Washington State
Department of Transportation

Highway Runoff Manual

M 31-16.04

Supplement February 2016

Engineering and Regional Operations
Development Division, Design Office

- Soil infiltration rates (see Section 2-1.2.2)
- Vegetation surveys
- Stormwater discharge points, including outfalls and connections to and from other storm sewer systems (discharge inventory and site reconnaissance)
- Stormwater features database
- Land use types and associated pollutants
- Adjacent development and stormwater facilities – in particular, any nearby infiltration facilities
- Groundwater data (including depth to seasonal high water table)
- Presence of hazardous materials or wastes
- Presence of cultural resources
- Average annual daily traffic (AADT)
- Roadway geometry (profiles/superelevations)
- Geotechnical evaluation (see Section 2-1.2.2)

Use WSDOT's *GIS Workbench* (an ArcView geographic information system tool) to access detailed site, environmental, and natural resource management data as well as generate maps to help with the project assessment, the selection of stormwater management alternatives, and the determination of maintenance applications.

2-1.2.2 Geotechnical Evaluations

Understanding the soils, geology, geologic hazards, and groundwater conditions at the project site is essential to optimizing the project's stormwater design. Contact the Region Materials Engineer (RME) and staff from the HQ Geotechnical Office as early as possible in the scoping phase for inclusion on the scoping and design team.

Infiltration is the preferred method for the management of stormwater runoff. Chapters 4 and 5 provide direction on how to apply optimal infiltration for stormwater management on transportation projects. However, you need to assess the extent to which infiltration can be used during the scoping phase because of its direct impact on stormwater alternatives and costs. The degree to which you can infiltrate runoff depends on the project location and context. Limiting factors include soil characteristics, depth to groundwater, and designated aquifer protection areas.

The RME evaluates the geotechnical feasibility of stormwater facilities that may be needed for the project. With assistance from the HQ Geotechnical Engineer, as needed, the RME gathers all available geotechnical data pertinent to the assessment of the geotechnical feasibility of the proposed stormwater facilities. Some subsurface exploration may be required at this stage, depending on the adequacy of the geotechnical data available to assess feasibility. Refer to the *Design Manual,* Section 610.04, for additional details.

2A-3.6 Maintenance Limitations to Construction Feasibility

Maintenance is essential to the performance of runoff treatment and flow control BMPs; therefore, it needs to be discussed and reviewed with the local maintenance office prior to finalizing the design. Maintenance considerations to address during the design process include: specific site restrictions that prevent access, long-term operation and maintenance costs, and necessary equipment and training. Complete the Hydraulic Report Checklist found on the WSDOT HQ Hydraulics website and review it with the area maintenance office. If no suitable, approved stormwater BMPs can be constructed and maintained, document the reasons in the EEF evaluation.

2A-3.7 Cost Limitations to Construction Feasibility

Critical factors found to affect stormwater management costs include the location and setting of projects relative to neighborhoods, streams, and wetlands. In addition, projects with poor soil conditions or high water tables generally have considerably higher costs for treating stormwater within the right of way. It is incumbent upon your project manager to consider all project costs and balance them to maximize the benefit-to-cost ratio. In some cases, the costs to treat stormwater, relative to the overall project costs, may seem out of proportion to the benefit. In these cases, your project team shall document the costs in the EEF evaluation.

Avoid placing BMPs in wetlands, 100-year floodplains, and intertidal areas. These natural systems have a higher net environmental benefit than engineered stormwater management systems. If the placement of a required flow control BMP would impact such a sensitive area, consult the Region Hydraulics Office as early as possible for aid in properly analyzing the effects of various flow control options. The Region Hydraulics and Environmental offices will also coordinate with the appropriate state, local, tribal, and federal agencies to ensure adequate protection of all natural resources and obtain the required permits.

Design specifications for conveyance and flood prevention are reviewed with the assistance of the Region or HQ Hydraulics Office.

Western Washington Design Criteria

Ensure stormwater discharges match developed discharge durations to predeveloped durations for the range of predeveloped discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. Also, check the 100-year peak flow rate for downstream flooding and property damage using an approved continuous simulation model.

Refer to Section 4-3.5.1 for the appropriate modeling process. Also, reference the same section for the modeling process to address mitigated and nonmitigated areas on projects in on-site and off-site flow bypass situations.

Predeveloped Condition for Stormwater Hydrology Modeling

The project site's predeveloped conditions for effective impervious surfaces are to assume "historic" land cover conditions unless one of the following conditions applies:

- Reasonable, historic information is provided that indicates the site was prairie prior to settlement (modeled as "pasture" in MGSFlood).
- The drainage area of the immediate stream and all subsequent downstream basins has had at least 40% total impervious area since 1985. In this case, the predeveloped condition to be matched must be the existing land cover condition. Where basin-specific studies determine a stream channel to be unstable, even though the above criterion is met, the predeveloped condition assumption must be the "historic" land cover condition or a land cover condition commensurate with achieving a target flow regime identified by an approved basin study. More information on qualifying basins is available at: www.ecy.wa.gov/programs/wq/stormwater/flowcontrol.html

For WSDOT projects, assume an existing land cover condition if following the Stormwater Retrofit Analysis procedure outlined in Section 3-4 and Figures 3-4 and 3-5. This process was created through an agreement between WSDOT and DOE for WSDOT projects.

Table 3-6 summarizes flow control criteria for western Washington. The duration standard does not apply to infiltration facilities that will reliably infiltrate all the runoff from impervious surfaces and converted pervious surfaces.

Table 3-6 Western Washington flow control criteria.

Facility Type	Criteria	Model
Infiltration facilities	Size facility to infiltrate sufficient volumes so that the overflow matches the duration standard, and check the 100-year peak flow to estimate the potential for downstream property damage, or infiltrate the entire runoff file.	Continuous simulation model using 15-minute time steps
Detention/combination treatment and detention facilities	Provide storage volume required to match the duration of predeveloped peak flows from 50% of the 2-year up to the 50-year storm flow, using a flow restrictor (such as an orifice or weir), and check the 100-year peak flow for property damage.	Continuous simulation model using 15-minute time steps

Establish an alternative flow control standard by applying watershed-scale hydrologic modeling and supporting field observations. Possible justifications for an alternative flow control standard include:

1. Establishment of a stream-specific threshold of significant bedload movement other than the assumed 50% of the 2-year peak flow; OR
2. Zoning and Land Clearing Ordinance restrictions that, in combination with an alternative flow control standard, maintain or reduce the naturally occurring erosive forces on the stream channel, with local jurisdiction approval; OR
3. A duration control standard is not necessary for protection, maintenance, or restoration of designated beneficial uses or Clean Water Act compliance.

Eastern Washington Design Criteria

Using a single-event model, flow control design requirements for projects must limit the peak release rate of the postdeveloped 2-year runoff volume to 50% of the predeveloped 2-year peak and maintain the predeveloped 25-year peak runoff rate. Check the 100-year event for downstream flooding and property damage.

Predeveloped Condition for Stormwater Hydrology Modeling

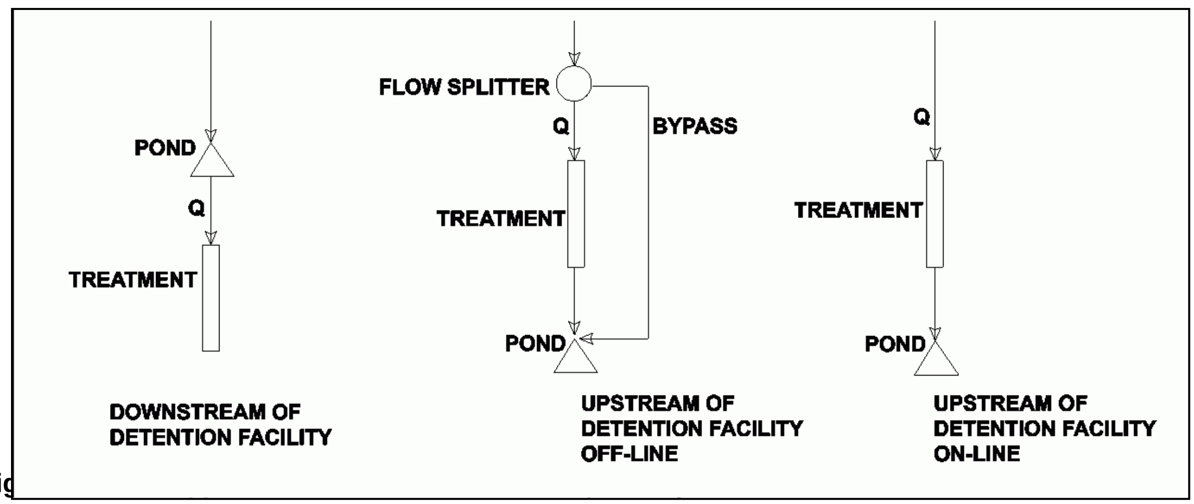
The project site's predeveloped conditions for effective impervious surfaces are to assume an existing land cover. Table 3-7 summarizes flow control criteria for eastern Washington. The peak flow matching standard does not apply to infiltration facilities that will reliably infiltrate all the runoff from impervious surfaces and converted pervious surfaces.

4-3 Western Washington Design Criteria

4-3.1 Runoff Treatment Flow-Based and Volume-Based BMPs

4-3.1.1 Flow-Based Runoff Treatment

Use an approved continuous simulation hydrologic model based on the U.S. Environmental Protection Agency's (U.S. EPA's) Hydrologic Simulation Program – Fortran (HSPF) when designing runoff treatment BMPs based on flow rate, in accordance with WSDOT Minimum Requirement 5 in Section 3-3.5. Use **MGSFlood** for designing flow-based runoff treatment BMPs in WSDOT right of way unless prior approval to use an alternate (equivalent Ecology approved) program is given by the Region or HQ Hydraulics Engineer. The design flow rate for these types of facilities is dependent upon whether the treatment facility is located upstream or downstream of a flow control facility and whether it is an *on-line* or *off-line* facility (see Figure 4-6).



Fig

Downstream of Flow Control Facilities

If the runoff treatment facility is located downstream of a stormwater flow control facility, use the full 2-year recurrence interval release rate from the flow control facility, as estimated by an approved continuous simulation model, to design the treatment facility. For biofiltration swale design, the 2-year recurrence interval release rate from detention pond is Q_{wq} and is "online".

