Infiltration Testing and Design

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Infiltration is the first, and usually the best, choice for managing stormwater runoff. Infiltration is required, where feasible, to meet the low-impact development (LID) requirements. However, infiltration BMPs are often the most difficult to site correctly because of the necessary lead time needed for infiltration rate testing and determination and groundwater monitoring, which takes a minimum of one wet season. This appendix is provided to describe the testing methods used to determine infiltration rates (and saturated hydraulic conductivities) used for stormwater design.

4D-1 Detailed Approach to Determine Saturated Hydraulic Conductivity of Subgrade Soils

The geotechnical investigation will typically provide a computation of the saturated hydraulic conductivity (K_{sat}) for the area proposed for infiltration. Contact your Region Materials Engineer (RME) if K_{sat} values were not provided.

Use the K_{sat} derived using the Detailed Approach to design the following:

- Bioinfiltration pond (BMP IN.01)

- Infiltration pond (BMP IN.02)

- Infiltration trench (BMP IN.03)

- Infiltration vault (BMP IN.04)

- Underlying soils of CAVFS (BMP RT.02)

- Drywell (BMP IN.05)

- Natural dispersion (BMP FC.01)

- Engineered dispersion (BMP FC.02)

For each defined layer below the facility to a depth below the facility bottom of 2.5 times the maximum depth of water in the facility, but not less than 6 feet, estimate the K_{sat} (cm/sec) using the following relationship (see Massmann, 2003, and Massmann et al., 2003):

$$\log_{10}(K_{sat}) = -1.57 + 1.90\,D_{10} + 0.015\,D_{60} - 0.013\,D_{90} - 2.08\,f_{\text{fines}}$$
(4D-1)

where: K_{sat} = the saturated hydraulic conductivity in cm/s

D_{10}, D_{60} and D_{90} = grain sizes in mm for which 10%, 60%, and 90% of the sample is more fine

f_{fines} = grain sizes in mm for the fraction of the soil (by weight) that passes the number-200 sieve

Use the following Equation to convert K_{sat} from cm/s to ft/day:

$$K_{sat} \text{ (ft/day)} = K_{sat} \text{ (cm/s) x 2,834.65} \tag{4D-2}$$

If the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, consider soil layers at greater depths when assessing the site's saturated hydraulic conductivity characteristics. Massmann (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 you need to consider only the layers near and above the water table or low-permeability zone (such as a clay, dense glacial till, or rock layer), 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 saturated hydraulic conductivity assumes minimal compaction consistent with the use of tracked (low-to-moderate ground pressure) excavation equipment, as described in the Site Design Elements of Section 5-4.2.1.

If the soil layer being characterized has been exposed to heavy compaction, or is heavily overconsolidated due to its geologic history (for example, overridden by continental glaciers), the saturated 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, take into account compaction effects when estimating saturated 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.

There are field tests that can estimate specific soil layer K_{sat} values. These tests include the packer permeability test (above or below the water table), the piezocone (below the water table), an air conductivity test (above the water table), and a pilot infiltration test (PIT), as described in the Washington State Department of Ecology's (Ecology's) *Stormwater Management Manual for Western Washington* (SWMMWW). Note that these field tests generally provide a saturated hydraulic conductivity combined with a hydraulic gradient (see Darcy's Law, Equation 4D-8). In some of these field tests, the hydraulic gradient may be close to 1.0. For this condition, Darcy's Law would show that the K_{sat} would be nearly equal to the infiltration rate of that soil layer. It is important to recognize that the gradient in theses field tests may not be the same as the gradient likely to occur in the full-scale infiltration facility in the long term (when groundwater mounding is fully developed). Evaluate this issue on a case-by-case basis when interpreting the results of field tests.

4D-1.1   Infiltration Pond, Trench, and Vault, Bioinfiltration Pond, Underlying Soils of CAVFS, Natural Dispersion, Engineered Dispersion

For infiltration pond (including bioinfiltration), infiltration trench, infiltration vault, and the underlying soils for CAVFS, once the saturated hydraulic conductivity for each layer has been identified, determine the effective average saturated hydraulic conductivity below the BMP. Combine saturated hydraulic conductivity estimates from different layers can be combined using the harmonic mean:

$$K_{equiv} = \frac{d}{\sum \dfrac{d_n}{K_{sat\_n}}}$$ (4D-3)

where: K_{equiv} = the average saturated hydraulic conductivity in ft/day
d = the total depth of the soil column in feet
d_n = the thickness of layer "n" in the soil column in feet
K_{sat_n} = the saturated hydraulic conductivity of layer "n" in the soil column in ft/day

The depth of the soil column, d, typically would include all layers between the BMP bottom and the water table. However, for sites with very deep water tables (>100 feet) where groundwater mounding to the base of the BMP is not likely to occur, it is recommended that you limit the total depth of the soil column in Equation 4D-3 to approximately 20 times the depth of BMP. This is to ensure the most important and relevant layers are included in the saturated hydraulic conductivity calculations. Deep layers that are not likely to affect the infiltration rate near the BMP bottom should not be included in Equation 4D-3. Equation 4D-3 may overestimate the effective saturated hydraulic conductivity value at sites with low-conductivity layers immediately beneath the infiltration BMP. For sites where the lowest conductivity layer is within 5 feet of the base of the BMP, it is suggested that you use this lowest saturated hydraulic conductivity value as the equivalent saturated hydraulic conductivity rather than the value from Equation 4D-3. The harmonic mean given by Equation 4D-3 is the appropriate effective saturated 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 with groundwater mounding).

For the soils underlying a CAVFS, apply a correction factor to the saturated hydraulic conductivity (Equation 4D-1) to account for compaction in the embankment (see Table 4D-1). Verify that this compaction factor is applied to K_{sat} before using these rates in any continuous simulation model.

Table 4D-1   Soils underlying a CAVFS – compaction correction factors to the Saturated Hydraulic Conductivity (Massmann, 2003).

