalt coated.
Catch Basin: type 2 Min. 72" diameter

Baffle Wall: to be designed with concrete reinforcing as required.
Spill containment must be provided to temporarily detain oil or floatable pollutants in runoff due to accidental spill

Figure D.8. Flow Restrictor (Weir).

Riser and Weir Restrictor

- Properly designed weirs may be used as flow restrictors (see Figure D.8). However, they must be designed to provide for primary overflow of the developed 100-year peak flow discharging to the detention facility.
- The combined orifice and riser (or weir) overflow may be used to meet performance requirements; however, the design must still provide for primary overflow of the developed 100-year peak flow assuming all orifices are plugged. Figure D.5 can be used to calculate the head in feet above a riser of given diameter and flow.

Information Plate

It is recommended that a brass or stainless steel plate be permanently attached inside each control structure with the following information engraved on it:

- Name and file number of project
- Name and company of (1) developer, (2) engineer, and (3) contractor
- Date constructed
- Date of manual used for design
- Outflow performance criteria
- Release mechanism size, type, and invert elevation
- List of stage, discharge, and volume at 1-foot increments
- Elevation of overflow
- Recommended frequency of maintenance.

V-D.2 Bypass and Diversion Structures

Bypass and diversion structures are used to isolate flows when only part of the contributing flows are being directed to water quality.

V-D.2.1 Applicability

Bypass and diversion structures apply to any BMPs that are designed to be "offline," where only part of the contributing stormwater flow is routed to the treatment BMP.

The structures included in this appendix are especially suited to the following:

- Basic Biofiltration Swale

V-D.3 Flow Spreading Options

Flow spreaders function to uniformly spread flows across the inflow portion of several water quality facilities (e.g., biofiltration swale, or filter strip). There are five flow spreader options described in this section:

- Option A – Anchored plate
- Option B – Concrete sump box
- Option C – Notched curb spreader
- Option D – Through-curb ports
- Option E – Interrupted curb.

Options A through C can be used for spreading flows that are concentrated, and when spreading is required by facility design criteria. Options A through C can also be used for unconcentrated flows, and in some cases must be used, such as to correct for moderate grade changes along a filter strip.

Options D and E are only for flows that are already unconcentrated and enter a filter strip or continuous inflow biofiltration swale. Other flow spreader options are possible with approval from the reviewing authority.

V-D.3.1 General Design Criteria

- Where flow enters the flow spreader through a pipe, it is recommended that the pipe be submerged to the extent practical to dissipate energy as much as possible.
- For higher inflows (greater than 5 cubic feet per second for the 100-year storm), a Type 1 catch basin should be positioned in the spreader and the inflow pipe should enter the catch basin with flows exiting through the top grate. The top of the grate should be lower than the level spreader plate, or if a notched spreader is used, lower than the bottom of the v-notches.

Option A – Anchored Plate (Figure D.9)

- An anchored plate flow spreader should be preceded by a sump with a minimum depth of 8 inches and minimum width of 24 inches. If not otherwise stabilized, the sump area should be lined to reduce erosion and provide energy dissipation.
- The top surface of the flow spreader plate should be level, projecting at least 2 inches above the ground surface of the water quality facility, or V-notched with notches 6 to 10 inches on center and 1 to 6 inches deep (use shallower notches with closer spacing). Alternative designs may also be used.

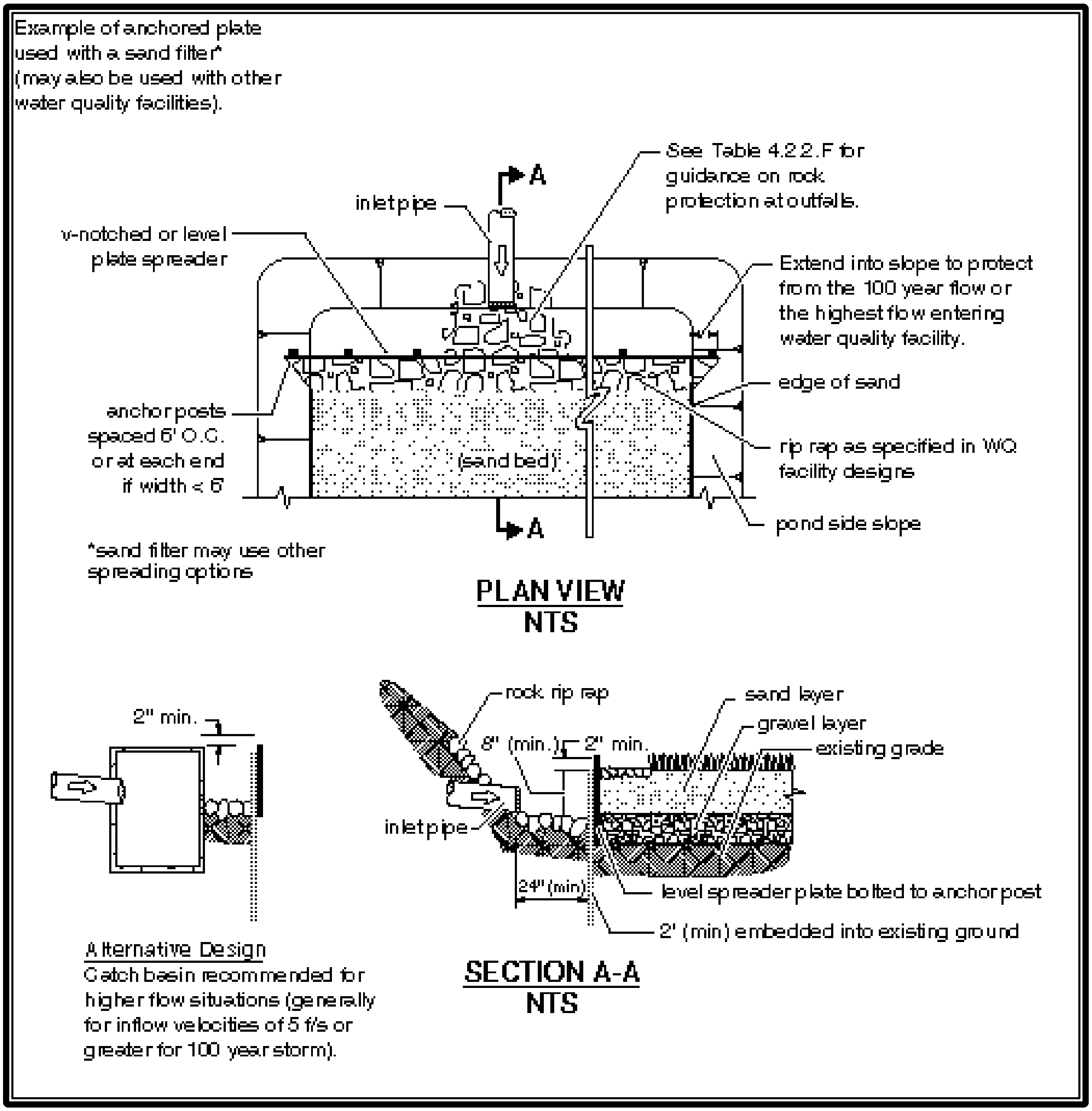


Figure D.9. Flow Spreader Option A: Anchored Plate.

- A flow spreader plate should extend horizontally beyond the bottom width of the facility to prevent water from eroding the side slope. The horizontal extent should be such that the bank is protected for all flows up to the 100-year flow or the maximum flow that will enter the runoff treatment facility.
- Flow spreader plates should be securely fixed in place.

- Flow spreader plates may be made of either wood, metal, fiberglass reinforced plastic, or other durable material. If wood, pressure treated 4- by 10-inch lumber or landscape timbers are acceptable.

- Anchor posts should be 4-inch square concrete, tubular stainless steel, or other material resistant to decay.