Upstream of Flow Control Facilities: Off-Line

The design flow rate for an off-line treatment facility located upstream of a flow control facility is the flow rate where 91% of the runoff volume for the developed TDA will be treated, based on a 15-minute time step, as estimated by an approved continuous simulation model. The bold horizontal line in Figure 4-7 is an example that shows the 91% runoff volume flow rate. All flows below that line will be treated, and the incremental portion of flow above that line will bypass the runoff treatment facility.

Increase the depth, number of test holes or test pits, and sampling described below if a licensed Civil (Geotechnical) Engineer with relevant geotechnical design expertise (P.E.), or other licensed professional acceptable to WSDOT, judges that conditions are highly variable and make it necessary to increase the depth or the number of explorations to accurately estimate the infiltration system's performance. You may decrease the exploration program described below if a licensed Civil (Geotechnical) Engineer with relevant geotechnical design expertise (P.E.), or other licensed professional acceptable to WSDOT, judges that conditions are relatively uniform; design parameters are known to be conservative based on site-specific data or experience; and the borings/ test pits omitted will not influence the design or successful operation of the facility. For design build projects, ensure the exploration program described below is approved by the WSDOT Region Materials Office prior to implementation.

- For infiltration ponds, ensure at least one test pit or test hole per 5,000 ft^2 of basin infiltrating bottom surface area, but there should be a minimum of 2 test pits or holes per pond.
- For infiltration trenches, infiltration vaults, and CAVFS, ensure at least one test pit or test hole per 100 to 300 feet of length.
- For drywells, collect samples from each layer beneath the facility to the depth of groundwater or to approximately 40 feet below the ground surface (approximately 30 feet below the base of the drywell). Subsurface explorations (test holes or test pits) to a depth below the base of the infiltration facility of at least 5 times the maximum design depth of water proposed for the infiltration facility, or at least 2 feet into the saturated zone.
- Continuously sample to a depth below the base of the infiltration facility of 2.5 times the maximum design depth of water proposed for the infiltration facility, or at least 2 feet into the saturated zone, but not less than 6 feet. Ensure samples obtained are adequate for the purpose of soil gradation/ classification testing.
- Install groundwater monitoring wells to locate the groundwater table and establish its gradient, direction of flow, and seasonal variations, considering both confined and unconfined aquifers. (Monitoring through at least one wet season is required unless site historical data regarding groundwater levels are available.) In general, a minimum of three wells per infiltration facility, or three hydraulically connected surface or groundwater features, are needed to determine the direction of flow and gradient. If gradient and flow direction are not required and there is low risk of downgradient impacts, one monitoring well is sufficient. You may consider alternative means of establishing the groundwater levels. If the groundwater in the area is known to be greater than 50 feet below the proposed facility, detailed investigation of the groundwater regime is not necessary.

- Conduct 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 within 2.5 times the maximum design water depth, but not less than 6 feet. When assessing the saturated hydraulic conductivity characteristics of the site, consider soil layers at greater depths 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. If an infiltration facility such as a CAVFS is constructed on a new embankment, the soil gradation of the embankment material will need to be assessed.

5. **From the geotechnical investigation, determine the following, as applicable:**

   - The stratification of the soil/rock below the infiltration facility, including the soil gradation (and plasticity, if any) characteristics of each stratum.
   - The depth to the groundwater table and to any bedrock/impermeable layers.
   - Seasonal variation of the groundwater table.
   - The existing groundwater flow direction and gradient.
   - The saturated hydraulic conductivity or the infiltration rate for the soil/rock at the infiltration facility including new embankment material if required.
   - The porosity of the soil below the infiltration facility, but above the water table.
   - The lateral extent of the infiltration receptor.
   - The impact of the infiltration rate and volume on flow direction and water table at the project site and the potential discharge point or area of the infiltrating water.

   For other aspects of the geotechnical design of infiltration facilities, see Chapters 2 and 5.

6. **Determine the saturated hydraulic conductivity as noted in Section 4-5.3.**

7. **For unusually complex, critical design cases, develop input data for a simulation model.**

   Use **MODFLOW**, including trial geometry, continuous hydrograph data, soil stratigraphy, groundwater data, saturated hydraulic conductivity data, and reduction in saturated hydraulic conductivity due to siltation or biofouling on the surface of the facility. Use of this approach will generally be fairly rare. If necessary, the design office should contact consulting services for help in locating an appropriate resource to complete a MODFLOW analysis. Otherwise, skip this step and develop the data needed to estimate the hydraulic gradient, as shown in the following steps.

8. **Calculate the hydraulic gradient.**

Calculate the steady state hydraulic gradient as follows:

$$\text{gradient} = \text{i} \approx \frac{D_{wt} + D_{pond}}{138.62(K_{equiv}{}^{0.1})} CF_{size} \tag{4D-6}$$

where: i = steady state hydraulic gradient

D_{wt} = the depth from the base of the infiltration facility to the water table in feet

K_{equiv} = the average saturated hydraulic conductivity in feet/day

D_{pond} = the depth of water in the facility in feet (see Massmann et al., 2003, for the development of this equation)

CF_{size} = the correction for pond size

The correction factor was developed for ponds with bottom areas between 0.6 and 6 acres in size. For small ponds (ponds with area equal to 2/3 acre or less), the correction factor is equal to 1.0. For large ponds (ponds with area equal to 6 acres), the correction factor is 0.2, as shown in Equation 4D-7.

$$CF_{size} = 0.73(A_{pond})^{-0.76} \tag{4D-7}$$

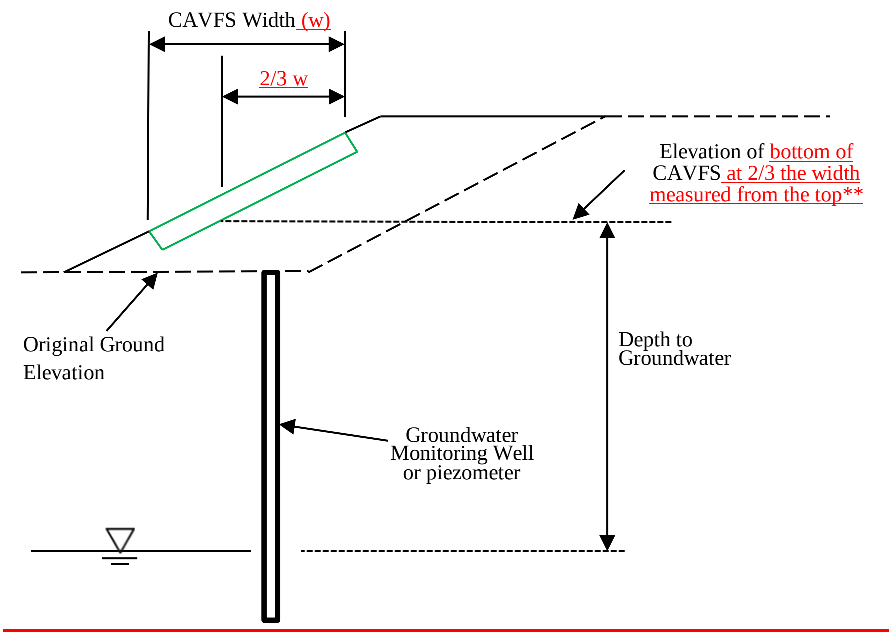
where: A_{pond} = the area of pond bottom in acres

This equation will generally result in a calculated gradient of less than 1.0 for moderate-to-shallow groundwater depths (or to a low-permeability layer) below the facility and conservatively accounts for the development of a groundwater mound. A more detailed groundwater mounding analysis, using a program such as MODFLOW, will usually result in a gradient that is equal to or greater than the gradient calculated using Equation 4D-6. If the calculated gradient is greater than 1.0, the water table is considered to be deep and a maximum gradient of 1.0 must be used.

Typically, a depth to groundwater of 100 feet or more is required to obtain a gradient of 1.0 or more using this equation. Since the gradient is a function of depth of water in the facility, the gradient will vary as the pond fills during the season. Therefore, calculate the gradient as part of the stage-discharge calculation used in MGSFlood for the continuous hydrograph method. For designs using the single-event hydrograph, it is sufficiently accurate to calculate the hydraulic gradient based on one-half the maximum depth of water in the pond.

For the underlying soils of a CAVFS, use Equation 4D-6 (pond gradient equation) to determine the hydraulic gradient if the CAVFS length is less than 30 times the width. A correction factor is not needed for CAVFS design. You can assume CF_{size} = 1.0 for CAVFS design. If the CAVFS length is greater than or equal to 30 times the width, use Equation 4D-12 (trench gradient equation) to determine the hydraulic gradient for the underlying soils of a CAVFS. No correction factors for biofouling or siltation are needed for underlying soils of CAVFS since those soils are under the CAVFS layer. Since the CAVFS is on a slope, the elevation from which the gradient is measured needs some discussion. For assessing the gradient component (i) in equations 4D-6 and 4D-12, the depth to the water table D_{wt}, should be calculated by using a reference point that is equal to 2/3 the distance between the upper and lower boundary of the CAVFS measured from the top (see the below drawing). D_{pond} is the depth of the CAVFS which is generally 12 inches since anything deeper than 12 inches on embankments may increase the potential for slope instability and excessive settlement at the CAVFS locations.

CAVFS PLACED IN A NEW FILL SECTION



**The elevation of the bottom of the CAVFS (2/3 w) is also valid for CAVFS placed in an existing embankment.

9. **Calculate the infiltration rate using Darcy's Law as follows:**

$$f = 0.5K_{equiv}\left(\frac{dh}{dz}\right) = 0.5K_{equiv}(i) \quad (4D\text{-}8)$$

where: f = the infiltration rate of water through a unit cross section of the infiltration facility (in/hr)

K_{equiv} = the average saturated hydraulic conductivity (ft/day)

dh/dz = the steady state hydraulic gradient

i = the steady state hydraulic gradient

0.5 = converts ft/day to in/hr

10. **Adjust the infiltration rate or infiltration stage-discharge relationship obtained in Steps 8 and 9.**

    Applying the reduction factors in Table 4D-2 are done by the designer and not the Region Material Engineer. This is done to account for reductions in the rate resulting from long-term siltation and biofouling, taking into consideration the degree of long-term maintenance and performance monitoring anticipated; the degree of influent control (such as presettling ponds or biofiltration swales); and the potential for (among others) siltation, litterfall, or moss buildup based on the surrounding environment. It should be assumed that an average-to-high degree of maintenance will be performed on these facilities. Consider a low degree of maintenance only when there is no other option (such as with access problems). Multiply the infiltration rates estimated in Steps 8 and 9 by the reduction factors summarized in Table 4D-2.