Condition	Factor
Clean, uniformly graded sands and gravels	0.2
Well-graded sands and gravels with moderate-to-high silt content	0.1
Soils contain clay	0.067

■ **Alternate method of determining the saturated hydraulic conductivity (K_{sat}) for CAVFS**

Refer to Ecology's SWMMWW, Volume III, Appendix III-D, Procedure for Conducting a Pilot Infiltration Test. Apply a correction factor of 1.5 to 6 to the measured infiltration rate (*f*) determined by this method. Apply a correction factor on the lower end of the range to the infiltration rate if the designer can verify that the underlying fill material being tested is relatively consistent for the length of proposed CAVFS. Otherwise, use a reduction factor toward the higher end of the range. Determine K_{sat} by using Equation 4D-1. Establish the hydraulic gradient for the CAVFS area.

4D-1.2   Drywells

For drywells, once the saturated hydraulic conductivity for each layer has been identified, you must convert the saturated hydraulic conductivity to (ft/min) and then calculate the geometric mean of the multiple saturated hydraulic conductivity values.

The geometric mean for saturated hydraulic conductivity value is given by the following expressions:

$$K_{geometric} = e^{Yaverage}$$

(4D-4)

where: $K_{geometric}$ = the average saturated hydraulic conductivity in ft/min
$Y_{average}$ = the average of the natural logarithms of the hydraulic conductivity values:

$$Y_{average} = \frac{1}{n}\sum Y_i = \frac{1}{n}\sum \ln(K_i)$$

(4D-5)

where: K_i = the saturated hydraulic conductivity of soil layer *i* in ft/min
Y_i = the natural logarithms of the saturated hydraulic conductivity values

4D-2 Determining Saturated Hydraulic Conductivity Using the Guelph Permeameter

Use the K_{sat} derived using the Geulph Permeameter to design:

- Natural dispersion for eastern Washington only (FC.01)

The determination of an appropriate K_{sat} measurement protocol is essential for the proper implementation of the *natural dispersion* BMP on the embankment. Equally, accurate K_{sat} measurements are one of the most challenging aspects in hydrologic modeling, particularly for surface infiltration methods. Use the following method in eastern Washington only.

In cases when the existing embankments will, for the most part, remain in place with little disturbance or additional embankment construction (minor shoulder widening), use the Guelph Permeameter (GP) method to determine the in situ K_{sat} values. Once a value has been established, apply a correction factor of 2 to K_{sat} for the natural dispersion design.

The recommended testing frequency should be 5 tests per 2,500 linear feet of roadway, with the average value of all tests representing the design K_{sat} value. This recommendation is based on the premise that existing roadway embankments were constructed with imported fill material hauled from off-site borrow sites. If you want to limit the number of test holes needed, it will be necessary to conduct a review of all as-built information and any other relevant design records to determine where placement of borrow material has occurred. If you determine that consecutive segments of the subject highway were constructed from the same materials source, then no additional testing outside the recommended frequency is necessary.

The GP method provides simultaneous in situ measurements in the vadose zone of field-saturated hydraulic conductivity sorptivity and the hydraulic conductivity pressure head relationship. The method involves measuring the steady-state rate of water recharge from a small cylindrical hole in which a constant depth of water is maintained. A simple "in-hole" bottle device is used to establish and maintain the depth to measure the corresponding discharge rate.

4D-3 Determination of Infiltration Rates

An overview of the design procedure is provided in Figures 4D-3 through 4D-5. The focus of these design procedures is to size the facility. For other geotechnical aspects of the facility design, including geotechnical stability of the facility and constructability requirements, see Chapter 5 and the *Design Manual*. A multidisciplinary approach is required to design infiltration facilities, as described in Chapter 2. This section describes the three methods for determining infiltration rates.

1. **Detailed Approach for determining infiltration rates.** This is a detailed analysis that allows you to consider the type of hydrograph used (continuous or single-event); the depth to the groundwater table; the site-specific hydraulic gradient for the facility; and the facility geometry.

2. **Simplified Approach for determining infiltration rates.** This method generally follows Ecology's SWMMWW and commonly produces a more conservative facility size.

3. **Determining Infiltration Rates for Soil Amendments and Topsoil.** This method follows a standard ASTM and has been accepted by Ecology.

4D-3.1   Detailed Approach for Determining Infiltration Rates

Use this Detailed Approach, obtained from Massmann (2003), for the design of infiltration ponds, infiltration vaults, and the underlying soils of a CAVFS. Procedures for the Detailed Approach are as follows (see Figures 4D-3 and 4D-4 for a process flowchart):

1. **Select a location.**

    This will be based on the ability to convey flow to the location and the expected soil conditions. You must meet the minimum setback distances. (See Section 4-5.1 for Site Suitability Criteria and setback distances.)

2. **Estimate volume of stormwater, V_{design}.**

    Estimating the stormwater volume is typically done by using a computer model and entering the basin area tributary to the infiltration BMP. The model will automatically compute the stormwater volume. Eastern Washington uses the StormShed 3G, a single-event hydrograph model based on the Santa Barbara Urban Hydrograph method to compute the stormwater volume. Western Washington uses MGSFlood, a continuous simulation hydrograph model to estimate the stormwater volume. (See Section 4-3 for western Washington and Section 4-4 for eastern Washington methodologies.)

3. **Develop a trial infiltration facility geometry based on length, width, and depth.**

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

4. **Conduct a geotechnical investigation.**

    Conduct a geotechnical investigation to evaluate the site's suitability for infiltration; to establish the infiltration rate for design; and to evaluate slope stability, foundation capacity, and other geotechnical design information needed to design and assess the constructability of the facility. Geotechnical investigation requirements are provided below.

Increase the depth, number of test holes or test pits, and sampling described below if a licensed engineer with geotechnical 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 engineer with geotechnical 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.

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.

■ 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:

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

   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.

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

   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.

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

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

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.

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

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:

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

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:

$$T_{req} = \frac{V_{design}}{Q}$$ (4D-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*.

Estimate volume of stormwater, V_{design}:
- Continuous hydrograph

Perform subsurface site characterization and data collection, including location of water table.

Choose trial geometry based on site constraints, or assume f = 0.5.

Estimate saturated hydraulic conductivity:
- Soil grain sizes
- Laboratory tests
- Field tests
- Layered systems

For unusually complex, critical design cases, perform computer simulation to obtain Q using MODFLOW, with continuous hydrograph, soil stratigraphy, groundwater data, hydraulic conductivity, and biofouling/ siltation data as input.