Option B – Concrete Sump Box (Figure D.10)

- The wall of the downstream side of a rectangular concrete sump box should extend a minimum of 2 inches above the treatment bed. This serves as a weir to spread the flows uniformly across the bed.

- The downstream wall of a sump box should have “wing walls” at both ends. Side walls and returns should be slightly higher than the weir so that erosion of the side slope is minimized.

- Concrete for a sump box can be either cast-in-place or precast, but the bottom of the sump should be reinforced with wire mesh for cast-in-place sumps.

- Sump boxes should be placed over bases that consists of 4 inches of crushed rock, 5/8-inch minus to help ensure the sump remains level.

Option C – Notched Curb Spreader (Figure D.11)

Notched curb spreader sections should be made of extruded concrete laid side-by-side and level. Typically, five “teeth” per 4-foot section provide good spacing. The space between adjacent “teeth” forms a v-notch.

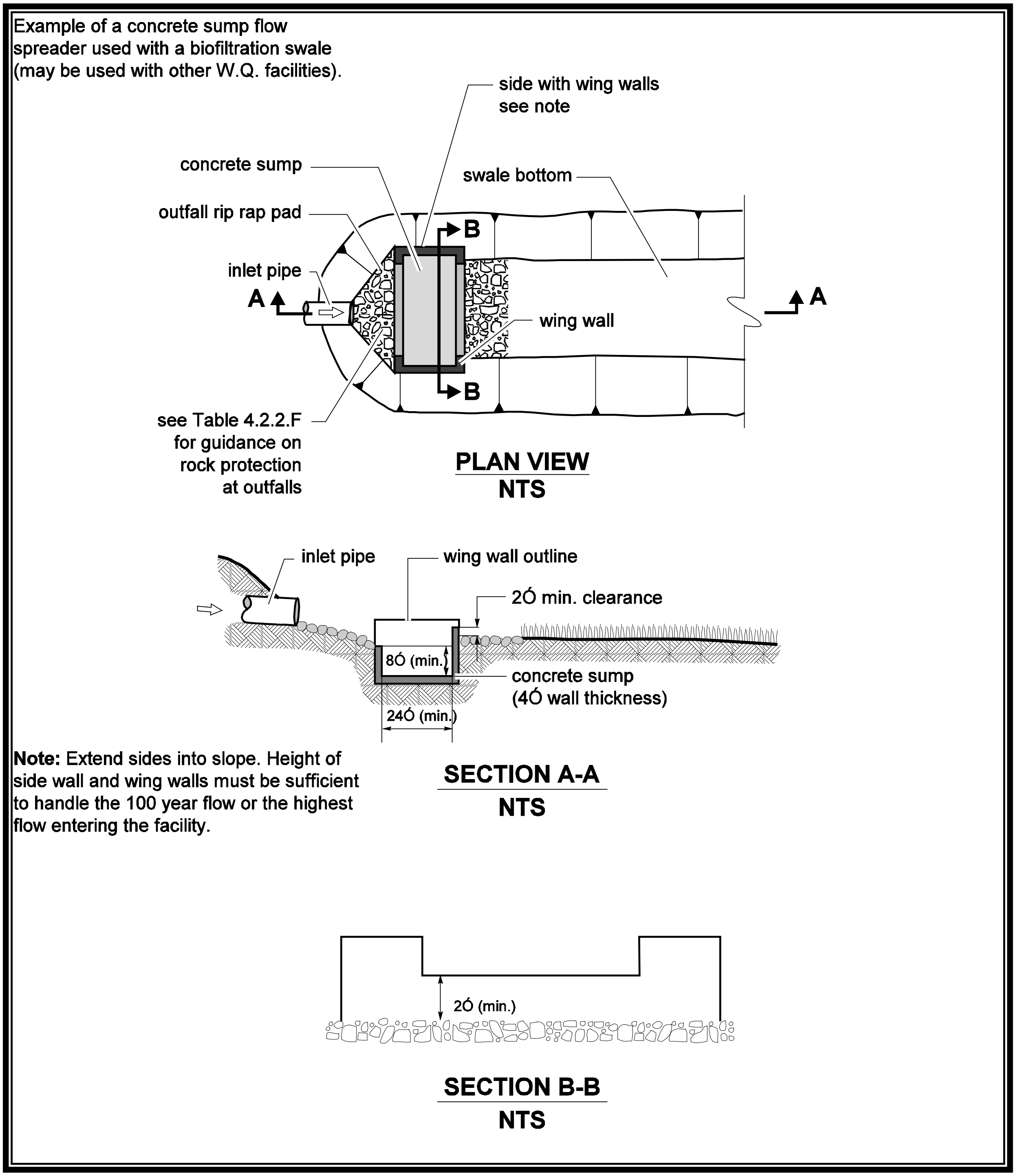


Figure D.10. Flow Spreader Option B: Concrete Sump Box.

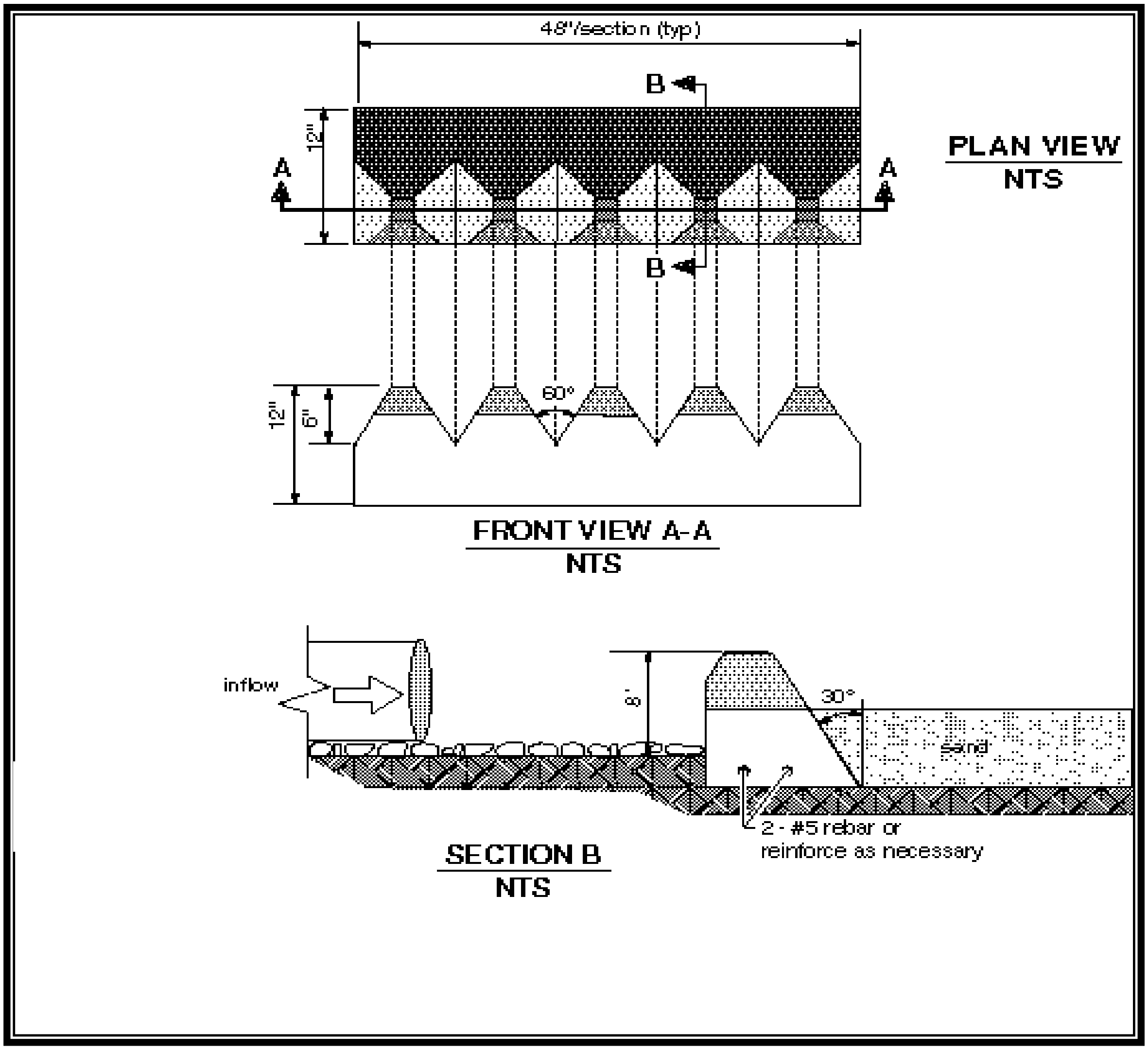


Figure D.11. Flow Spreader Option C: Notched Curb Spreader.