Table 4D-2 Infiltration rate reduction factors to account for biofouling and siltation effects for ponds (Massmann, 2003).

Potential for Biofouling	Degree of Long-Term Maintenance/Performance Monitoring	Infiltration Rate Reduction Factor, $CF_{silt/bio}$
Low	Average to High	0.9
Low	Low	0.6
High	Average to High	0.5
High	Low	0.2

The values in this table assume that final excavation of the facility to the finished grade is deferred until all disturbed areas in the upgradient drainage area have been stabilized or protected (for example, construction runoff is not allowed into the facility after final excavation of the facility) as required in Section 5-4.2.1.

An example of a situation with a high potential for biofouling would be a pond located in a shady area where moss and litterfall from adjacent vegetation can build up on the pond bottom and sides, the upgradient drainage area will remain in a long-term disturbed condition, and no pretreatment (such as presettling ponds or biofiltration swales) is provided. Situations with a low degree of long-term maintenance include locations where access to the facility for maintenance is very difficult or limited or where there is minimal control of the party responsible for enforcing the required maintenance. Consider a low degree of maintenance only when there is no other option.

Adjust this infiltration rate for the effect of pond aspect ratio by multiplying the infiltration rate determined in Step 9 (Equation 4D-8) by the aspect ratio correction factor CF_{aspect}, as shown in the following equation. In no case shall CF_{aspect} be greater than 1.4.

$$CF_{aspect} = 0.02A_r + 0.98 \qquad \text{(4D-9)}$$

where: CF_{aspect} = the aspect ratio correction factor
A_r = the aspect ratio for the pond (length/width)

The final infiltration rate will therefore be as follows:

$$f = (0.5K_{equiv})(i)(CF_{aspect})(CF_{silt/bio}) \quad (4D\text{-}10)$$

The infiltration rates calculated based on Equations 4D-8 and 4D-10 are long-term design rates. No additional reduction factor or factor of safety is needed.

11. **Determine the infiltration flow rate *Q*.**

If the infiltration facility is located in eastern Washington, determine the infiltration flow rate *Q* using the Infiltration Pond Design Spreadsheet at:
www.wsdot.wa.gov/design/hydraulics/training.htm.

If the infiltration facility is located in western Washington, determine the infiltration flow rate *Q* using MGSFlood.

12. **Size the facility.**

Size the facility to ensure the pond depths are between 2 and 6 feet, with 1 foot-minimum required freeboard. Use one of the following two approaches, depending on the type of hydrograph used:

- If using a continuous hydrograph for runoff treatment design, refer to Appendix 4A for a "Time-to-Drain" spreadsheet web link.
- If using a single-event hydrograph, calculate T_{req} using StormShed to determine the time it takes the pond to empty or from the value of *Q* determined from Step 11 and V_{design} from Step 2, as follows:

$$T_{req} = \frac{V_{design}}{Q} \quad (4D\text{-}11)$$

where: T_{req} = the time required to infiltrate the design stormwater volume
V_{design} = volume of stormwater in cubic feet
Q = infiltration flow rate in cfs

This value of T_{req} must be less than or equal to the maximum allowed infiltration time specified in the Site Suitability Criteria in Section 4-5.1.

13. **Construct the facility.**

Maintain and monitor the facility for performance in accordance with the *Maintenance Manual*.

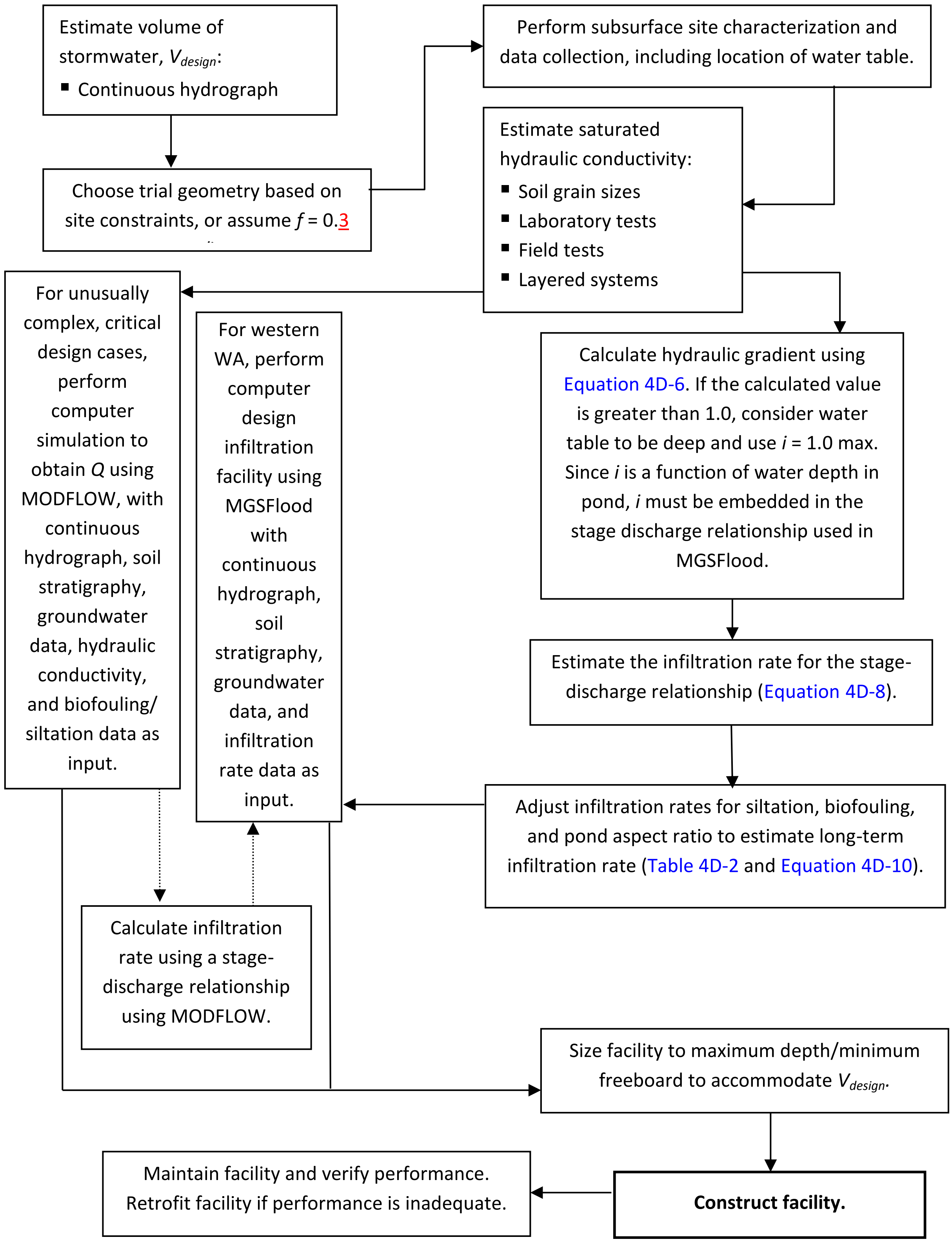


Figure 4D-1 Engineering design steps for final design of infiltration facilities using the continuous hydrograph method (western Washington).

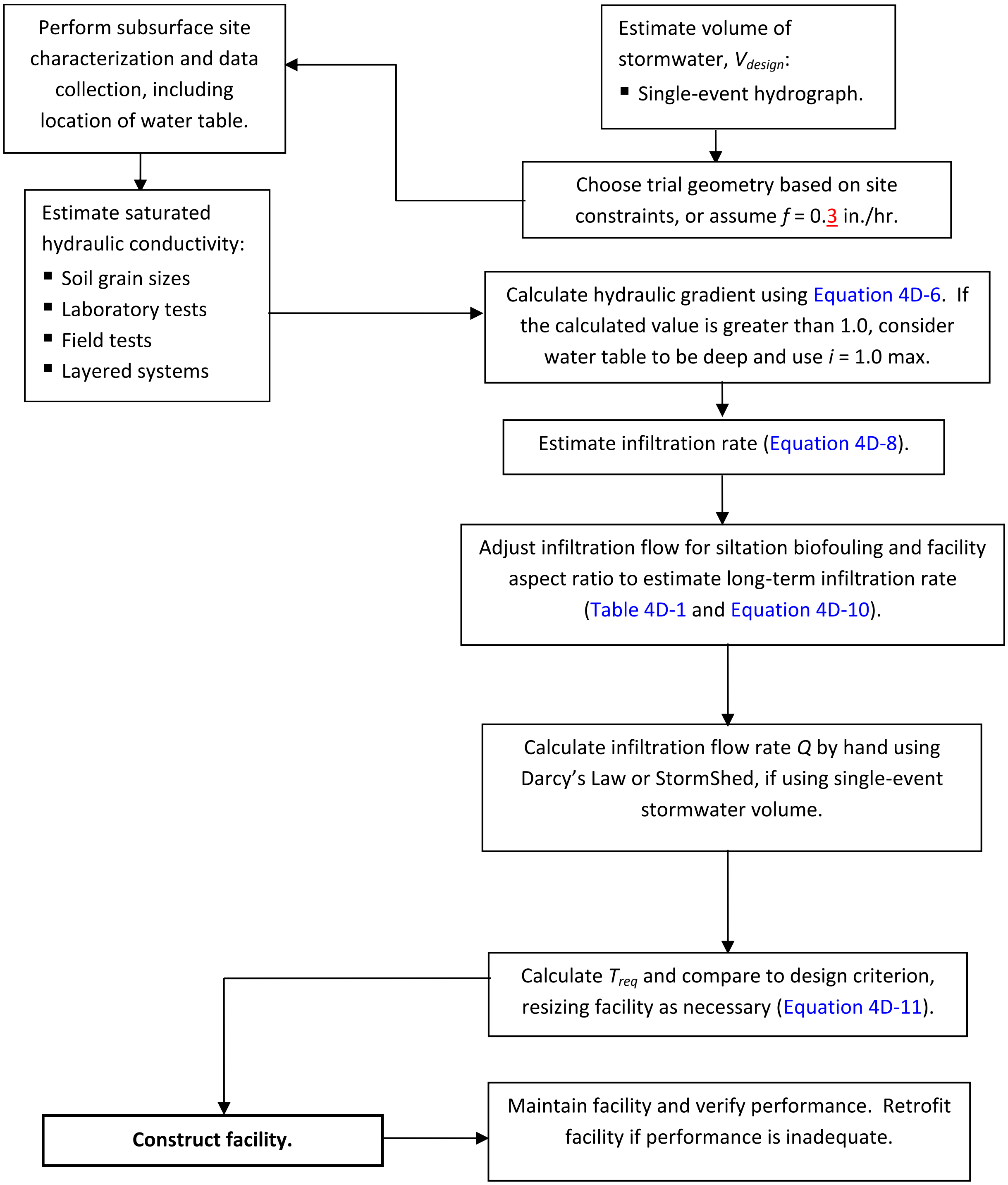


Figure 4D-2 Engineering design steps for final design of infiltration facilities using the single-event hydrograph method (eastern Washington).