For western WA, perform computer design infiltration facility using MGSFlood with continuous hydrograph, soil stratigraphy, groundwater data, and infiltration rate data as input.

Calculate hydraulic gradient using Equation 4D-6. If the calculated value is greater than 1.0, consider water table to be deep and use i = 1.0 max. Since i is a function of water depth in pond, i must be embedded in the stage discharge relationship used in MGSFlood.

Estimate the infiltration rate for the stage-discharge relationship (Equation 4D-8).

Adjust infiltration rates for siltation, biofouling, and pond aspect ratio to estimate long-term infiltration rate (Table 4D-2 and Equation 4D-10).

Calculate infiltration rate using a stage-discharge relationship using MODFLOW.

Size facility to maximum depth/minimum freeboard to accommodate V_{design}.

Maintain facility and verify performance. Retrofit facility if performance is inadequate.
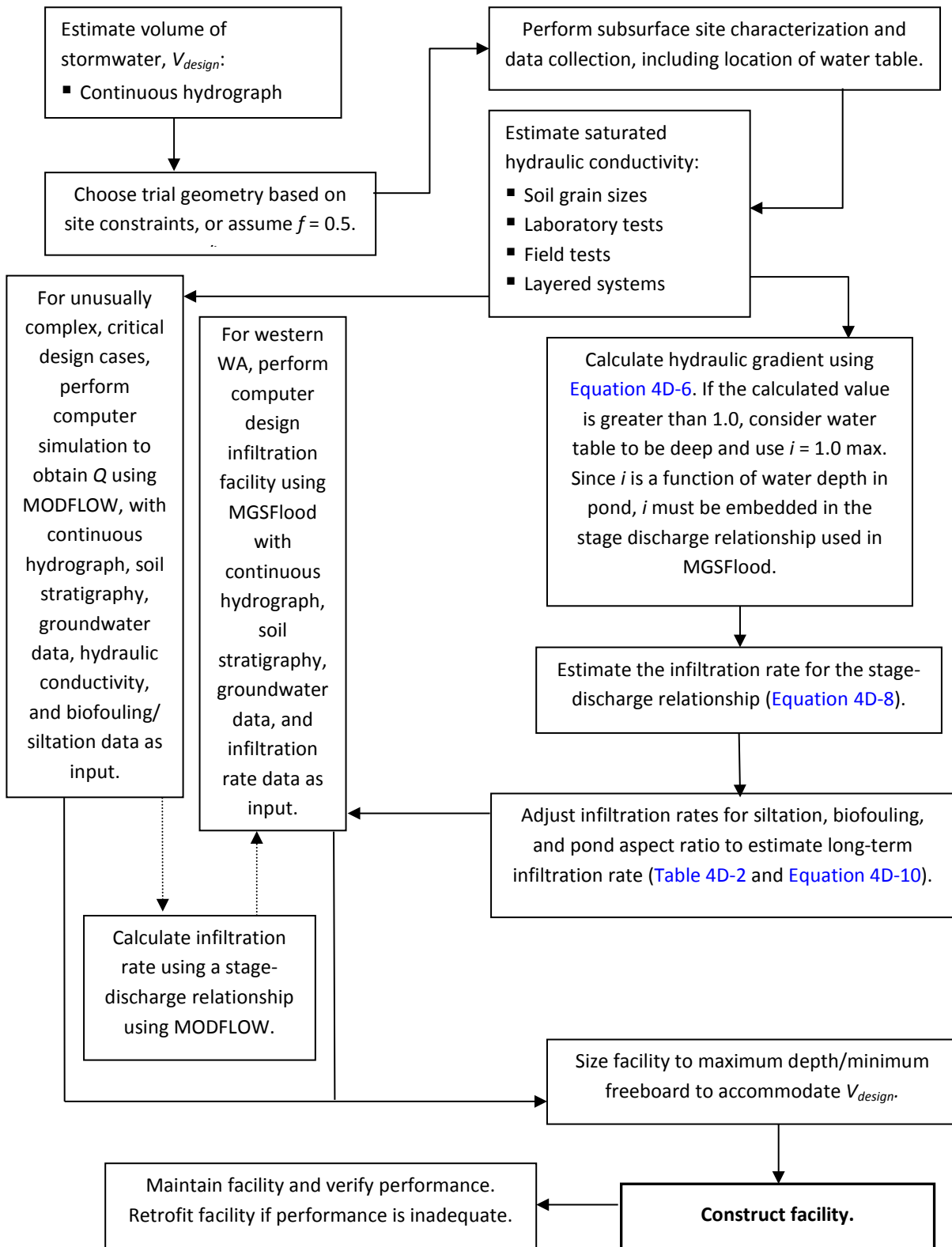
Construct facility.