Option D –Through-Curb Ports (Figure D.12)

Unconcentrated flows from paved areas entering filter strips or continuous inflow biofiltration swales can use curb ports or interrupted curbs (Option E) to allow flows to enter the strip or swale. Curb ports use fabricated openings that allow concrete curbing to be poured or extruded while still providing an opening through the curb to admit water to the runoff treatment facility.

Openings in the curb should be at regular intervals but at least every 6 feet (minimum). The width of each curb port opening should be a minimum of 11 inches. Approximately 15 percent or more of the curb section length should be in open ports, and no port should discharge more than about 10 percent of the flow.

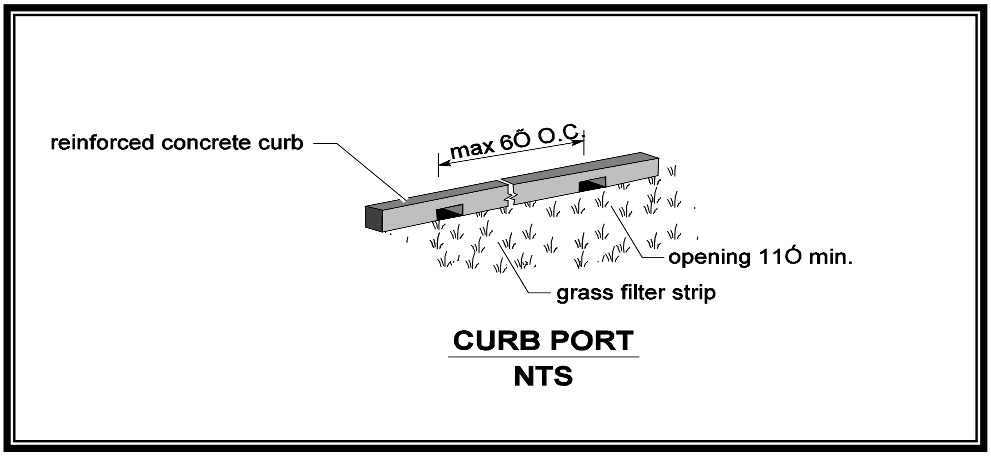


Figure D.12. Flow Spreader Option D: Through-Curb Port.

Option E – Interrupted Curb (No Figure)

Interrupted curbs are sections of curb placed to have gaps spaced at regular intervals along the total width (or length, depending on facility) of the treatment area. At a minimum, gaps should be every 6 feet to allow distribution of flows into the treatment facility before they become too concentrated. The opening should be a minimum of 11 inches. As a general rule, no opening should discharge more than 10 percent of the overall flow entering the facility.

Appendix V-E – Facility Liners

Liners are intended to reduce the likelihood that pollutants in stormwater will reach groundwater when runoff treatment facilities are constructed.

Low permeability liners reduce infiltration to a very slow rate, generally less than 0.02 inches per hour (1.4 x 10^{-5} centimeters squared). These types of liners are used for industrial or commercial sites with a potential for high pollutant loading in the stormwater runoff. Low permeability liners may be fashioned from compacted till, clay, geomembrane, or concrete.

V-E.1 Applicability

Liners are used when there is a need to protect underlying soils from pollutants or retain permanent water for wet BMPs.

This appendix applies to the following BMPs:

- Downspout Infiltration Systems
- Basic Biofiltration Swale
- Presettling Basins
- Stormwater Treatment Wetlands
- Wet Ponds
- Combined Detention and Wet Pool Facilities

V-E.2 Liners Design Criteria

- Table E.1 shows the type of liner required for use with various runoff treatment facilities. Other liner configurations may be used with prior approval from the city.
- Liners shall be evenly placed over the bottom and/or sides of the treatment area of the facility as indicated in Table E.1. Areas above the treatment volumes that are required to pass flows greater than the water quality treatment flow (or volume) need not be lined. However, the lining must be extended to the top of the interior side slope and anchored if it cannot be permanently secured by other means.

Table E.1. Lining Types Required for Runoff Treatment Facilities.

Water Quality Facility	Area To Be Lined	Type of Liner Required
Presettling basin	Bottom and sides	Treatment liner or Low permeability liner (If the basin will intercept the known or estimated high groundwater table, a treatment liner may be recommended.)
Wet pond	First cell: bottom and sides to water quality design water surface -- Second cell: bottom and sides to water quality design water surface	Treatment liner or Low permeability liner -- Treatment liner
Combined detention/water quality facility	First cell: bottom and sides to water quality design water surface -- Second cell: bottom and sides to water quality design water surface	Treatment liner or Low permeability liner -- Treatment liner
Stormwater wetland	Bottom and sides, both cells	Low permeability liner
Media filter (in vault)	Not applicable	No liner needed
Wet vault	Not applicable	No liner needed

Low Permeability Liners

This section presents the design criteria for each of the following four low permeability liner options: compacted till liners, clay liners, geomembrane liners, and concrete liners.

- For low permeability liners, the following criteria apply:
  - Where the known or estimated high groundwater elevation is likely to contact a low permeability liner, liner buoyancy may be a concern. In these instances, use of a low permeability liner shall be evaluated and recommended by a geotechnical engineer.
  - Where grass must be planted over a low permeability liner per the facility design, a minimum of 6 inches of good topsoil or compost-amended native soil (2 inches compost tilled into 6 inches of native till soil) must be placed over the liner in the area to be planted. Twelve inches of cover is preferred.

Compacted Till Liners

- Liner thickness shall be 18 inches after compaction.
- Soil shall be compacted to 95 percent minimum dry density, modified proctor method (ASTM D-1557).

- A different depth and density sufficient to retard the infiltration rate to 2.4 x 10^{-5} inches per minute (1 x 10^{-6} centimeters squared) may also be used instead of the thickness and density criteria above.

- Soil should be placed in 6-inch lifts.

- Soils may be used that meet the gradation in Table E.2 below:

Table E.2. Compacted Till Liners.

Sieve Size	Percent Passing
6-inch	100
4-inch	90
#4	70 to 100
#200	20

Clay Liners

- Liner thickness shall be 12 inches.

- Clay shall be compacted to 95 percent minimum dry density, modified proctor method (ASTM D-1557).

- A different depth and density sufficient to retard the infiltration rate to 2.4 x 10^{-5} inches per minute (1 x 10^{-6} centimeters squared) may also be used instead of the above criteria.

- Plasticity index shall not be less than 15 percent (ASTM D-423, D-424).

- Liquid limit of clay shall not be less than 30 percent (ASTM D-2216).

- Clay particles passing shall not be less than 30 percent (ASTM D-422).

- The slope of clay liners must be restricted to 3H:1V for all areas requiring soil cover; otherwise, the soil layer must be stabilized by another method so that soil slippage into the facility does not occur. Any alternative soil stabilization method must take maintenance access into consideration.