4D-3.2 Simplified Approach to Determining Infiltration Rates

The Simplified Approach was derived from high groundwater and shallow pond sites in western Washington and, in general, will produce conservative designs. Applying this method to eastern Washington will produce even more conservative designs. The Simplified Approach can be used when determining the trial geometry of the infiltration facility for small or low-impact facilities or for facilities where a more conservative design is acceptable. Do not use the simplified method to determine short-term soil infiltration rates for runoff treatment infiltration facilities in western Washington, as referenced in SSC 5. Apply the Simplified Approach to ponds, vaults, and trenches and include the following steps (see Figure 4D-3 for a flowchart of this process):

1. **Select a location.**

   This will be based on the ability to convey flow to the location and the expected soil conditions of the location. You must meet the minimum setback distances.

2. E**stimate volume of stormwater, V_{design}.**

   For eastern Washington, use a single-event hydrograph for the volume, allowing for a simplified modeling approach such as StormShed. For western Washington, use a continuous hydrograph, requiring MGSFlood for the calculations.

3. **Develop trial infiltration facility geometry.**

   To accomplish this, assume an infiltration rate based on previously available data, or use a default infiltration rate of 0.3 inches/hour. Use this trial facility geometry to help locate the facility and for planning purposes in developing the geotechnical subsurface investigation plan.

4. **Conduct a geotechnical investigation.**

   The geotechnical investigation evaluates the suitability of the site for infiltration; establishes the infiltration rate for design; and evaluates slope stability, foundation capacity, and other geotechnical design information needed to design and assess constructability of the facility. The geotechnical investigation is described in Section 4D-3.1, Steps 4 and 5 (Figures 4D-3 and 4D-4).

5. **Determine the infiltration rate.**

   Ecology's SWMMWW provides a correlation between the D_{10} size of the soils **below the infiltration facility and the infiltration rate, as shown in Table 4D-3**, which you can use to estimate the infiltration rate.

   The data that form the basis for Table 4D-3 were from soils that would be classified as sands or sandy gravels. No data were available for finer soils at the time the table was developed. However, additional data based on recent research (Massmann et al., 2003) for these finer soils are now available and are shown in Figure 4D-4.

Figure 4D-4 provides a plot of this relationship between the infiltration rate and the D_{10} of the soil, showing the empirical data upon which it is based. The figure provides an upper- and lower-bound range for this relationship, based on the empirical data. Use these upper- and lower-bound ranges to adjust the design infiltration rate to account for site-specific issues and conditions.

The long-term rates provided in Table 4D-3 represent average conditions regarding site variability, the degree of long-term maintenance, and pretreatment for TSS control. They also represent a moderate depth to groundwater below the pond.

Table 4D-3 Recommended infiltration rates based on ASTM Gradation Testing.

D_{10} Size from ASTM D422 Soil Gradation Test (mm)	Estimated Long-Term (Design) Infiltration Rate (inch/hour)
≥ 0.4	9
0.3	6.5
0.2	3.5
0.1	**2.0**
0.05	0.8

The long-term infiltration rates in Table 4D-3 may need to be decreased (toward the lower-bound in Figure 4D-4) if the site is highly variable; the groundwater table is shallow; there is fine layering present that would not be captured by the soil gradation testing; or maintenance and influent characteristics are not well controlled. However, if influent control is good (for example, water entering the pond is pretreated through a biofiltration swale or presettling basin); if a good, long-term maintenance plan will be implemented; and if the water table is moderate in depth, then you could use an infiltration rate toward the upper-bound in the figure.

The infiltration rates provided in Figure 4D-4 represent rates for homogeneous soil conditions. If more than one soil unit is located within 2.5 times the maximum design depth of water proposed for the infiltration facility, or at least 2 feet into the saturated zone but no less than 6 feet below the base of the infiltration facility, use the lowest infiltration rate determined from each of the soil units as the representative site infiltration rate.

The rates shown in Table 4D-3 and Figure 4D-4 are long-term design rates. No additional reduction factor or factor of safety is needed.

Note that Table 4D-3 provides an infiltration rate, not a saturated hydraulic conductivity that must be multiplied by a hydraulic gradient or other factors, as provided in Equation 4D-10. The infiltration rates provided in this table assume a fully developed groundwater mound and very low hydraulic gradients. Hence, if the water table is relatively deep, the infiltration rate calculated from Equation 4D-10 will likely be more accurate, but less conservative, than the infiltration rates provided in Table 4D-3. For shallow water table situations, Equation 4D-10 will produce infiltration rates similar to those provided in Table 4D-3 and shown in Figure 4D-4.

6. **Determine the infiltration flow rate *Q*.**

   If the infiltration facility is located in eastern Washington, determine the infiltration flow rate *Q* using the Infiltration Pond Design Spreadsheet (🖰 www.wsdot.wa.gov/design/hydraulics/training.htm) or use StormShed.

   If the infiltration facility is located in western Washington, determine the infiltration flow rate *Q* using MGSFlood.

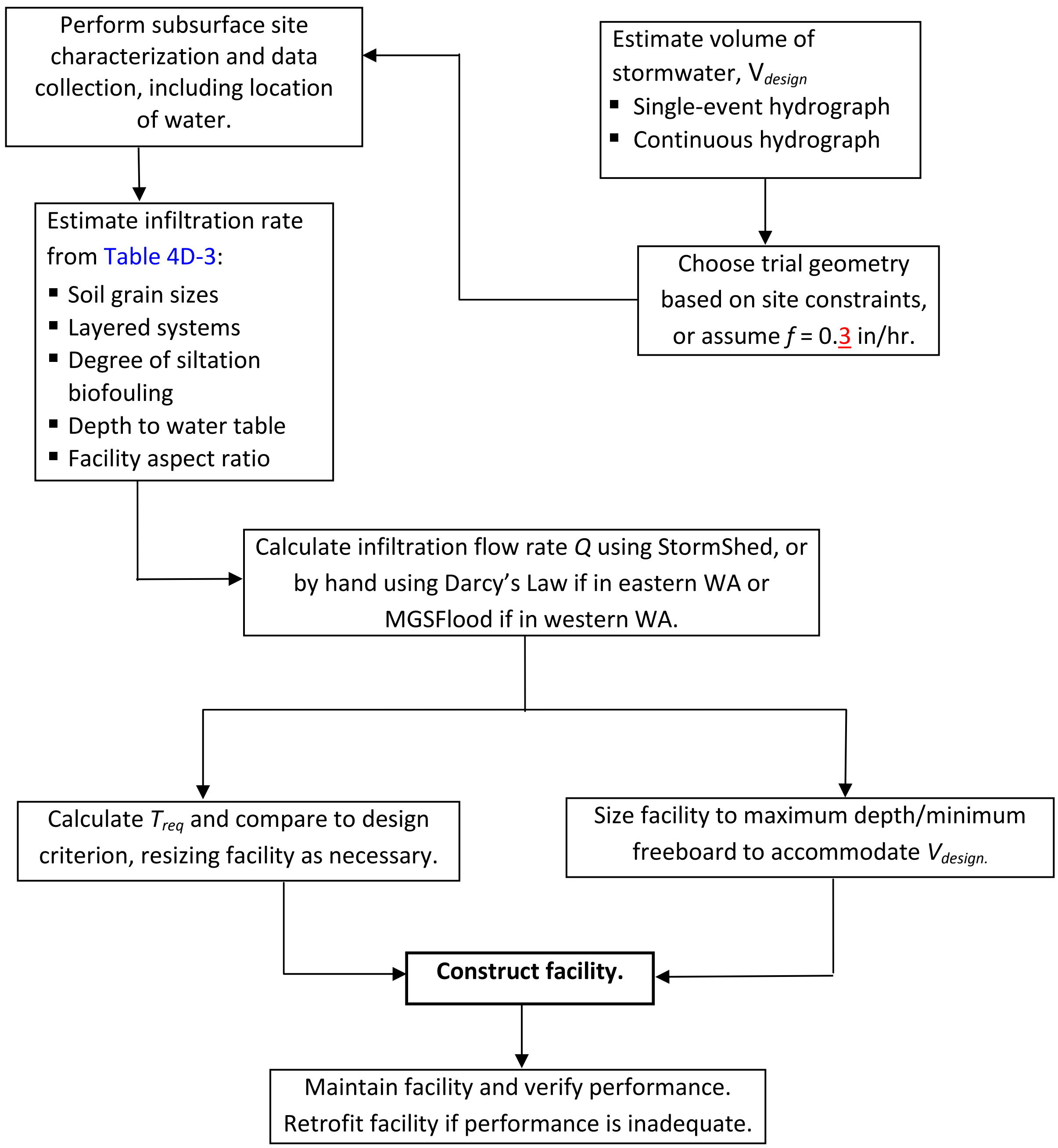
7. **Size the facility.**

   Size the facility to ensure the pond depths are between 2 and 6 feet, with 1 foot minimum required freeboard. Use one of the following two approaches, depending on the type of hydrograph used:

   - If using a continuous hydrograph for runoff treatment design, refer to Appendix 4A for a "Time-to-Drain" spreadsheet web link.
   - If using a single-event hydrograph, use StormShed or calculate T_{req} using Equation 4D-11 from the Detailed Approach in Section 4D-3.1, using the value of *Q* determined from Step 11 and V_{design} from Step 2 of that approach. The value of T_{req} calculated must be less than or equal to the maximum allowed infiltration time specified in the Site Suitability Criteria in Section 4-5.1.

8. **Construct the facility.**

   Maintain and monitor the facility for performance in accordance with the *Maintenance Manual*.