Figure 4D-1   Engineering design steps for final design of infiltration facilities using the continuous hydrograph method (western Washington).
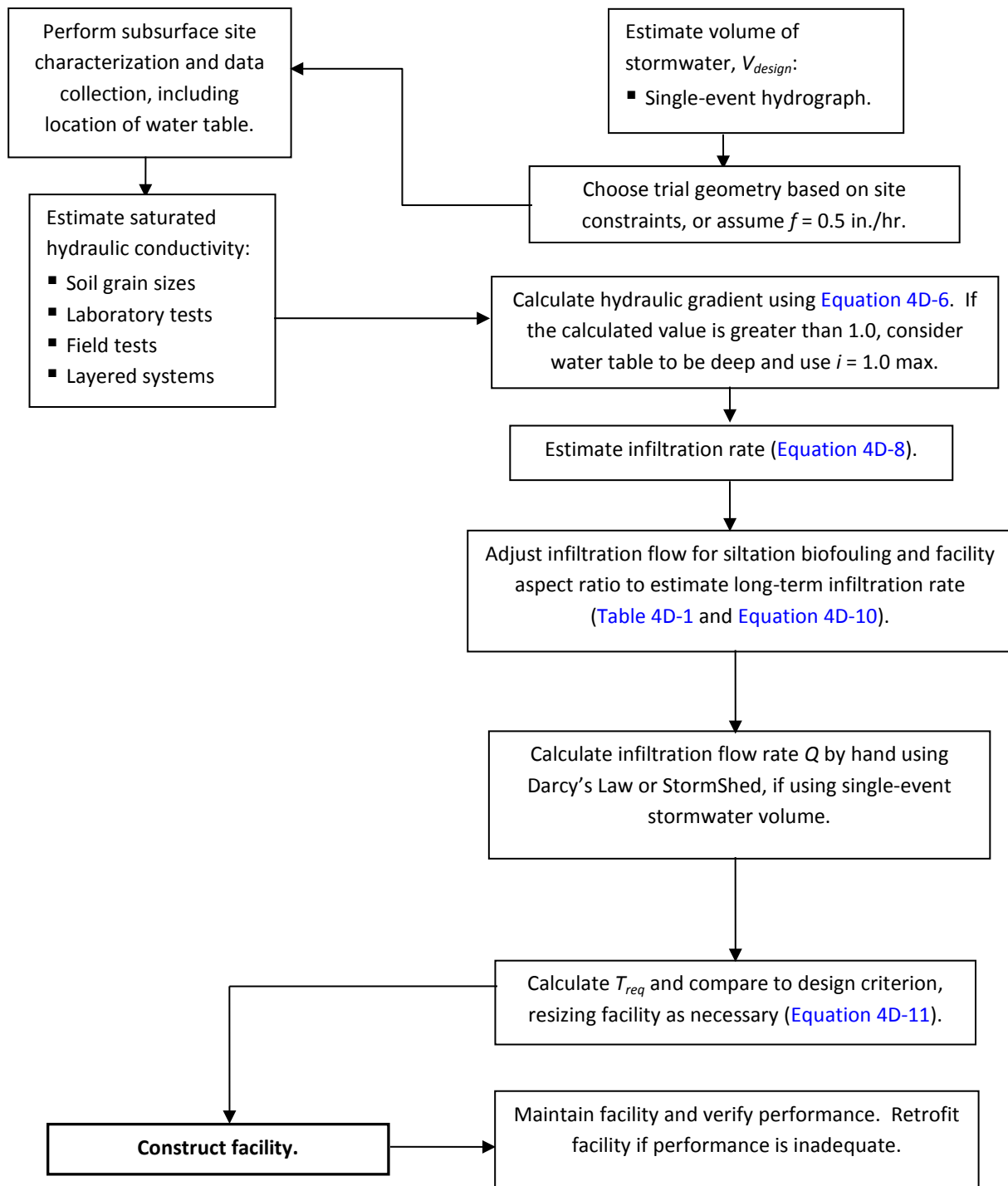
Figure 4D-2   **Engineering design steps for final design of infiltration facilities using the single-event hydrograph method (eastern Washington).**

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 0.5 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.

The minimum infiltration rate at which infiltration would be considered the primary function of the facility is 0.5 inches/hour. Infiltration can still be taken into account if the infiltration rate is lower, but consider it a secondary design parameter for the facility.