- Where clay liners form the sides of ponds, the interior side slope should not be steeper than 3H:1V, irrespective of fencing. This restriction is to ensure that anyone falling into the pond may safely climb out.

Geomembrane Liners

- Geomembrane liners shall be ultraviolet (UV) light resistant and have a minimum thickness of 30 mils. A thickness of 40 mils shall be used in areas of maintenance access or where heavy machinery must be operated over the membrane.

- The geomembrane fabric shall be protected from puncture, tearing, and abrasion by installing geotextile fabric on the top and bottom of the geomembrane determined to have a high survivability per the WSDOT standard specifications, specifically Section 9-33 Construction Geotextile (2006 or the latest version as amended). Equivalent methods for protection of the geomembrane liner will be considered. Equivalency will be judged on the basis of ability to protect the geomembrane from puncture, tearing, and abrasion.

- Geomembranes shall be bedded according to the manufacturer's recommendations.

- Liners must be covered with 12 inches of top dressing forming the bottom and sides of the water quality facility. Top dressing shall consist of 6 inches of crushed rock covered with 6 inches of native soil. The rock layer is to mark the location of the liner for future maintenance operations. As an alternative to crushed rock, 12 inches of native soil may be used if orange plastic “safety fencing” or another highly visible, continuous marker is embedded 6 inches above the membrane.

- If possible, liners should be of a contrasting color so that maintenance workers are aware of any areas where a liner may have become exposed when maintaining the facility.

- Geomembrane liners shall not be used on slopes steeper than 5H:1V to prevent the top dressing material from slipping. Textured liners may be used on slopes up to 3H:1V upon recommendation by a geotechnical engineer that the top dressing will be stable for all site conditions, including maintenance.

Concrete Liners

- Concrete liners may also be used for sedimentation chambers and for sedimentation and filtration basins less than 1,000 square feet in area. Concrete shall be 5-inch thick Class 3000 or better and shall be reinforced by steel wire mesh. The steel wire mesh shall be six (6) gage wire or larger and 6 inch by 6 inch mesh or smaller. An “Ordinary Surface Finish” is required. When the underlying soil is clay or has an unconfined compressive strength of 0.25 ton per square foot or less, the concrete shall have a minimum 6 inch compacted aggregate base consisting of coarse sand and river stone, crushed stone or equivalent with diameter of 0.75 to 1 inch. Where visible, the concrete shall be inspected annually and all cracks shall be sealed.

- Portland cement liners are allowed irrespective of facility size, and shotcrete may be used on slopes. However, specifications must be developed by a professional engineer who certifies the liner against cracking or losing water retention ability under expected conditions of operation, including facility maintenance operations. Weight of maintenance equipment can be up to 80,000 pounds when fully loaded.

- Asphalt concrete may not be used for liners due to its permeability to many organic pollutants.
- If grass is to be grown over a concrete liner, slopes must be no steeper than 5H:1V to prevent the top dressing material from slipping. Textured liners may be used on slopes up to 3H:1V upon recommendation by a geotechnical engineer that the top dressing will be stable for all site conditions, including maintenance.

Appendix V-F – Planting and Landscaping Requirements

This appendix provides guidelines for r naturalistic plantings of stormwater facilities.

V-F.1 Applicability

All disturbed or exposed soil must be planted and/or landscaped. Landscaping is encouraged for most stormwater tract areas (see below for areas not to be landscaped). Landscaped stormwater tracts may, in some instances, provide a recreational space. In other instances, "naturalistic" stormwater facilities may be placed in open space tracts. Bioretention facilities also have specific planting requirements.

The final landscape design shall be prepared by a licensed landscape architect or certified nursery person. Wherever possible, existing trees and other native vegetation around the facility shall be saved. This allows for a smooth transition to other developed areas and helps retain the character of the site.

New vegetation will need to be planted regardless of how much is cleared. Plantings should be designed with specific functions in mind: soil preservation, erosion control, evapotranspiration, screening, space definition, sun and shade and others. Use a combination of trees, shrubs and groundcovers to provide variety and interest. Plant at least three different species of trees and shrubs.

Native plants that will tolerate flooding and wet conditions are preferred. To ensure survival of newly planted vegetation, it is recommended that the plants be irrigated for the first season. In wet ponds with standing water, wetland herbaceous species (cattails, sedges, rushes, etc.) must be included.

Regional wet ponds located in commercial developments should be designed with consideration for pedestrian and passive recreation facilities. Amenities around regional wet ponds, such as picnic tables, benches, gazebos, etc., are encouraged. Aeration and/or recirculation of the water, such as waterfalls, cascades and fountains, should be considered to reduce the potential for odors to develop during the warmer months, to add visual interest, and mask unwanted traffic noise.

Manage unwanted vegetation in accordance with BMP A3.6. Utilize Integrated Pest Management and consider alternative methods such as covering or harvesting to control weeds. Do not apply pesticides unless approved by the city through submittal of a pesticide-use plan (see Volume IV).

This appendix applies to the following BMPs:

- Bioretention Facilities or Rain Gardens
- Detention Ponds

Other facilities may be subject to these requirements if they include landscaping.

V-F.2 Design Criteria

Exposed earth on pond interiors side slopes shall be sodded or seeded with an appropriate seed mixture. Exposed earth on the pond bottom should also be sodded or seeded. All remaining areas of the tract should be planted with grass or be landscaped and mulched with a 4-inch cover of hog fuel or shredded wood mulch. Shredded wood mulch is made from shredded tree trimmings, usually from trees cleared on site. The mulch must be free of garbage and weeds and shall not contain excessive resin, tannin, or other material detrimental to plant growth.

V-F.3 General Landscaping Guidelines

The following guidelines shall be followed if landscaping is proposed for facilities.

Setbacks from Structures and Pipes

No trees or shrubs may be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways or flow spreaders. Species with roots that seek water, such as willow or poplar, shall be avoided within 50 feet of pipes or manmade structures.

Berms

Planting shall be restricted on berms that impound water either permanently or temporarily during storms. 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.
- Grasses allow unobstructed visibility of berm slopes for detecting potential dam safety problems such as animal burrows, slumping, or fractures in the berm.
- 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. These trees reduce the likelihood of blow-down trees, or the possibility of channeling or piping of water through the root system, which may contribute to dam failure on berms that retain water.
- ***Note:*** *The internal berm in a wet pond is not subject to this planting restriction since the failure of an internal berm would be unlikely to create a safety problem.*
- All landscape material, including grass, shall be planted in good topsoil. Poor underlying soils may be made suitable for planting if amended with 4 inches of well-aged compost tilled into the subgrade. General information and links on soil amendment and can be found at the Soils for Salmon web site: <https://www.soilsforsalmon.org/>.

- Soil in which trees or shrubs are planted may need additional enrichment or additional compost top-dressing. Consult a nursery, landscape professional, or arborist for site-specific recommendations.

Trees and Shrubs

- 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 should 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-foot 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 trees that produce relatively little leaf-fall (such as Oregon ash, mimosa, or locust) are preferred in areas draining to the pond.

- Deciduous trees must be set back so that branches do not extend over the pond (to prevent leaf-drop into the water).

V-F.4 Naturalistic Planting

Two generic kinds of naturalistic planting are outlined below, but other options are also possible. Native vegetation is preferred in naturalistic plantings.

Open Woodland

- In addition to the general landscaping guidelines above, the following are recommended.

- Landscaped islands (when mature) should cover a minimum of 30 percent or more of the tract, exclusive of the pond area.

- Shade-tolerant shrubs and groundcover plants should be planted under tree clumps. The goal is to provide a dense understory that need not be weeded or mowed.

- Landscaped islands should be placed at several elevations rather than "ring" the pond, and the size of clumps should vary from small to large to create variety.