(Note: Use for trial geometry, small or low-impact facilities, or for facilities where a more conservative design is acceptable.)

Figure 4D-3 Engineering design steps for design of infiltration facilities: Simplified infiltration rate procedure.

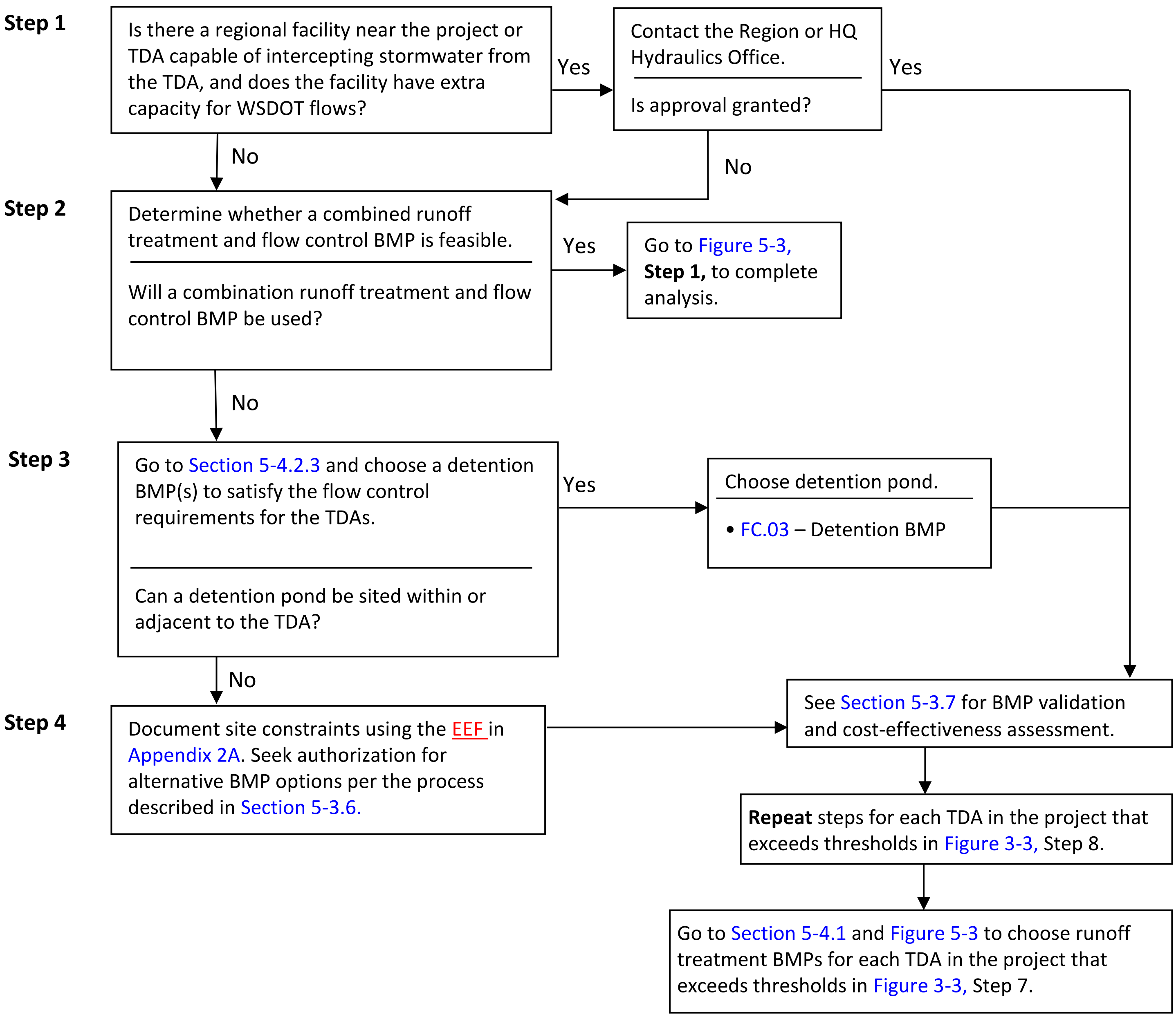


Figure 5-2 Flow control BMP selection flow chart.

- **Groundwater management plans** (wellhead protection plans and sole-source aquifers): To protect groundwater quality and quantity, these plans may identify actions required of stormwater discharges.
- **Lake management plans:** These plans are developed to protect lakes from eutrophication due to phosphorus-laden runoff from the drainage basin. Control of phosphorus from new development is a likely requirement in any such plans.

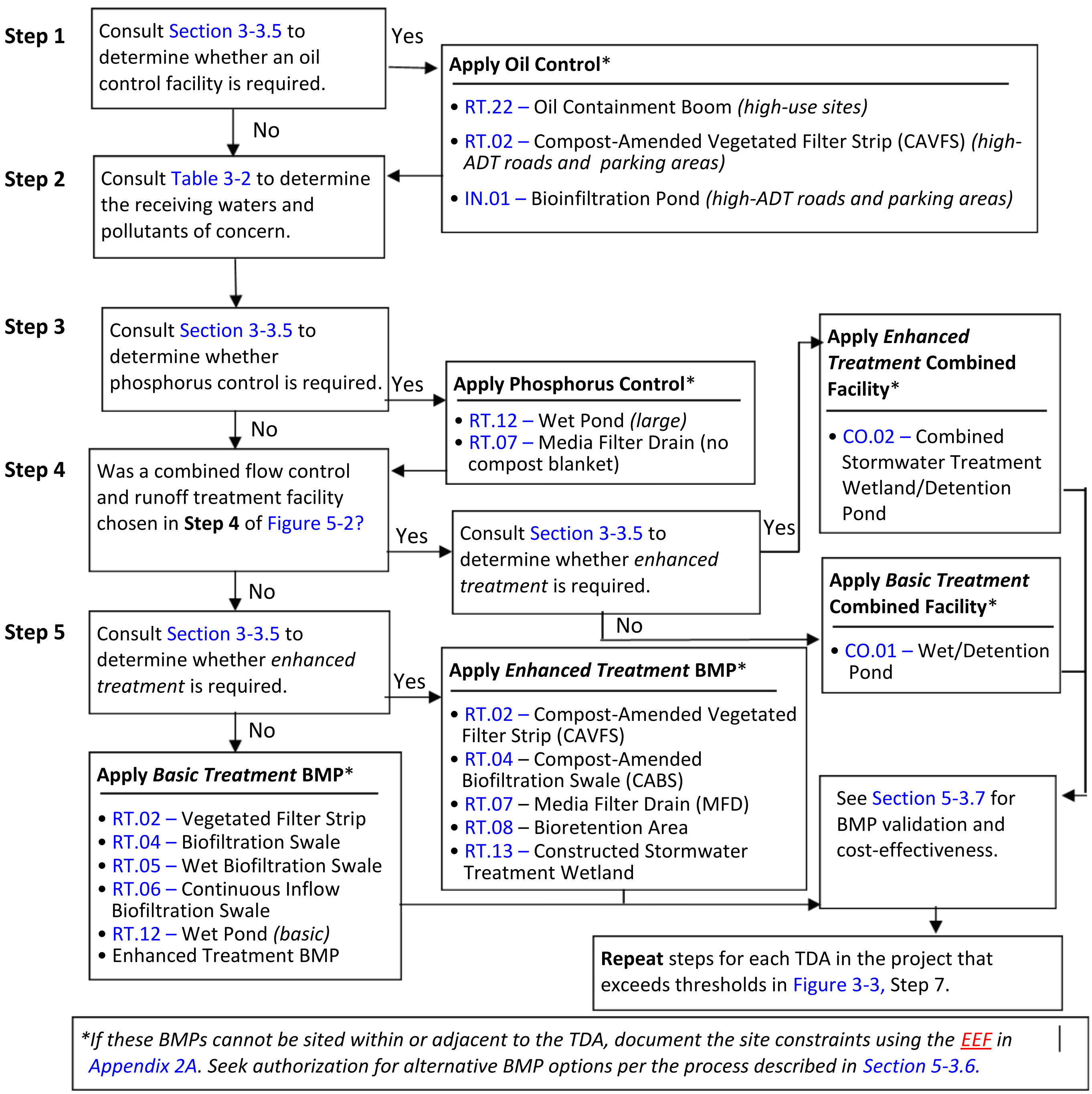


Figure 5-3 Runoff treatment BMP selection flow chart.

Depending on the nature of the alternative approach proposal, you may need a dilution analysis to demonstrate that the project will not adversely affect water quality. If applicable to the proposal, base the dilution analysis on (1) critical flow rates of the discharge and the receiving water, and (2) estimated concentrations of pollutants of concern in the discharge and the upgradient receiving water. A standard procedure for determining the value of those four variables has yet to be developed by Ecology. Until it is developed, Ecology will have to make case-by-case decisions concerning valid approaches to the analysis.

5-3.7 BMP Validation and Cost-Effectiveness

Once you select a stormwater BMP, be aware that there are costs and obligations involved in the long-term operation and maintenance of the BMP. For this reason, you should contact the local maintenance office and discuss the proposed stormwater BMPs and overall stormwater design to determine any area-specific BMP restrictions or requirements. Table 5-1 helps you evaluate the cost-effectiveness of different stormwater BMPs by assessing typical construction costs, annual operation and maintenance (O&M) expenses, and effective life (how soon the BMP may need to be replaced).

Table 5-1 Relative rankings of cost elements and effective life of BMP options.

BMP	Capital Costs	O&M Costs	Effective Life[1]
Vegetated Filter Strip	Low	Low	20–50 years
Wet Biofiltration Swale	Low to Moderate	Low to Moderate	5–20 years
Continuous Inflow Biofiltration Swale	Low to Moderate	Low	5–20 years
Media Filter Drain	Low	Low to Moderate	25 years
Compost-Amended Vegetated Filter Strip	Low	Low	5–20 years[2]
Wet Pond	Moderate to High	Low to Moderate	20–50 years
Combined Wet/Detention Pond	Moderate	Low to Moderate	20–50 years
Constructed Stormwater Treatment Wetland	Moderate to High	Moderate	20–50 years
Combined Stormwater Wetland/Detention Pond	Low to Moderate	Moderate	20–50 years
Wet Vault (Category 1 BMP)	Moderate to High	High	50–100 years
Combined Wet/Detention Vault (Category 1 BMP)	Moderate to High	High	50–100 years
Bioinfiltration Pond	Low to Moderate	Low	5–20 years
Infiltration Pond	Moderate	Moderate	5–10 years before deep tilling required
Infiltration Trench	Moderate to High	Moderate	10–15 years
Infiltration Vault	Moderate	Moderate to High	5–10 years
Drywell	Low to Moderate	Low to Moderate	5–20 years
Engineered and Natural Dispersion	Low	Low	50–100 years
Detention Pond	Moderate	Low	20–50 years
Detention Vault (Category 1 BMP)	Moderate to High	High	50–100 years
Detention Tank (Category 1 BMP)	Moderate to High	High	50–100 years
Presettling Basin	Low to Moderate	Moderate	
Proprietary Presettling Devices	Moderate	Moderate	50–100 years
Bioretention	Moderate	Moderate	5–20 years

Sources: Adapted from Young et al. (1996); Claytor and Schueler (1996); U.S. EPA (1993); and others.