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*.

```
┌─────────────────────────┐                    ┌──────────────────────────┐
│ Perform subsurface site │                    │ Estimate volume of       │
│ characterization and    │◄──────────┐        │ stormwater, V_design     │
│ data collection,        │           │        │ ■ Single-event hydrograph│
│ including location      │           │        │ ■ Continuous hydrograph  │
│ of water.               │           │        │                          │
└───────────┬─────────────┘           │        └─────────────┬────────────┘
            │                         │                      │
            ▼                         │                      ▼
┌─────────────────────────┐          │        ┌──────────────────────────┐
│ Estimate infiltration   │          │        │ Choose trial geometry    │
│ rate from Table 4D-3:   │          └────────│ based on site            │
│ ■ Soil grain sizes      │                   │ constraints, or assume   │
│ ■ Layered systems       │                   │ f = 0.5 in/hr.           │
│ ■ Degree of siltation   │                   └──────────────────────────┘
│   biofouling            │
│ ■ Depth to water table  │
│ ■ Facility aspect ratio │
└───────────┬─────────────┘
            │
            ▼
┌────────────────────────────────────────────┐
│ Calculate infiltration flow rate Q using   │
│ StormShed, or by hand using Darcy's Law if  │
│ in eastern WA or MGSFlood if in western WA. │
└───────────────────────┬────────────────────┘
            ┌───────────┴───────────┐
            ▼                       ▼
┌───────────────────────┐  ┌─────────────────────────┐
│ Calculate T_req and   │  │ Size facility to        │
│ compare to design     │  │ maximum depth/minimum   │
│ criterion, resizing   │  │ freeboard to accommodate│
│ facility as necessary.│  │ V_design.               │
└───────────┬───────────┘  └──────────┬──────────────┘
            │                         │
            └──────────►┌────────────┐◄──┘
                        │ Construct  │
                        │ facility.  │
                        └─────┬──────┘
                              ▼
                 ┌────────────────────────────┐
                 │ Maintain facility and      │
                 │ verify performance.        │
                 │ Retrofit facility if       │
                 │ performance is inadequate. │