- Not all islands need to have trees. Shrub or groundcover clumps are acceptable, but lack of shade should be considered in selecting vegetation.

  Note: Landscaped islands are best combined with the use of wood-based mulch (hog fuel) or chipped, on-site vegetation for erosion control (only for slopes *above the flow control water surface). It is often difficult to sustain a low-maintenance understory if the site was previously hydroseeded. Compost or composted mulch (typically used for constructed wetland soil) can be used below the flow control water surface (materials that are resistant to and preclude flotation). The method of construction of soil landscape systems can also cause natural selection of specific plant species. Consult a soil restoration or wetland soil scientist for site-specific recommendations.*

Northwest Savannah or Meadow

In addition to the general landscape guidelines above, the following are recommended.

- Landscape islands (when mature) should cover 10 percent or more of the site, exclusive of the pond area.
- Planting groundcovers and understory shrubs is encouraged to eliminate the need for mowing under the trees when they are young.
- Landscape islands should be placed at several elevations rather than “ring” the pond.

The remaining site area should be planted with an appropriate grass seed mix. Grass seed mixes are provided in Volume II, BMP C120.

Note: *Amended soil or good topsoil is required for all plantings.*

Creation of areas of emergent vegetation in shallow areas of the pond is recommended. Native wetland plants, such as sedges (*Carex* sp.), bulrush (*Scirpus* sp.), water plantain (*Alisma* sp.), and burreed (*Sparganium* sp.) are recommended. If the pond does not hold standing water, a clump of wet-tolerant, non-invasive shrubs, such as salmonberry or snowberry, is recommended below the detention design water surface.

Note: *This landscape style is best combined with the use of grass or sod for site stabilization and erosion control.*

V-F.5 Plant Recommendations for Bioretention Facilities

Bioretention facilities generally feature three planting zones, reflecting the different soil moisture and frequency of inundation. Tables F.1 through F.5 provide planting recommendations for the different planting zones. Tables F.2 through F.5 include both native and nonnative plant species commonly available in the Puget Sound region and suitable for bioretention facilities. Refer to the bioretention facility design guidelines (Chapters 9 and 25) for additional planting requirements. Consultation with a landscape architect is recommended for site-specific planting recommendations.

Table F.1. Bioswale Seed Mix.				
Common Name	**Species**	**Percent Species Composition**	**Desired Seeds Per Square Foot**	**Pounds Pure Live Seed per Acre**
American sloughgrass	*Beckmannia syzigachne*	15	23	0.9
Tufted hairgrass	*Deschampsia cespitosa*	20	30	0.5
Blue wildrye	*Elymus glaucus*	18	27	10.7
Native red fescue	*Festuca rubra* var. *rubra*	20	30	2.6
Meadow barley	*Hordeum brachyantherum*	12	18	9.2
Northwestern mannagrass	*Glyceria occidentalis*	15	23	4.9
Total			**151**	**28.8**

Table F.2. Groundcovers and Grasses Suitable for the Upper Side Slopes of a Biofiltration Swale in Western Washington.	
Groundcovers	
Kinnikinnick	*Arctostaphylos uva-ursi*
Strawberry	*Fragaria chiloensis*
Broadleaf lupine	*Lupinus latifolius*
Grasses (drought-tolerant, minimum mowing)	
Dwarf tall fescues	*Festuca* spp. (e.g., Many Mustang, Silverado)
Hard fescue	*Festuca ovina duriuscula* (e.g., Reliant, Aurora)
Tufted fescue	*Festuca amethystine*
Buffalo grass	*Buchloe dactyloides*
Red fescue	*Festuca rubra*
Tall fescue grass	*Festuca arundinacea*
Blue oatgrass	*Helictotrichon sempervirens*

Table F.3. Plant Species Appropriate for Area of Periodic or Frequent Standing or Flowing Water.

Species	Common Name	Exposure	Mature Size/ Spread	Comments
Trees				
*Alnus rubra**	Red alder	Sun/ partial shade	30 to 120 feet 25-foot spread	Prefers moist, rich soils, highly adaptable, drought tolerant; nitrogen fixer; rapid growing, relatively short-lived (60 to 90 years).
*Fraxinus latifolia**	Oregon ash	Sun/ partial shade	30-foot spread	Moist, saturated or ponded soils; flood tolerant; small green-white flowers.
*Malus fusca**	Pacific crabapple	Sun/ partial shade	To 40 feet 35-foot spread	Tolerant of prolonged soil saturation; produces fruit (do not plant near public walkways).
*Salix lucida**	Pacific willow	Sun	40 to 60 feet 30-foot spread	Wet soils; tolerates seasonal flooding should not be planted in areas near pavement or underground structures.
Shrubs				
*Cornus sericea**	Red-osier dogwood, Red-twig dogwood	Sun/ partial shade	To 15 feet	Prefers wet to moist organically rich soils, but is adaptable; tolerates seasonal flooding; small white flowers; berrylike fruits.
Cornus sericea "Kelseyi"	Dwarf dogwood	Sun	To 1.5 feet	Prefers wet to moist organically rich soils, but is adaptable; small white flowers; berrylike fruit; low growing, compact form; good ground cover.
Cornus sericea	"Flaviramea" Yellow dogwood	Sun/ partial shade	6 to 8 feet	Prefers wet to moist organically rich soils, but is adaptable; easily transplanted and grown; small, white flowers; yellow stems and reddish, purple fall color.
Cornus sericea "Isanti"	Isanti dogwood	Sun/ partial shade	4 to 5 feet	Prefers wet to moist organically rich soils, but is adaptable; deciduous shrub; tiny white flowers; red stems; purple fall color.
*Lonicera involucrata**	Black twinberry	Partial shade/ shade	2 to 8 feet	Moist soils; prefers loamy soils; tolerant of shallow flooding; yellow, tubular flowers attract hummingbirds.

Table F.3 (continued). Plant Species Appropriate for Area of Periodic or Frequent Standing or Flowing Water.

Species	Common Name	Exposure	Mature Size/ Spread	Comments
Shrubs (continued)				
*Myrica californica**	Pacific wax myrtle	Sun/ partial shade	To 30 feet	Evergreen shrub preferring moist soils; inconspicuous spring flowers; drought tolerant; if drought tolerance is not an issue try the smaller Washington native, *Myrica gale*.*
*Physocarpus capitatus**	Pacific ninebark	Sun/ partial shade	6 to 13 feet	Moist or dry soils; drought tolerant; snowball shaped; white flowers; seeds persist into winter.
*Rosa pisocarpa**	Clustered wild rose	Sun/ partial shade	6 to 8 feet	Moist soils, tolerates seasonal flooding but also tolerant of dry conditions; pink clustered flowers; fruits persist.
Salix purpunea "*Nana*"	Dwarf Arctic willow	Sun/ partial shade	3 to 5 feet	Grows well in poor soils; moderately drought tolerant; small yellow flowers in the fall.
*Spiraea douglasii**	Douglas spirea, Steeplebush	Sun/ partial shade	4 to 7 feet	Moist or dry, to seasonally inundated soils; spikes of small, pink flower clusters.
Emergents				
*Carex obnupta**	Slough sedge	Sun/ partial shade	1 to 5 feet	Moist to seasonally saturated soils; shiny foliage; excellent soil binder; drought tolerant.
*Carex stipata**	Sawbeak sedge	Partial shade	10 inches to 3 feet	Wet soils; excellent soil binder.
*Juncus effusus**	Common rush	Sun/ partial shade	1 to 2 feet	Wet soils; evergreen perennial; hardy and adaptable; drought tolerant; small, non-showy flowers.
*Juncus ensifolius**	Daggerleaf rush	Sun	12 to 18 inches	Wet soils; shallow water; excellent soil binder.
*Juncus tenuis**	Slender rush	Sun	0.5 to 2.5 feet	Moist soils; tufted perennial.
*Scirpus acutus**	Hardstem bulrush	Sun	4 to 8 feet	Wet soils; favors prolonged inundation; excellent soil binder.
*Scirpus microcarpus**	Small-fruited bulrush	Sun/shade	2 to 4 feet	Wet soils; tolerates prolonged inundation; good soil binder; drought tolerant.