[1] Assumes regular maintenance, occasional removal of accumulated materials, and removal of any clogged media.

[2] Estimated based on best professional judgment.

5-3.7.1 General Maintenance Requirements

Design with maintenance in mind. Maintenance is crucial to performance of runoff treatment and flow control BMPs; therefore, you must build provisions to facilitate maintenance operations into the project when the BMP is installed. You must ensure maintenance is a basic consideration in design and in determination of cost. Include maintenance personnel early and throughout the design process. During discussions with maintenance personnel, describe the maintenance procedures that will need to be performed on the BMP. Obtain maintenance review and concurrence and document in the Hydraulic Report. Use the Hydraulic Report Checklist on the WSDOT HQ Hydraulics website to document discussions, reviews, and concurrence by maintenance of the final design. This will help ensure future maintenance work and potential access needs are clearly understood.

General Maintenance Access Requirements

Access Roads

- Maximum grade for access roads will vary depending on what type of vehicle the local area maintenance office uses. Contact the local area maintenance office to discuss this issue.
- Make sure the outside turning radius is a minimum of 48 feet.
- Ensure access roads are 15 feet wide on curves and 12 feet wide (minimum) on straight sections.
- Construct access roads with an asphalt or gravel surface or with modular grid pavement. Make sure all surfaces conform to the WSDOT *Standard Specifications for Road, Bridge, and Municipal Construction (Standard Specifications)* and to manufacturer's specifications if the surfacing material is a vendor product.
- Provide a paved apron where access roads connect to paved public roadways.

Table 5-2 Surface roughness/Manning's *n* for vegetated filter strip design calculations.

Option	Soil and Vegetation Conditions	Manning's *n*
1	VFS fully compacted and hydroseeded	0.20
2	VFS compaction minimized and soils amended, hydroseeded	0.35
3	CAVFS compaction minimized; soils amended to a minimum 10% organic content (see Section 5-4.3.2); hydroseeded; grass maintained at 95% density and 4-inch length via mowing; periodic reseeding; possible landscaping with shrubs	0.40*
4	CAVFS compaction minimized, soils amended to a minimum 10% organic content (see Section 5-4.3.2), top-dressed with ≥ 3 inches compost or mulch (seeded or landscaped)	0.55*

*Values estimated using the SCS TR-55 Peak Discharge and Runoff Calculator: www.lmnoeng.com/hydrology/hydrology.htm. This tool lists the Manning's *n* values for woods: light underbrush at 0.4, and woods: dense underbrush at 0.8. The intent of Option 3 is to amend the soils so that they have surface roughness characteristics equivalent to forested conditions with light underbrush. Option 4 adds a 3-inch top dressing of compost or mulch to simulate a thick forest duff layer, which warrants a higher Manning's *n*, estimated at 0.55.

Water Depth and Velocity

- The maximum depth of sheet flow through a vegetated filter strip for the runoff treatment design flow rate is 1.0 inch.
- The maximum flow velocity for the runoff treatment design flow velocity is 0.5 feet per second.

Maintain Sheet Flow Conditions

- Maintain sheet flow conditions from the pavement into the vegetated filter strip. A no-vegetation zone may help establish and maintain this condition.
- In areas where it may be difficult to maintain sheet flow conditions for embankment and VFS slopes steeper than 15%, use aggregate or gravel level spreaders.[8] Place them between the pavement surface and the vegetated filter strip. Make sure the aggregate meets the specifications for crushed surfacing base course listed in Section 9-03.9(3) of the *Standard Specifications* or other aggregate providing the equivalent functionality.
- If there are concerns that water percolated within the aggregate flow spreader may exfiltrate into the highway prism, use impervious geotextiles to line the bottom of the aggregate layer.

Compost-Amended Vegetated Filter Strip (CAVFS) for Western Washington

Design Method

The design for CAVFS in western Washington is an iterative process in the stormwater model MGSFlood. This allows MGSFlood to adequately analyze the infiltrative capacity of both the compost-amended layer and the underlying soils to achieve the 91% volume treatment criteria. Please note that because the CAVFS has infiltration as a unit function, the **CAVFS design may require significant upfront geotechnical investigation and time to establish the infiltration rates, Ksat, and gradients for the CAVFS soil and underlying soil layers**.

[8] "Eastern Washington Steep Slope Research for Management of Highway Stormwater," WARD 77.1, Research Report, May 2011.

Structural Design Considerations

Level Spreaders and Energy Dissipaters

Install level spreaders at the head of the biofiltration swale and every 50 feet of swale length if the swale is 6 feet or greater in bottom width. Install level spreaders at the head of the biofiltration swale if a swale divider is used. Include sediment cleanouts at the head of the swale as needed (see Section 5-4.3.5 for level spreader options).

Construct level spreaders and swale dividers of plastic boards, concrete, or other materials that will not leach contaminants harmful to aquatic life. Stake level spreaders, other than gravel energy dissipaters, with nongalvanized metal pins at 4 feet on center minimum. (See Figure 5-16 for more information.)

Use energy dissipaters for swales on longitudinal slopes exceeding 2.5%. Energy dissipaters may take the place of level spreaders if they are designed and installed to maintain level flow in the swale.

Design Method

WSDOT has a bioswale design spreadsheet available on the HRM website that is required on WSDOT projects. The spreadsheet uses the following procedure for both eastern and western Washington.

Sizing Procedure

Design Steps (D)

D-1 Determine the runoff treatment design flow rate (Q_{wq}) (see Sections 4-3.1 and 4-4.1).

D-2 Determine the biofiltration design flow rate (Q_{biofil}):

$$Q_{biofil} = kQ_{wq} \quad \text{(E-7)}$$

For western Washington:[10]

$$k = 1.41\ (P_{72\%,\ 2\text{-yr.}}) - 0.052 \text{ (for on-line biofiltration swales)} \quad \text{(E- 8)}$$

$$k = 2.50\ (P_{72\%,\ 2\text{-yr.}}) - 0.052 \text{ (for off-line biofiltration swales)} \quad \text{(E- 9)}$$

where: $P_{72\%,\ 2\text{-yr}}$ = 72% of the 2-year, 24-hour precipitation depth (in.)

Note: If the 6-month, 24-hour precipitation depth (in.) is known for the project site, you can use that value instead of $P_{72\%,\ 2\text{-yr.}}$

For eastern Washington:

$$k = 1.0 \quad \text{(E-10)}$$

D-3 Establish the longitudinal slope of the proposed biofiltration swale (see Table 5-4 for criteria).

[10] The coefficient k is derived by calculating the linear regression of the ratios of the 91st percentile flow event at 15-minute intervals (determined by MGSFlood) vs. 72% of the 2-year, 24-hour event (determined by the rational method) at each of the major continuously-operating rain gages in western Washington and applied to the design flow rate in order to meet the 9-minute residence time criteria.

Table 5-4 Biofiltration swale sizing criteria.

Design Parameter	Basic Biofiltration Swale	Wet Biofiltration Swale	Continuous Inflow Biofiltration Swale
Longitudinal slope	0.015–0.050[1] feet per foot	0.020 feet or less per foot	Same as basic swale
Maximum velocity	1 foot per second at Q_{biofil}	Same as basic swale	Same as basic swale
Maximum water depth at Q_{biofil}, y	2 inches if swale mowed frequently; 4 inches if mowed infrequently or inconsistently. For dryland grasses in eastern Washington, set depth to 3 inches.	4 inches	Same as basic swale
Manning coefficient at Q_{biofil}	See Table 5-3	Same as basic swale	Same as basic swale
Bottom swale width (b)	2–10 feet[2]	2–25 feet	Same as basic swale
Freeboard height	1 foot for the peak conveyance flow rate (Q_{convey})[3]	Same as basic swale	Same as basic swale
Minimum length	100 feet	Same as basic swale	Same as basic swale
Maximum side slope (for trapezoidal cross section)[4]	3H:1V	Same as basic swale	Same as basic swale

[1] For slopes greater than 5%, install energy dissipaters.

[2] Multiple parallel swales can be constructed when the calculated swale bottom width exceeds 10 feet. Swales with bottom calculated widths up to 16 feet can be divided in half using a non-erodible weather-resistant material such as plastic lumber.

[3] See Freeboard discussion for definition of Q_{convey} for eastern and western Washington.

[4] From swale bed to top of water surface at Q_{biofil}.

RT.05 – Wet Biofiltration Swale

Wet Biofiltration Swale along I-5 in Snohomish County

Description: Variation of basic biofiltration swale. Vegetation is specifically selected for areas where water tables are high, or continuous base flow results in saturated soil conditions.