                 └────────────────────────────┘
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(Note: Use for trial geometry, small or low-impact facilities, or for facilities where a more conservative design is acceptable.)
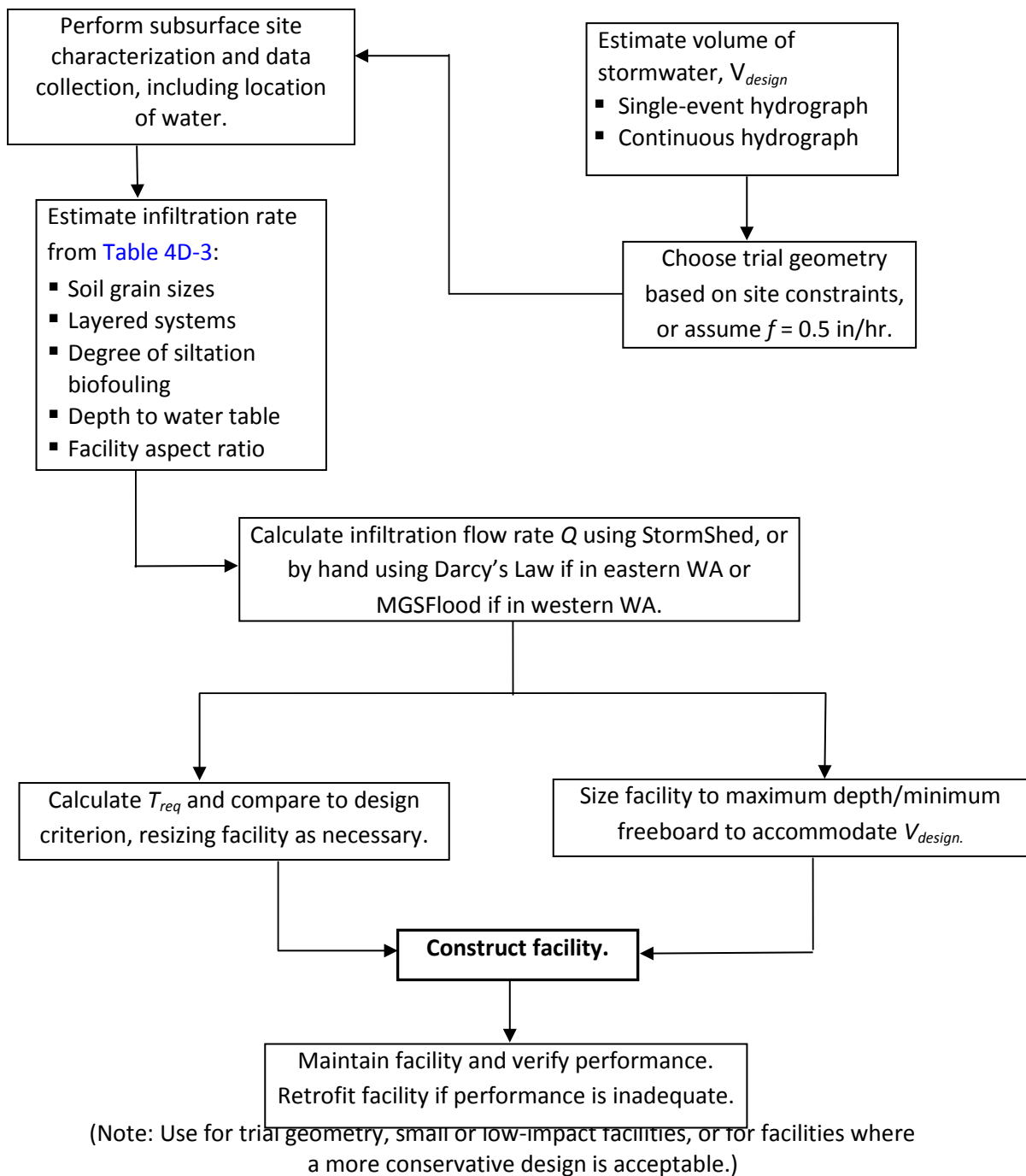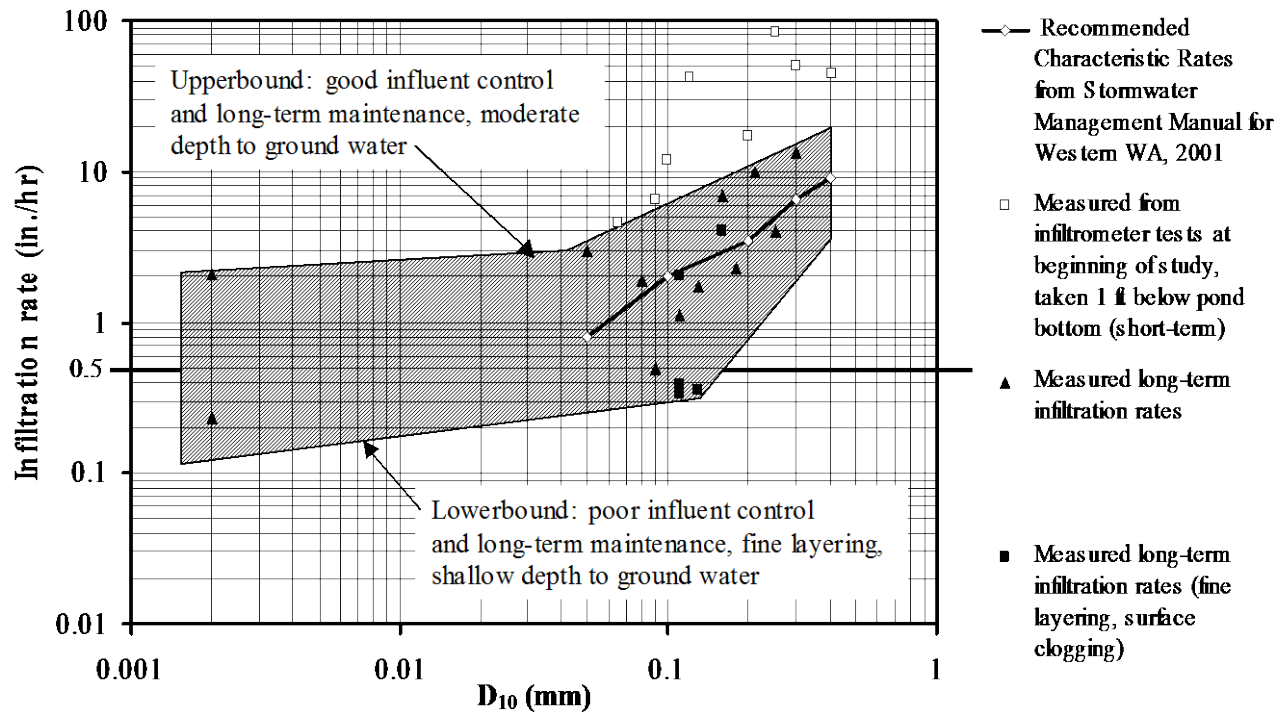
Figure 4D-3   Engineering design steps for design of infiltration facilities: Simplified infiltration rate procedure.

(Note: The mean values represent low-gradient conditions and relatively shallow ponds.)

Figure 4D-4   Infiltration rate as a function of the D_{10} size of the soil for ponds in western Washington.

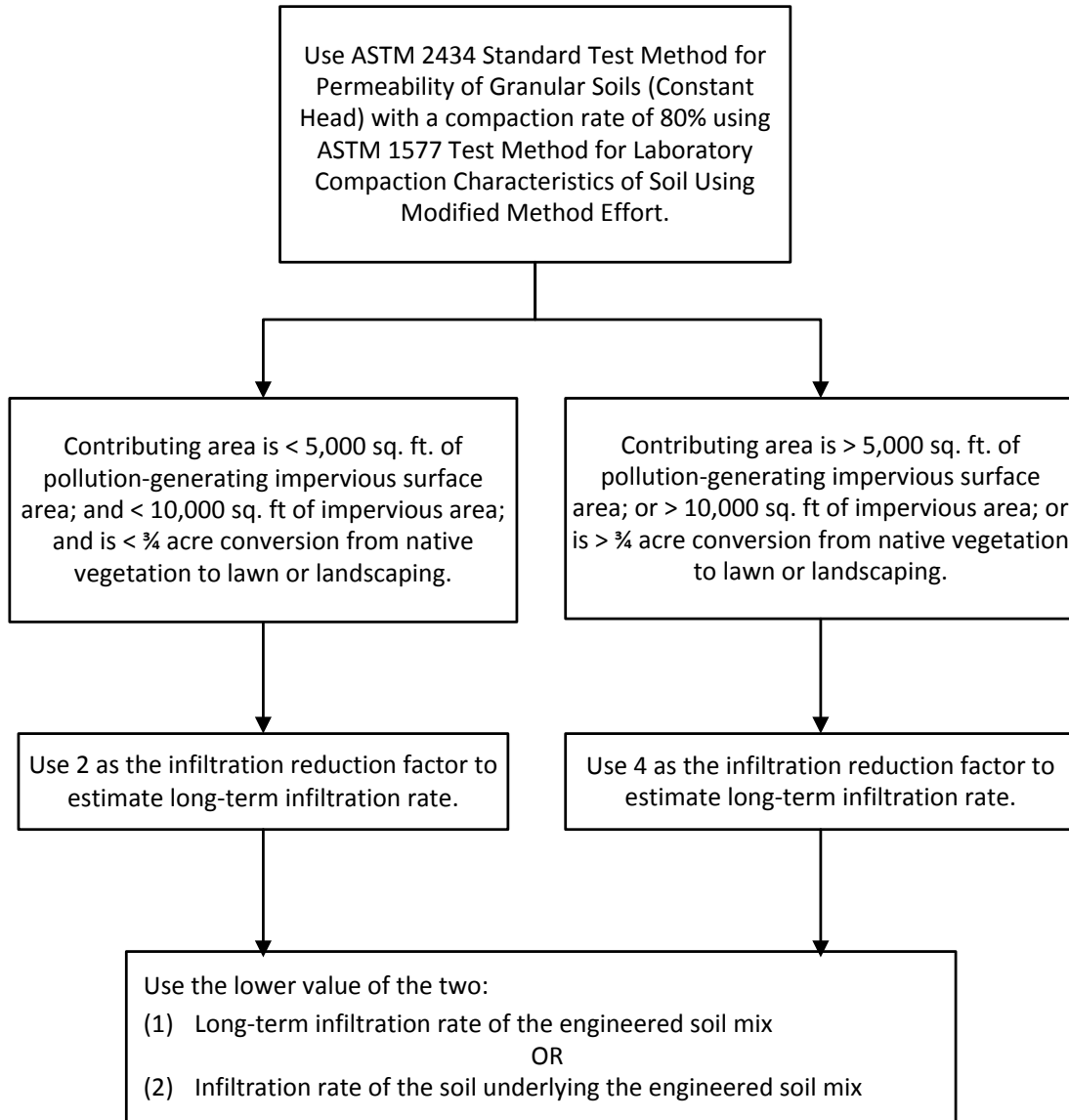## 4D-3.3   Determining Infiltration Rates for Soil Amendment BMPs

It is necessary to establish the long-term infiltration rate of an amended soil or engineered soil mix when used as a BMP design component to achieve treatment or flow control requirements. These guidelines are applicable to CAVFS, engineered dispersion, and infiltration ponds using topsoil or other engineered lining. The assumed design infiltration rate should be the lower of the following two rates: (1) the estimated long-term rate of the engineered soil mix (see Figure 4D-5), or (2) the initial (short-term or measured) infiltration rate of the underlying soil profile. Test the underlying native soil using either the Detailed Approach in Section 4D-3.1 or the Simplified Approach in Section 4D-3.2.

Use the long-term infiltration rate of the engineered soil mix as the assumed infiltration rate of the overlying soil mix if it is lower than the underlying native soil. If the underlying native soil is lower than the engineered soil mix, use either the underlying native soil infiltration rate or a varied infiltration rate that includes both the engineered soil mix infiltration rate and the native soil infiltration according to Section 4D-3.1, Step 6. Also, refer to Table 4-1 for flow control modeling guidelines to determine flow reduction benefits using MGSFlood.

Soil Specification

Proper soil specification, preparation, and installation are the most critical factors for LID BMP performance. Soil specifications can vary according to the design objectives and the in situ soil. For more information, see Section 5-4.3.2.

**Determining long-term infiltration rate of engineered soil mix (CAVFS and
Engineered Dispersion)**