Source: Adapted from PSAT 2005.

*Denotes native plant species.

Table F.4. Plant Species Appropriate for Bioretention Facility Areas Subject to Periodic Saturation During Large Storms.				
Trees				
Species	Common Name	Exposure	Mature Size	Comments
Acer truncatum	Pacific sunset maple	Sun	To 25 feet 20-foot spread	Prefers moist, well-drained soils, but drought tolerant; very cold hardy; deciduous tree with moderate growth rate.
*Amelanchier alnifolia**	Western serviceberry	Sun/ partial shade	10 to 20 feet 25-foot spread	Moist to dry, well-drained soils; drought tolerant; large white flowers; purple to black berries; deciduous.
*Corylus cornuta**	Beaked hazelnut	Sun/ partial shade	20 to 30 feet 15-foot spread	Moist, well-drained soils; edible nuts; intolerant of saturated soils; catkins throughout winter add interest; deciduous.
*Crataegus douglasii**	Black hawthorn	Sun/ partial shade	3 to 30 feet 25-foot spread	Moist to dry, well drained, gravelly soils; small white flowers, black berries; 1 inch spines; forms thickets; deciduous.
Fraxinus oxycarpa	Raywood ash	Sun	25 to 50 feet 25-foot spread	Drought tolerant; grows in varying soil types; deciduous; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than other nonnative ashes; inconspicuous flowers.
*Rhamnus purshiana**	Cascara sagrada	Sun/shade	20 to 40 feet 25-foot spread	Moist to fairly dry soils; small greenish-yellow flowers; deciduous; sensitive to air pollution; yellow fall color.
*Salix scouleriana**	Scouler willow	Sun/ partial shade	6 to 40 feet 15-foot spread	Moist to dry soils; drought tolerant; deciduous tree; do not plant near paved surfaces or underground structures.
*Salix sitchensis**	Sitka willow	Sun/ partial shade	3 to 26 feet 25-foot spread	Moist soils; tolerates seasonal flooding; deciduous tree; do not plant near paved surfaces or underground structures.
*Thuja plicata**	Western red cedar	Partial shade/ shade	200 feet+ 60-foot spread	Moist to swampy soils; tolerates seasonal flooding and saturated soils; long-lived; prefers shade while young.

Table F.4 (continued). Plant Species Appropriate for Bioretention Facility Areas Subject to Periodic Saturation During Large Storms.

Shrubs – Deciduous

Species	Common Name	Exposure	Mature Size	Comments
*Acer circinatum**	Vine maple	Filtered sun/ shade	To 25 feet	Dry to moist soils; tolerant of shade and clay soils; excellent soil binder; beautiful fall color.
Hamamelis intermedia	Diane witchhazel	Sun/ partial shade	10 to 20 feet 10-foot spread	Moist, fertile, acidic soil; showy fall color—yellow to yellow-orange; long-lasting, slightly fragrant, coppery-red flowers; not drought tolerant; may require watering in dry season.
*Oemleria cerasiformis**	Indian plum/ osoberry	Sun/ partial shade	5 to 16 feet	Moist to dry soils; prefers shade; tolerates fluctuating water table.
Philadelphus x lemoinei	"Belle Etoile" mock orange	Sun/ partial shade	5 to 6 feet	Prefers moist, well-drained soils, high in organic matter, but soil and pH adaptable; easily transplanted and established; fragrant, large white flowers, tinged red at the base; other cultivars available.
*Ribes lacustre**	Black swamp gooseberry	Partial shade	1.5 to 3 feet	Moist soils; deciduous shrub; reddish flowers in drooping clusters; dark purple berries; *R. divaricatum** (Wild gooseberry) grows to 5 feet and is also an option; attracts butterflies, but is very thorny.
*Rosa nutkana**	Nootka rose	Sun/ partial shade	6 to 10 feet	Moist to fairly dry soils; tolerates inundation and saturated soils; aggressive spreader; fruits persist; less thorny that *R. rugosa*.
Rosa rugosa	Rugosa rose	Sun	To 8 feet	Drought resistant; hardy, vigorous and aggressive; highly prickly; fragrant white to purple flowers; fruits persist.
*Rubus parviflorus**	Thimbleberry	Sun/ partial shade	4 to 10 feet	Moist to dry soils; white flowers; red berries; makes thickets and spreads easily.
*Rubus spectabilis**	Salmonberry	Partial sun/ shade	5 to 10 feet	Prefers moist, wet soils; good soil binder; magenta flowers; yellow/ orange fruit; early nectar source for hummingbirds; makes thickets.
*Sambucus racemosa**	Red elderberry	Partial sun/ partial shade	To 20 feet	Moist to dry soils; small white flowers; bright red berries; vase shaped; pithy stems lead to "messy" form—prune for tidiness.

Table F.4 (continued). Plant Species Appropriate for Bioretention Facility Areas Subject to Periodic Saturation During Large Storms.

Shrubs – Deciduous (continued)

Species	Common Name	Exposure	Mature Size	Comments
*Symphoricarpos albus**	Snowberry	Sun/shade	2 to 6 feet	Wet to dry soils, clay to sand; excellent soil binder; drought and urban air tolerant; provides good erosion control; spreads well in sun; white berries; flowers attract hummingbirds.
*Vaccinium parvifolium**	Red huckleberry	Partial shade/shade	4 to 10 feet	Slightly moist to dry soils; prefers loamy, acid soils or rotting wood; tolerant of dry, shaded conditions; red fruit; tricky to transplant.

Herbaceous

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Aquilegia formosa** | Western columbine	Sun/ partial shade	1 to 3 feet	Spring	Moist soils of varying quality; tolerant of seasonal flooding; red and yellow flowers attract hummingbirds and butterflies.
*Asarum caudatum** | Wild ginger	Partial shade/ shade	To 10 inches	Mid-spring	Moist organic soils; heart-shaped leaves; reddish-brown flowers.
*Aster chilensis** | Common California aster	Sun	1.5 to 3 feet	June – September	Moist soils; white to purple flowers.
*Aster subspicatus** | Douglas aster	Sun	.5 to 2.5 feet	June – September	Moist soils; blue to purple flowers.
*Camassia quamash** | Common camas	Sun/ partial shade	To 2.5 feet	May – June	Moist to dry soils; lots of watering needed to establish; loose clusters of deep blue flowers.
Camassia leichtlinii | Giant camas		2 to 4 feet	May – June	Moist to dry soils; lots of watering to establish; large clusters of white, blue or greenish-yellow flowers.
*Iris douglasiana** | Pacific coast iris	Sun/ partial shade	1 to 2 feet	Spring	Tolerates many soils; withstands summer drought and seasonal flooding; white, yellow, blue, reddish purple flowers; fast growing; velvety purple flowers; vigorous.
Iris foetidissima | Gladwin iris	Sun/ partial shade	1 to 2 feet	May	Moist to dry, well-drained soils; pale lilac flower; also called Stinking iris.
*Juncus tenuis** | Slender rush	Sun	6 inches to 2.5 feet		Moist soils; yellow flowers.
Iris sibirica | Siberian iris	Sun	1 to 2.5 feet	Late spring – early summer	Moist soils; deep blue, purple to white flowers.

Table F.4 (continued). Plant Species Appropriate for Bioretention Facility Areas Subject to Periodic Saturation During Large Storms.