Geometry Limitations

Longitudinal Slope	≤ 2.0%
Max Water Depth	4"
Bed Width	2-10'
Min Length	100'
Max Side Slopes	3H:1V

BMP Function

- ☐ LID
- ☐ Flow Control
- ☑ Runoff Treatment
  - ☐ Oil Control
  - ☐ Phosphorus
  - ☑ TSS - Basic
  - ☐ Dissolved Metals - Enhanced

Effective Life (Years)

➲ 5-20

Capital Cost

➲ Low to Moderate

O & M Cost

➲ Low to Moderate

Additional Constraints/Requirements

- ☐ 4-5 Infiltration Design Criteria
- ☐ Setback
- ☑ Landscaping/Planting
- ☑ Wetland Planting and Plant Establishment
- ☐ Inlet and Outlet Spacing
- ☐ Overflow
- ☐ Multidisciplinary Team
- ☐ WSDOT Pavement Engineer Approval
- ☐ Soil Amendments/Compost
- ☑ Energy Dissipater/Level Spreader
- ☐ 5-4.3.3 Facility Liners
- ☑ 5-4.3.7 Signing
- ☐ Fencing
- ☐ Presettling/Pretreatment
- ☐ Underdrain
- ☐ Soil Preparation

TMDL/303(d) – Considerations[1]

Avoid	Preferred	
☑	☐	Fecal Coliform
☐	☐	Phosphorus
☐	☐	Nitrogen
☑	☐	Temperature
☐	☐	Dissolved Metals
☐	☑	Total Suspended Solids/Turbidity
☐	☐	Dissolved Oxygen
☐	☐	pH
☐	☐	Oil/Grease
☐	☐	PAHs
☐	☐	Pesticides

1. See Table 3-1 and Section 2-4.2 for additional guidance.

Maintenance Requirements

- ☑ Access Roads or Pullouts
- ☐ Vactor Truck Access
- ☑ Mowing
- ☐ Valve Access
- ☐ Specialized Equipment
- ☐ Specialized Training

Further Requirements: See Sections 5-3.7.1 and 5.5.

Introduction

General Description

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 base flow is likely to result in saturated soil conditions. Where saturation exceeds about two continuous weeks, typical grasses die; thus, vegetation specifically adapted to saturated soil conditions is needed. This type of vegetation in turn requires modification of several of the design parameters for the basic biofiltration swale to remove low concentrations of pollutants such as total suspended solids (TSS), heavy metals, nutrients, and petroleum hydrocarbons.

Applications and Limitations

Applications

Apply wet biofiltration swales where a basic biofiltration swale is desired but not allowed or advisable because of one or more of the following conditions:

- The swale is on till soils and is downstream of a detention pond providing flow control.
- Saturated soil conditions are likely because of seeps, high groundwater, or base flows on the site.
- Longitudinal slopes are slight (generally less than 2.0%) and ponding is likely.

Limitations

- Wet biofiltration swales are off-line and require a flow splitter.

Design Flow Elements

Flows to Be Treated

Design wet biofiltration swales to treat the runoff treatment off-line flow rate discussed in Section 3-3.5 under Minimum Requirement 5. Hydrologic methods are presented in Sections 4-3 and 4-4.

Structural Design Considerations

Use the same Structural Design Considerations for basic biofiltration swales (see BMP RT.04), except for the following:

Geometry

- You may increase the bottom width to 25 feet maximum, but must maintain a length-to-width ratio of 5:1 (see Figure 5-19). No longitudinal dividing berm is needed. ***Note:*** The minimum swale length is 100 feet.
- If longitudinal slopes are greater than 2%, you must step the wet swale so that the slope within the stepped sections averages 2% or less. Steps may be made of retaining walls, log check dams, short riprap sections, or similar structures. Design steps to prevent scour on the downstream side of the step.

RT.06 – Continuous Inflow Biofiltration Swale

Continuous Inflow Biofiltration Swale along I-5 in Snohomish County

Description: Variation of basic biofiltration swale. Water enters swale continuously along side slope. The basic Biofiltration design is modified by increasing swale length to achieve an equivalent average hydraulic time.

Geometry Limitations

Max Inlet Port Flow	10%
Longitudinal Slope	1.5- 5%
Max Water Depth	2-4"
Bed Width	2-10'
Min Length	>100'
Max Side Slope	3H:1V

BMP Function

☑ LID
☐ Flow Control
☑ Runoff Treatment
- ☐ Oil Control
- ☐ Phosphorus
- ☑ TSS - Basic
- ☑ Dissolved Metals - Enhanced

Effective Life (Years)

➲ 5-20

Capital Cost

➲ Low to Moderate

O & M Cost

➲ Low to Moderate

Additional Constraints/Requirements

☐ 4-5 Infiltration Design Criteria
☐ Setback
☑ Landscaping/Planting
☐ Wetland Planting and Plant Establishment
☐ Inlet and Outlet Spacing
☐ Overflow
☐ Multidisciplinary Team
☐ WSDOT Pavement Engineer Approval
☑ Soil Amendments/Compost
☑ Energy Dissipater/Level Spreader
☐ 5-4.3.3 Facility Liners
☑ 5-4.3.7 Signing
☐ Fencing
☐ Presettling/Pretreatment
☐ Underdrain
☐ Soil Preparation

TMDL/303(d) – Considerations[1]

Avoid	Preferred	
☐	☐	Fecal Coliform
☐	☐	Phosphorus
☐	☐	Nitrogen
☐	☐	Temperature
☐	☐	Dissolved Metals
☐	☑	Total Suspended Solids/Turbidity
☐	☐	Dissolved Oxygen
☐	☐	pH
☐	☐	Oil/Grease
☐	☐	PAHs
☐	☐	Pesticides

1. See Table 3-1 and Section 2-6.4 for additional guidance.

Maintenance Requirements

☑ Access Roads or Pullouts
☐ Vactor Truck Access
☑ Mowing
☐ Valve Access
☐ Specialized Equipment
☐ Specialized Training

Further Requirements: See Sections 5-3.6.1 and 5.5.

Table 5-7 Media filter drain mix.

Amendment	Quantity
Mineral aggregate shall meet all requirements for the WSDOT 2014 Standard Specifications 9-03.4 Aggregate for Bituminous Surface Treatment - Crushed screenings 3/8-inch to No.#4 with the exception of: The fracture requirement shall be at least two fractured faces and will apply to material retained on the U.S. No. 4 sieve in accordance with FOP for AASHTO T 335.	3 cubic yards
Perlite: ▪ WSDOT 2016 Standard Specifications 9-14.4(9) ▪ Horticultural grade ▪ 99% - 100% passing U.S. No. 4 Sieve ▪ 30% maximum passing U.S. No. 18 Sieve ▪ 10% maximum passing U.S. No. 30 Sieve	1 cubic yard per 3 cubic yards of mineral aggregate
Dolomite: CaMg(CO3)2 (calcium magnesium carbonate) ▪ WSDOT 2016 Standard Specifications 9-14.4(5) ▪ Agricultural grade ▪ ASTM C 602 Class Designation E	40 pounds per cubic yard of perlite
Gypsum: CaSO4•2H2O (hydrated calcium sulfate) ▪ WSDOT 2016 Standard Specifications 9-14.4(6) ▪ Agricultural grade ▪ 99% - 100% passing the ¼ -inch Sieve ▪ 20% maximum passing U.S. No. 20 Sieve	12 pounds per cubic yard of perlite

RT.08 – Bioretention Area

Bioretention Area along SR 99 in King County

Description: Bioretention areas (also known as rain gardens) are shallow landscaped depressions that use a designed soil mix and plants to provide runoff treatments and flow control.

Geometry Limitations

Ponding Depth	12" Max
Pool Drawdown	24 Hours
Groundwater Clearance	1-3' Min
Interior Sidewalls	2H-1V
Soil Depth	18" Min

BMP Function

- ☑ LID
- ☑ Flow Control
- ☑ Runoff Treatment
  - ☐ Oil Control
  - ☐ Phosphorus
  - ☑ TSS - Basic
  - ☑ Dissolved Metals - Enhanced

Effective Life (Years)

➲ 5-20

Capital Cost	O&M Cost
➲ Moderate	➲ Moderate

Additional Constraints/Requirements

- ☑ 4-5 Infiltration Design Criteria
- ☐ Setback
- ☑ Landscaping/Planting
- ☐ Wetland Planting and Plant Establishment
- ☐ Inlet and Outlet Spacing
- ☐ Overflow
- ☐ Multidisciplinary Team
- ☐ WSDOT Pavement Engineer Approval
- ☑ Soil Amendments/Compost
- ☐ Energy Dissipater/Level Spreader
- ☑ 5-4.3.3 Facility Liners
- ☑ 5-4.3.7 Signing
- ☐ Fencing
- ☑ Presettling/Pretreatment
- ☑ Underdrain (where required)
- ☐ Soil Preparation

TMDL/303(d) – Considerations[1]

Avoid	Preferred	
☐	☐	Fecal Coliform
☐	☐	Phosphorus
☐	☐	Nitrogen
☐	☐	Temperature
☐	☑	Dissolved Metals
☐	☐	Total Suspended Solids/Turbidity
☐	☐	Dissolved Oxygen
☐	☐	pH
☐	☐	Oil/Grease
☐	☐	PAHs
☐	☐	Pesticides

1. See Table 3-1 and Section 2-6.4 for additional guidance.

Maintenance Requirements

- ☑ Access Roads
- ☐ Vactor Truck Access
- ☐ Mowing Considerations
- ☐ Valve Access
- ☑ Specialized Training Requirements

Additional Considerations: See Sections 5-3.6.1 and 5.5.

Structural Design Considerations

Geometry

Stormwater wetlands must consist of two cells: presettling cell and wetland cell.

- The presettling cell must contain approximately 33% of the wetpool volume.
- The depth of the presettling cell must be between 4 feet (minimum) and 8 feet (maximum), excluding sediment storage.
- The presettling cell must provide 1 foot of sediment storage.
- The wetland cell must not exceed a water depth of about 1.5 feet (plus or minus 3 inches).

Where right of way allows, orient the wetland length along the direction of prevailing summer winds (typically west or southwest) to enhance wind mixing.

Berms, Baffles, and Slopes

The top of the berm separating the two cells must be either at the runoff treatment design water surface or submerged 1 foot below this surface, as for wet ponds. Correspondingly, the side slopes of the berm must meet the following criteria:

- For safety reasons the berm should not be greater than 3H:1V, just as the wetland banks should not be greater than 3H:1V if the wetland is not fenced.

Liners

Ensure both the presettling and wetland cell are lined with a low-permeability liner as described in Section 5-4.3.3. You may use a treatment liner if the soil permeability can retain sufficient water to support wetland plants. Sufficient water means that the top 1 foot of soil is saturated for a minimum of 30 days during the growing season. This shall be demonstrated by:

1. Performing a wetland hydroperiod analysis using MGSFlood or other methods as described in Appendix D of Volume 1 of the *Ecology Stormwater Management Manual for Western Washington*. Section 4-5 describes the methods for estimating infiltration and groundwater monitoring requirements.
2. Receiving approval from the Multidisciplinary Team as described below.

Buoyancy checks and counterweight may be necessary depending on groundwater conditions.

Inlet and Outlet

Provide an inlet to the presettling cell according to the requirements described in Section 5-4.1.4, Wetpool BMPs. Provide an overflow structure with debris cage per Figure 5-37 to discharge flows from the wetland cell.