```
┌─────────────────────────────────────┐
│ Use ASTM 2434 Standard Test Method   │
│ for Permeability of Granular Soils   │
│ (Constant Head) with a compaction    │
│ rate of 80% using ASTM 1577 Test     │
│ Method for Laboratory Compaction     │
│ Characteristics of Soil Using        │
│ Modified Method Effort.              │
└─────────────────────────────────────┘
```

Contributing area is < 5,000 sq. ft. of pollution-generating impervious surface area; and < 10,000 sq. ft of impervious area; and is < ¾ acre conversion from native vegetation to lawn or landscaping.	Contributing area is > 5,000 sq. ft. of pollution-generating impervious surface area; or > 10,000 sq. ft of impervious area; or is > ¾ acre conversion from native vegetation to lawn or landscaping.
Use 2 as the infiltration reduction factor to estimate long-term infiltration rate.	Use 4 as the infiltration reduction factor to estimate long-term infiltration rate.

Use the lower value of the two:

(1)   Long-term infiltration rate of the engineered soil mix
                              OR
(2)   Infiltration rate of the soil underlying the engineered soil mix

Figure 4D-5   Determining infiltration rate of soil amendments.

4D-4 UIC Subsurface Geological Data

4D-4.1 Subsurface Geological Data

Geologic information may be available from regional subsurface geology maps in publications from the Department of Natural Resources (DNR) or the U.S. Geological Survey; from a well borehole log(s) in the same quarter section on Ecology's website; or from local governments. Surface soil maps generally do *not* provide adequate information, although the parent material information provided may be helpful in some locations. Verify well borehole log locations because electronic databases contain many errors of this type.

When using borehole logs, a "nearby" site is generally within ¼ mile. Subsurface geology can vary considerably in a very short horizontal distance in many areas of the state, so use professional judgment to determine whether the available data are adequate or site exploration is necessary.

Where reliable regional information or nearby borehole logs are not readily available, you will need to obtain data through site exploration. Alternatively, for small projects where site exploration is not cost-effective, a design professional might apply a conservative design approach, subject to the approval of region or HQ hydraulics staff and/or the WSDOT Materials Lab.