Herbaceous (continued)				
Species | Common Name	**Exposure**	**Mature Size**	**Time of Bloom**	**Comments**
*Tellima grandiflora** | Fringecup	Partial sun/ shade	1 to 3 feet	March – June	Perennial preferring moist soils; yellowish-green to pink flowers.
*Tiarella trifoliata** | Foamflower	Partial sun/ shade	To 1 foot	Early – mid-summer	Moist soils; perennial with some drought tolerance after established; can form dense colonies; white flowers.
*Tolmiea menziesii** | Youth-on-age/ Piggy-back plant	Partial shade/ shade	1 to 2 feet	April – August	Moist soils; brownish-purple flowers; also makes an effective groundcover.
Viola species* | Violets	Partial shade/ shade	6 to 12 inches	Late spring – early summer	Moist soils; yellow to blue flowers.

Table F.5. Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Trees				
Arbutus unedo | Strawberry tree	Sun/ partial shade	8 to 35 feet 8- to 20-foot spread	November – December	Tolerant of extremes; tolerant of urban/ industrial pollution; white or greenish white flowers.
*Calocedrus decurrens** | Incense cedar	Sun	75 to 90 feet 12-foot spread		Tolerant of poor soils; drought tolerant after established; fragrant evergreen with a narrow growth habit; slow growing.
Chamaecyparis obtusa | Hinoki false cypress	Sun/ partial shade	40 to 50 feet 15- to 30-foot spread		Moist, loamy, well-drained soils; very slow growing; prefers sun, but tolerates shade; does not transplant well or do well in alkaline soils. Note there are many alternative varieties of false cypress of varying sizes and forms from which to choose.
Cornus spp. | Dogwood	Sun/ partial shade	20 to 30 feet 30-foot spread	May	Reliable flowering trees with attractive foliage and flowers; may need watering in dry season; try *C. florida* (Eastern dogwood), or *C. nuttallii** (Pacific dogwood) or hybrid "Eddie's White Wonder." Also, *C. kousa* for small tree/ shrub that is resistant to anthracnose.
Pinus mugo | Swiss mountain pine	Sun/ partial shade	15 to 20 feet 25 to 30-foot spread		Prefers well-drained soil; slow growing, broadly spreading, bushy tree; hardy evergreen.
Pinus thunbergiana | Japanese black pine	Sun	To 100 feet 40-foot spread		Dry to moist soils; hardy; fast growing.
*Prunus emarginata** | Bitter cherry	Sun/ partial shade	20 to 50 feet 20-foot spread	May – June	Dry or moist soils; intolerant of full shade; bright red cherries are attractive to birds; roots spread extensively.
Prunus virginiana | Choke cherry		15 to 25 feet 15- to 20-foot spread	Late spring – early summer	Dry or moist soils; deep rooting; attractive white fragrant flowers; good fall color.
*Pseudotsuga menziesii** | Douglas-fir	Sun	100 to 250 feet 50- to 60-foot spread		Does best in deep, moist soils; evergreen conifer with medium to fast rate of growth; provides a nice canopy, but potential height will restrict placement.
*Quercus garryana** | Oregon white oak	Sun	To 75 feet		Dry to moist, well-drained soils; slow growing; acorns.

Table F.5 (continued). Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Shrubs				
*Holodiscus discolor** | Oceanspray	Sun/ partial shade	To 15 feet	June – July	Dry to moist soils; drought tolerant; white to cream flowers; good soil binder.
*Mahonia aquifolium** | Tall Oregon grape	Sun/ partial shade	6 to 10 feet	March – April	Dry to moist soils; drought resistant; evergreen; blue-black fruit; bright yellow flowers; "Compacta" form averages 2 feet tall; great low screening barrier.
*Philadelphus lewisii** | Mock-orange	Sun/ partial shade	5 to 10 feet	June – July	Adapts to rich moist soils or dry rocky soils; drought tolerant; fragrant flowers.
Pinus mugo pumilio | Mugo pine	Sun	3 to 5 feet 4- to 6-foot spread		Adapts to most soils; slow growing and very hardy; newer additions with trademark names such as "Slo-Grow" or "Lo-Mound" are also available.
Potentilla fruticosa | Shrubby cinquefoil	Sun	To 4 feet	May – September	Moist to dry soils; several cultivars available with varying foliage and flower hues; try "Tangerine" or "Moonlight."
*Ribes sanguineum** | Red-flowering currant	Sun/ partial shade	8 to 12 feet	March – April	Prefers dry soils; drought tolerant; white to deep-red flowers attract hummingbirds; dark-blue to black berries; thornless.
*Rosa gymnocarpa** | Baldhip rose	Partial shade	To 6 feet	May – July	Dry or moist soils; drought tolerant; small pink to rose flowers.
Shrubs – Evergreen				
Abelia x grandiflora | Glossy abelia	Partial sun/ partial shade	To 8 feet 5-foot spread	Summer	Prefers moist, well-drained soils, but drought tolerant; white or faintly pink flowers.
Arbutus unedo "Compacta" | Compact strawberry tree	Sun/ partial shade	To 10 feet	Fall	Prefers well drained soils; tolerant of poor soils; good in climate extremes; white to greenish-white flowers; striking red-orange fruit.
Cistus purpureus | Orchid rockrose	Sun	To 4 feet	June – July	Moist to dry well-drained soils; drought resistant; fast growing; reddish purple flowers.
Cistus salvifolius | White rockrose	Sun	2 to 3 feet 6-foot spread	Late spring	Moist to dry well-drained soils preferred, but can tolerate poor soils; tolerant of windy conditions and drought; white flowers.
Escallonia x exoniensis "*fradesii*" | Pink Princess	Sun/ partial sun	5 to 6 feet	Spring – Fall	Tolerant of varying soils; drought tolerant when established; pink to rose colored flowers; good hedge or border plant; attracts butterflies.

Table F.5 (continued). Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Shrubs – Evergreen (continued)				
Osmanthus delavayi | Delavay osmanthus	Sun/ partial shade	4 to 6 feet	March – May	Tolerant of a broad range of soils; attractive foliage and clusters of white fragrant flowers; slow growing.
Osmanthus x burkwoodii | Devil wood	Sun/ partial shade	4 to 6 feet	March – April	Drought tolerant once established; masses of small, white fragrant flowers.
Rhododendron | "PJM" hybrids	Sun/partial shade	To 4 feet	Mid – late April	Moist to fairly dry soils; well drained organic soil; lavender to pink flowers.
Stranvaesia davidiana	Sun	6 to 20 feet	June	Moist soils; white flowers in clusters; showy red berries.
Stranvaesia davidiana | undulata	Sun	To 5 feet	June	Moist soils; lower growing irregularly shaped shrub; great screening plant.
*Vaccinium ovatum** | Evergreen huckleberry	Partial shade/ shade	3 to 15 feet	March	Moist to slightly dry soils; small pinkish-white flowers; berries in August.
Groundcover – Evergreen				
*Arctostaphylos uva-ursi** | Kinnikinnik	Sun/ partial shade		April – June	Prefers sandy/rocky, well-drained soils; flowers pinkish-white; bright red berries; slow to establish; plant closely for good results.
*Gaultheria shallon** | Salal	Partial shade/ shade	3 to 7 feet	March – June	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit.
*Fragaria chiloensis** | Wild/coastal strawberry	Sun/ partial shade	10 inches	Spring	Sandy well drained soils; flowers white; small hairy strawberries; evergreen; aggressive spreader.
Helianthemum nummularium | Sunrose	Sun	To 2 feet 2-foot spread	May – July	Prefers well-drained soils, but will tolerate various soils; low-growing, woody sub shrub; many varieties are available with flowers in salmon, pink, red, yellow and golden colors.
Lavandula angustifolia | Lavender	Sun/ partial shade	To 1.5 feet	June – August	Adaptable to various soils; blue, lavender, pink to white flowers, semi-evergreen aromatic perennial.
*Mahonia nervosa** | Cascade Oregon grape/ Dull Oregon grape	Partial shade/ shade	To 2 feet	April – June	Dry to moist soils; drought resistant; evergreen; yellow flowers; blue berries.