Table 5-8 Plants and water depths for western Washington[2] constructed stormwater treatment wetlands

Species[1]	Common Name	Design Water Depth[3]
Shrubs		
Cornus sericea	Red osier dogwood	2 inches
Salix species	Willows	4 inches
Spiraea douglasii	Hardhack	6 inches
Emergents		
Carex obnupta	Slough sedge	3 inches
Juncus effuses ssp. pacificus	Soft rush	4 inches
Scirpus microcarpus	Small-fruited bulrush	3 inches
Schoenoplectus (Scirpus) acutus	Hardstem bulrush, tule	18 inches
Schoenoplectus (Scirpus)tabernaemontani)	Softstem bulrush, tule	18 inches

Primary sources: Azous & Horner, 2001, Cooke, 2005, modified by WSDOT staff.

[1] Other species may be appropriate depending on location and site conditions and will require Region Landscape Architect approval as well.

[2] Plant species, growing season, and other details will need to be adjusted for eastern Washington and the mountains.

[3] Water levels must be controlled during plant establishment as described in the Soil Preparation section. Tops of plants must be above highest water level. May need larger plants and temporary summer irrigation to accelerate full operation of facility.

Note: Cattails (*Typha latifolia*) are not recommended. They tend to crowd out other species in constructed wetlands, as well as escape to natural wetlands where they do the same. In addition, the shoots die back each fall, resulting in oxygen depletion in the treatment wetland unless they are removed.

Maintaining Optimum Soil Moisture

Successful constructed stormwater wetlands rely on thick and vigorous plant communities. Establishing the plant communities depends on maintaining the optimal soil moisture throughout the growing season. There are many ways of doing this depending on the site and availability of water.

This section describes the principle of maintaining the soil moisture necessary to achieve full wetland operation where plant cover is at least 60% to 80%. The contractor should consider this principle to develop a Water Management Plan that describes an irrigation source for the plant establishment period as well as water level control. The plan must be approved by the multidisciplinary team prior to planting.

Incorrect control of soil moisture is the most frequent cause of failure to establish wetland plants. Inadequate water results in desiccation of roots. Too much water causes oxygen depletion in the root zone, submergence and drowning, or flotation of plants, which results in slow growth or plant death.

IN.06 – Permeable Pavement Surfaces

Test Section of Pervious Pavement at Anacortes Ferry Terminal

Description: The pervious concrete or asphalt pavement surface is an open-graded mix placed in a manner that results in a high degree of interstitial spaces or voids within the cemented aggregate. This technique allows runoff to infiltrate through to the subsoils.

Geometry Limitations

Limited to pedestrians and light to medium-load parking areas.

BMP Function*

- ☑ LID
- ☑ Flow Control
- ☐ Runoff Treatment
  - ☐ Oil Control
  - ☐ Phosphorus
  - ☐ TSS - Basic
  - ☐ Dissolved Metals - Enhanced

*Currently, this BMP cannot be considered a stand-alone runoff treatment BMP. A sand filter or soils meeting the Site Suitability Criteria 5 and 7 must be beneath the Pervious Pavement. See the SWMMWW BMP T5.15 for more details on how to design Pervious Pavement as part of a BMP treatment train for runoff treatment.

Effective Life (Years): --

Capital Cost: Medium

O & M Cost: High

Additional Constraints/Requirements

- ☑ 4-5 Infiltration Design Criteria
- ☐ Setback
- ☐ Landscaping/Planting
- ☐ Wetland Planting and Plant Establishment
- ☐ Inlet and Outlet Spacing
- ☐ Overflow
- ☐ Multidisciplinary Team
- ☑ WSDOT Pavement Engineer Approval
- ☐ Soil Amendments/Compost
- ☐ Energy Dissipater/Level Spreader
- ☐ 5-4.3.3 Facility Liners
- ☑ 5-4.3.7 Signing
- ☐ Fencing
- ☐ Presettling/Pretreatment
- ☐ Underdrain
- ☑ Soil Preparation

TMDL/303(d) – Considerations[1]

Avoid	Preferred	
☐	☑	Fecal Coliform
☐	☑	Phosphorus
☐	☑	Nitrogen
☐	☑	Temperature
☐	☑	Dissolved Metals
☐	☑	Total Suspended Solids/Turbidity
☐	☑	Dissolved Oxygen
☐	☑	pH
☐	☑	Oil/Grease
☐	☑	PAHs
☐	☑	Pesticides

1. See Table 3-1 and Section 2-4.2 for additional guidance.

Maintenance Requirements

- ☐ Access Roads or Pullouts
- ☐ Vactor Truck Access
- ☐ Mowing
- ☐ Valve Access
- ☑ Specialized Equipment
- ☑ Specialized Training

Further Requirements: See Sections 5-3.6.1 and 5-5. Consult WSDOT Maintenance for guidance.

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, if the site exhibits other more continuous seeps and springs extending through longer dry periods, they are likely from a deeper groundwater source. When continuous flows are intercepted and directed through flow control facilities, you may have to make adjustments to the facility design to account for the additional base flow (unless already considered in the design).

Setback Requirements

Detention ponds must be a minimum of 5 feet from any property line or vegetative buffer. You may need to increase this distance based on the permit requirements of the local jurisdiction.

Ensure detention ponds are 100 feet from any septic tank or drain field (except wet vaults, which must be a minimum of 20 feet).

Request from the WSDOT Materials Lab a geotechnical report for the project that evaluates any potential structural site instability due to extended subgrade saturation or head loading of the permeable layer, including the potential impacts to downgradient properties—especially on hills with known side-hill seeps. The report should address the adequacy of the proposed detention pond locations and recommend the necessary setbacks from any steep slopes and building foundations.

Landscaping (Planting Considerations) and Vegetation Establishment

The project should revegetate the side slopes of the detention pond to the maximum extent practicable. The minimum vegetation effort would be to hydroseed the pond's interior above the 100-year water surface elevation and the exterior side slopes before completion of the project. Contact the Region Landscape Office if using a different seed mix than shown below.

Erosion Control Seed Mix

Kind and Variety of Seed in Mixture	**Pounds of Pure Live Seed Per Acre**
Roemer's Fescue (Festuca)	16
Western Fescue (Festuca idahoensis)	16
Canby's Bluegrass (Poa secunda 'Canbyi')	8
Sterile Triticale	5
TOTAL	45

Fencing

Pond walls may be retaining walls as long as you provide a fence along the top of the wall and ensure at least 25% of the pond perimeter will have a slope of 3H:1V or flatter. (See the *Design Manual* for additional fencing requirements.)

Operations and Maintenance Requirements

For general maintenance requirements, see Section 5-3.7.1.

Maintenance Access Roads (Access Requirements)

Refer to Section 5-3.7.1 for maintenance access road requirements and other general maintenance considerations.

Signage

Refer to Section 5-4.3.7 for signing requirements.

Maintenance

Compost, as with sand filters or other filter mediums, can become plugged with fines and sediment, which may require removal and replacement. Including vegetation with compost helps prevent the medium from becoming plugged with sediment by breaking up the sediment and creating root pathways for stormwater to penetrate into the compost. It is expected that soil amendments will have a removal and replacement cycle; however, this time frame has not yet been established.

Structural Design Considerations

Materials

Ensure compost material are aged and cured according to Section 9-14.4(8) of the *Standard Specifications*.

There are three types of compost specified in the *Standard Specifications*: fine, medium, and coarse. Fine compost is a finer and usually more mature form of compost. It is for general soil amendment use and should not be used for compost filter berms or socks. Coarse compost has been screened to remove most of the fines. Medium compost has a blend of finer and coarser particles. To prevent failure due to clogging, medium compost is specified for compost berms and socks. Different types of compost can be used as a soil amendment or blanket depending on the soil type and desired final outcome. Consult the Region or HQ Landscape Architect for site-specific recommendations.

Compost

Organic soil amendment, suitable for landscaping and stormwater management, should be a stable, **mature compost** derived from organic waste materials, including yard debris, wood wastes, or other organic materials that meet the intent of the organic soil amendment specification. **Compost stability** indicates the level of microbial activity in the compost and is measured by the amount of CO_2 produced over a given period of time by a sample in a closed container. Unstable compost can render nutrients temporarily unavailable and create objectionable odors.

Determine compost quality by examining the material and by qualitative tests. A simple way to judge compost quality is to smell and examine the finished product, which should have the following characteristics (WORC, 2003):

- Earthy smell that is not sour, sweet, nor ammonia-like
- Brown to black in color
- Mixed particle sizes
- Stable temperature and does not get hot when rewetted
- Crumbly texture

Qualitative tests and producer documentation should have the following specifications:

- Material must meet the definition for "composted materials" in WSDOT's *Standard Specifications*, Section 9-14, and WAC 173-350, Section 220, which is available online: http://apps.leg.wa.gov/wac/default.aspx?cite=173-350-220
- Compost used in enhanced runoff treatment applications must not contain biosolids or any street or highway sweepings

For further information, see the *Roadside Manual* (Chapter 700).

Organic Matter Content of Soil Mixes

You can achieve the minimum organic matter content by amending soils using the preapproved *Presumptive Method* (as outlined below) or by amending soils using the *Custom Method*, where you would have to calculate a custom amendment rate for the existing site soil conditions. The Presumptive Method simplifies planning and implementation; however, the organic matter content of the disturbed on-site soils may be relatively good and not require as extensive an application of amendment material. In many cases, calculating a site-specific rate using the Custom Method may result in significant savings in amendment material and application costs.

Presumptive Method for Determining Soil Organic Content

Soil amendments can be used two ways: placed on top of the soil or incorporated into it. The intent of incorporation is to increase the organic content of the soil, replicating a forested soil condition. Figure 5-59 shows typical details for soil amendments used in woody planting areas and grass or CAVFS areas.

To encourage native woody plant species, employ the following *presumptive* technique (see Figure 5-59, Figure A):

- Incorporate 3 inches of medium compost into the top 9 inches of soil
- Place 3 inches of bark or wood chip mulch on the surface
- Plant through the layers

To encourage grass or CAVFS, employ the following *presumptive* technique (see Figure 5-59, Figure B):

- Incorporate 1.75 inches of medium compost into the top 6.25 inches of soil
- Roll to compact soil to 85% maximum density.[15]
- Establish vegetation on top of incorporated soil

[15] 2012 *Stormwater Management Manual for Western Washington*.