4D-4.2 Design Procedure for Infiltration Trenches

The Detailed Approach for infiltration trenches was obtained from Massmann (2003) and is applicable for trenches with flat or shallow slopes—not to be used for slopes greater than 0.5%. Procedures for the Detailed Approach for both sheet flow and end of pipe applications are as follows:

A. **Follow Steps 1 through 7 in the Detailed Approach (see Section 4D-3.1).**

B. **Calculate the hydraulic gradient.**

   If using a single-event hydrograph or continuous hydrograph, calculate the hydraulic gradient for trenches as follows:

$$gradient = i_t \approx \frac{D_{wt} + D_{trench}}{78(K_{equiv}^{0.05})} \qquad (4D\text{-}12)$$

   where: i_t = steady state hydraulic gradient in the trench
   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_{trench} = the depth of water in the trench, in feet

As is true of Equation 4D-6, Equation 4D-12 is applicable to conditions where a full groundwater mound develops.

If the calculated gradient is greater than 1.0, the water table is considered to be deep and you must use a maximum gradient of 1.0. It is sufficiently accurate to calculate the hydraulic gradient assuming that D_{trench} is equal to one-half the trench depth.

C. **Follow Step 9 in the Detailed Approach** (see Section 4D-3.1). Once the infiltration rate is obtained, go to Step 2 in the Design Method of HRM BMP IN.03 in Chapter 5.

4D-5 Stormwater Infiltration Modeling Inputs for Western Washington
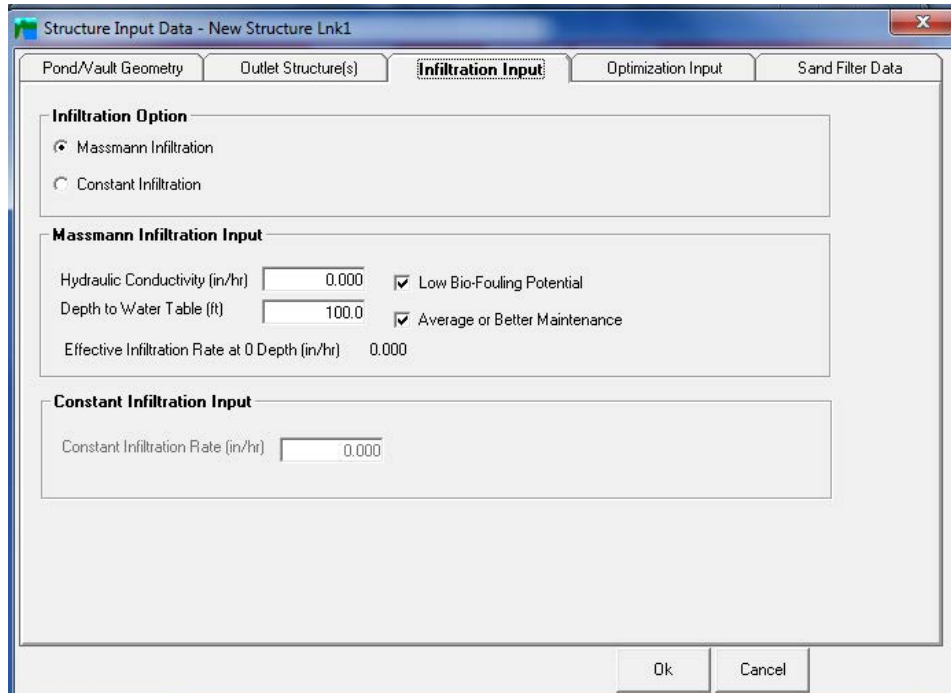
Figure 4D-6   **MGSFlood Infiltration pond (BMP IN.02)**
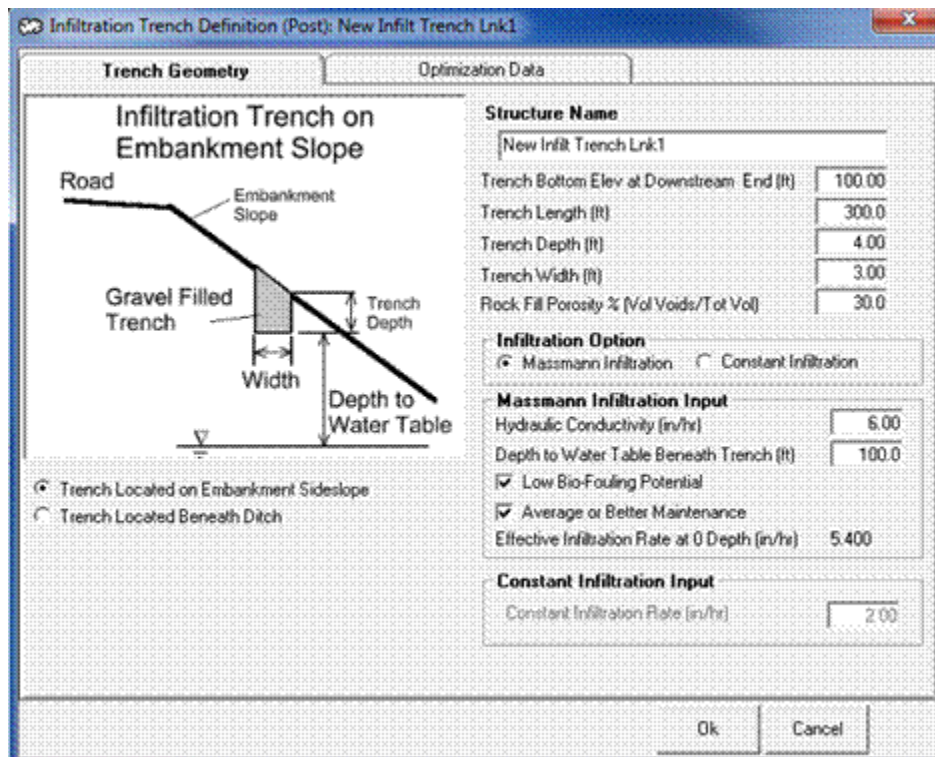
Figure 4D-7   **MGSFlood Infiltration trench on slope (BMP IN.03)**
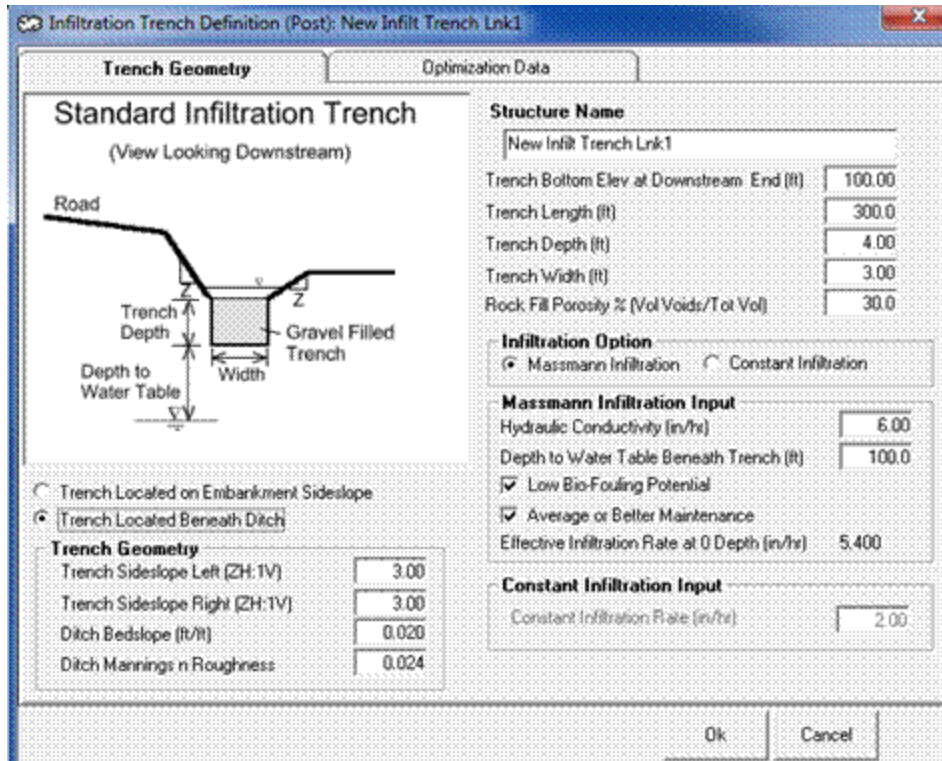
Figure 4D-8   MGSFlood Infiltration trench at the bottom of the slope (BMP IN.03)
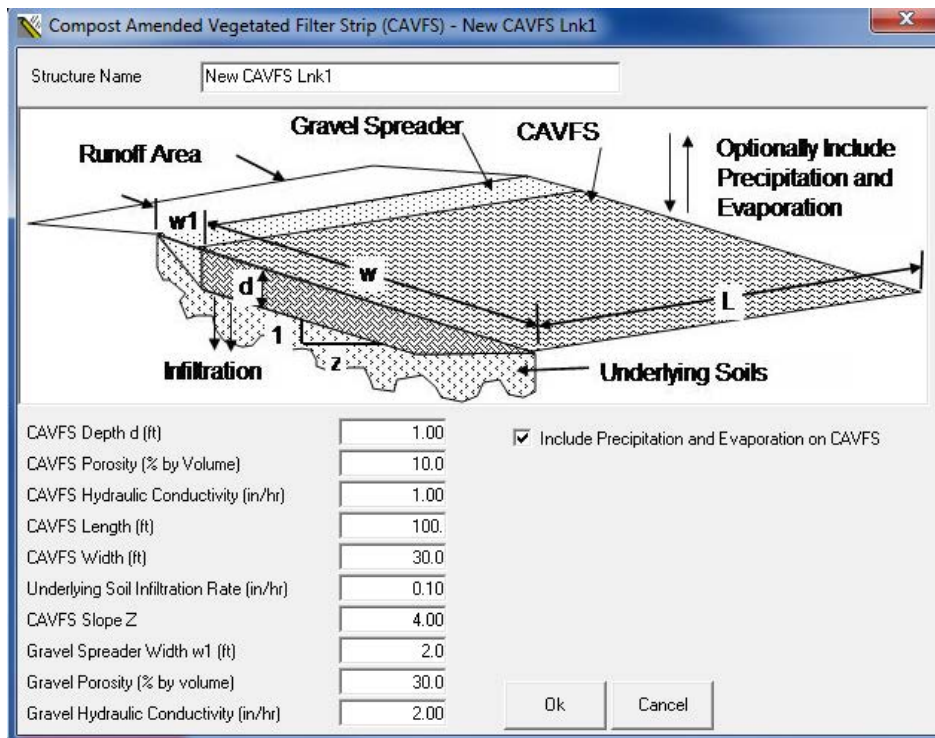
Figure 4D-9   MGSFlood Underlying Soils of CAVFS (BMP RT.02)

4D-6 Stormwater Infiltration Modeling Inputs for Eastern Washington

Infiltration Pond and Infiltration Trench calculation spreadsheets and **Bioinfiltration Pond example**

Figure 4D-10   StormShed 3G Infiltration Pond, Trench, and Drywell