Table F.5 (continued). Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Groundcover – Evergreen (continued)				
Mahonia repens | Creeping mahonia	Sun/ partial shade	3 feet	April – June	Dry to moist soils; drought resistant; yellow flowers; blue berries; native of eastern Washington.
*Penstemon davidsonii** | Davidson's penstemon	Sun	To 3 inches	June – August	Low-growing, evergreen perennial; prefers well-drained soils; drought tolerant; blue to purple flowers.
Perennials and Ornamental Grasses				
*Achillea millefolium** | Western yarrow	Sun	4 inches to 2.5 feet	June – September	Dry to moist, well-drained soils; white to pink/reddish flowers; many other yarrows are also available.
Anaphalis margaritaceae | Pearly everlasting	Sun/ partial shade	To 18 inches		Drought tolerant perennial; spreads quickly; attracts butterflies.
*Bromus carinatus** | Native California brome	Sun/ partial shade	3 to 5 feet		Dry to moist soils; tolerates seasonal saturation.
Carex buchannii | Leather leaf sedge	Sun/ partial shade	1 to 3 feet		Prefers well-drained soils; copper-colored foliage; perennial clumping grass; tolerant of a wide range of soils; inconspicuous flowers.
Carex comans | "Frosty curls" New Zealand hair sedge	Sun/ partial shade	1 to 2 feet	June – August	Prefers moist soils; finely textured and light green; compact, clumping perennial grass; drought tolerant when established; inconspicuous flowers.
Coreopsis spp. | Tickseed	Sun	1 to 3 feet		Dry to moist soils; drought tolerant; seeds attract birds; annual and perennial varieties; excellent cut flowers.
Echinacea purpurea | Purple coneflower	Sun	4 to 5 feet		Prefers well drained soils; hardy perennial; may need occasional watering in dry months.
*Elymus glaucus** | Blue wildrye	Sun/ partial shade	1.5 to 5 feet		Dry to moist soils; shade tolerant; rapid developing, but short lived (1 to 3 years); not good lawn grass.
*Dicentra formosa** | Pacific bleeding-heart	Sun/shade	6 to 20 inches	Early spring – early summer	Moist, rich soils; heart-shaped flowers.
*Erigeron speciosus** | Showy fleabane	Sun/ partial shade	To 2 feet	Summer	Moist to dry soils; dark violet or lavender blooms; fibrous roots.
Festuca ovina "Glauca" | Blue fescue	Sun/ partial shade	To 10 inches	May – June	Prefers moist, well-drained soils; blue-green evergreen grass; drought tolerant; shearing will stimulate new growth.

Table F.5 (continued). Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Perennials and Ornamental Grasses (continued)				
*Festuca idahoensis** | Idaho fescue	Sun/ partial shade	To 1 foot		Bluish-green bunching perennial grass; drought tolerant.
*Fragaria vesca** | Wood strawberry	Partial shade	To 10 inches	Late spring – early summer	Dry to moist soils; white flowers.
Gaura lindheimeri | Gaura	Sun	2.5 to 4 feet		Perennial; fairly drought tolerant and adaptable to varying soil types; long blooming period.
*Geum macrophyllum** | Large-leaved avens	Sun/ partial shade	To 3 feet	Spring	Moist, well-drained soil; bright yellow flowers; other Geum cultivars available, some of which may require supplemental watering.
Geranium maculatum | Spotted geranium	Sun/shade	To 1.5 feet	July	Moist, well-drained soils; low perennial; pale pink, blue to purple flowers.
Geranium sanguineum | Cranesbill	Sun/ partial shade	To 1.5 feet	May – August	Moist soils; deep purple almost crimson flowers.
Helichrysum italicum | Curry plant	Sun	To 2 feet	Summer	Moist or dry soils; hardy evergreen perennial; a good companion to lavender; bright yellow flowers; fragrant.
Helictotrichon sempervirens | Blue oat grass	Sun/ partial shade	1 to 1.5 feet	June – August	Tolerant of a variety of soil types but prefers well-drained soil; clumping bright blue evergreen grass; bluish white flowers.
Hemerocallis fulva | Daylilies	Sun/ partial shade	1 to 4 feet	Summer	Tolerant of a variety of soil types; easy to grow and tolerant of neglect; hardy perennial; entire plant is edible.
Heuchera americana | Coral bells (alumroot)	Sun/ partial shade	1 to 2 feet	June – August	Moist to dry, well-drained soils; never wet; easily transplantable perennial; red, greenish-white flowers; may need supplemental watering in dry season.
Heuchera micrantha | “Palace purple” (alumroot)	Sun/ partial shade	1 to 2 feet	June – August	Moist, well-drained soils; bronze to purple foliage in shade; small, yellowish-white flowers; perennial, evergreen; a number of other species and varieties are available. Try *H. sanguinea* for bright red flowers.
*Lupinus** spp. | Lupines	Sun	3 to 5 feet	March – September	Moist to dry soils; various native varieties; blue to purple, violet to white flowers; both native and nonnative varieties.

Table F.5 (continued). Plant Species Appropriate for Rarely Inundated Areas of Bioretention Facility.

Species | Common Name	Exposure	Mature Size	Time of Bloom	Comments
Perennials and Ornamental Grasses (continued)				
*Lupinus bicolor** | Two-color lupine	Sun	4 inches to 1.5 feet	Spring	Dry gravelly soils; small-flowered; annual.
*Lupinus latifolius** | Broadleaf lupine	Sun	To 1 foot	June – August	Dry to moist soils; perennial; bushy herb; bluish flowers.
*Lupinus polyphyllus** | Large-leafed lupine	Sun	To 3 feet	Spring – summer	Dry to moist, sandy to gravelly soils; perennial.
*Maianthemum dilatatum** | False lily-of-the-valley	Partial shade/ shade	3 to 12 inches	Spring	Prefers moist soils; small, white flowers; light-green to red berries.
Pennisetum alopecuroides | Fountain grass	Sun/ partial shade	1 to 2 feet	August – September	Moist, well-drained soils; tolerant of many soil types; clump-forming grasses. A number of varieties are available in different heights and bloom times. Try *P. caudatum* (White-flowering fountain grass) and *P. alopecuroides* cultivars “Hameln” and “Little Bunny” (Dwarf fountain grass).
Pennisetum orientale | Oriental fountain grass	Sun/ partial shade	1 to 3 feet	June – October	Prefers moist, well-drained soils; somewhat drought tolerant; small clumping, blooming grass, showy pink flowers; fountain grasses will benefit from annual shearing in late winter/early spring, but not required.
Penstemon fruticosus | Shrubby penstemon	Sun	8 to 10 inches	May	Prefers well-drained soils; evergreen perennial; drought tolerant; violet-blue flowers 1-inch long attract hummingbirds.
*Polystichum munitum** | Swordfern	Partial shade/ deep shade	2 to 4 feet		Prefers moist, rich soil conditions, but drought tolerant; large evergreen fern.
*Potentilla gracilis** | Graceful cinquefoil	Sun	1 to 2 feet	July	Moist to dry soils; yellow flowers.
Rudbeckia hirta | Black-eyed Susan	Sun/ partial shade	3 to 4 feet	Summer	Moist to dry soils; showy flowers, hardy and easy to grow; several other varieties are available.
*Smilacina racemosa** | False Solomon’s seal	Partial sun/ shade	1 to 3 feet	April – May	Moist soils; creamy white flowers; red berries.

*Denotes native plant species.