Appendix III-A – Methods for Determining Design Infiltration Rates

Determine Design Infiltration Rate:

There are three acceptable methods for estimating initial infiltration rates. Each is described in detail in this appendix. A safety/correction factor is applied to the initial rate to determine the design infiltration rate. Note that the subgrade safety/correction factors in this appendix may not apply to bioretention, permeable pavement, and rain gardens. Refer to Sections 3.4, 3.5, and 3.8 for additional guidance on infiltration testing methods and application of appropriate safety/correction factors specific to bioretention, permeable pavement, and rain gardens.

- Method 1. Field Testing Procedures (must incorporate safety factor)
  - U.S. EPA Falling Head Percolation Test Procedure (as Modified for Gig Harbor). This test applies to all infiltration facilities, but may not be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.
  - Large-Scale Pilot Infiltration Test (PIT). This test applies to infiltration facilities with drainage areas greater than one acre and may be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.
  - Small-Scale (PIT). This test applies to infiltration facilities with drainage areas less than one acre and may be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.
- Method 2. USDA Soil Textural Classification. This method only applies to projects sites that trigger Minimum Requirement #1 through #5 (not #1 through #10) AND are underlain by Spanaway soils (as defined by the Soils Survey of Pierce County Area, 1979, and field verified by a qualified professional). This method may not be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.
- Method 3. Soil Grain Size Analysis. This method applies to project sites that are that are underlain by type A soils (see Appendix III-B Table B.5 Major Soil Groups in Pierce County), and may not be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.

Method 1 – Field Testing Procedures

- Excavate to the bottom elevation of the proposed infiltration facility. Measure the infiltration rate of the underlying soil using either the **U.S. EPA falling**

head percolation test procedure as modified for the City of Gig Harbor (presented below), the double ring infiltrometer test (ASTM D3385, not presented in this appendix), or Ecology large and small scale Pilot Infiltration Test (PIT) described below and presented in the 2014 Ecology Stormwater Management Manual for Western Washington.

- Fill test hole or apparatus with water and maintain at depths above the test elevation for the saturation periods specific for the appropriate test.
- Following the saturation period, the infiltration rate shall be determined in accordance with the specified test procedures.
- See individual BMP descriptions for requirements related to the number and location of tests required.
- **For all field testing procedures, apply safety factor to obtain design infiltration rate (see next section).**

Safety Factor for Field Measurements

The following equation incorporates safety factors to adjust for uncertainties related to testing, depth to the water table or impervious strata, infiltration receptor geometry, and long-term reductions in permeability due to biological activity and accumulation of fines. Note that the safety factors below may not apply to the infiltration testing conducted for bioretention, permeable pavement and/or rain gardens (see Sections 3.4, 3.5, and 3.8 for additional information). This equation estimates the maximum design infiltration rate, I_{design}. Additional reduction of the design infiltration rate may be appropriate depending on site conditions. **In no case may the design infiltration rate exceed 30 inches/hour**.

$$I_{design} = I_{measured} \times F_{testing} \times F_{geometry} \times F_{plugging}$$

$F_{testing}$ accounts for uncertainties in the testing methods. For the full scale PIT method, $F_{testing} = 0.75$; for the small-scale PIT method, $F_{testing} = 0.50$; for smaller-scale infiltration tests such as the double-ring infiltrometer test, $F_{testing} = 0.40$; for grain size analysis, $F_{testing} = 0.40$. These values are intended to represent the difference in each test's ability to estimate the actual saturated hydraulic conductivity. The assumption is the larger the scale of the test, the more reliable the result.

$F_{geometry}$ accounts for the influence of facility geometry and depth to the water table or impervious strata on the actual infiltration rate. A shallow water table or impervious layer will reduce the effective infiltration rate of a large pond, but this would not be reflected in a small scale test. $F_{geometry}$ must be between 0.25 and 1.0 as determined by the following equation:

$$F_{geometry} = 4\ D/W + 0.05$$

Where:

D = depth from the bottom of the proposed facility to the maximum wet season water table or nearest impervious layer, whichever is less.

W = width of facility

$F_{plugging}$ accounts for reductions in infiltration rates over the long term due to plugging of soils. This factor is:

- 0.7 for loams and sandy loams
- 0.8 for fine sands and loamy sands
- 0.9 for medium sands
- 1.0 for coarse sands or cobbles.

Falling Head Percolation Test Procedure (as Modified for Gig Harbor) (Source: U.S. EPA, On-site Wastewater Treatment and Disposal Systems, 1980)

Note: This test may not be used to demonstrate infeasibility of bioretention, permeable pavement, or rain gardens in meeting Minimum Requirement #5.

1. Location of Tests

   Tests shall be spaced uniformly throughout the area. If soil conditions are highly variable, more tests may be required.

2. Preparation of Test Hole (as modified for Gig Harbor)

   The diameter of each test hole is 8 inches, dug or bored to the proposed depths of the absorption systems or to the most limiting soil horizon. To expose a natural soil surface, the bottom of the hole is scratched with a sharp pointed instrument and the loose material is removed from the test hole. A 6-inch-inner-diameter, 4-foot long, PVC pipe is set into the hole and pressed into the soil 6 inches and then 2 inches of one-half to three-fourths-inch rock are placed in the pipe to protect the bottom from scouring when water is added.

3. Soaking Period

   The pipe is carefully filled with at least 12 inches of clear water. The depth of water must be maintained for at least 4 hours and preferably overnight if clay soils are present. A funnel with an attached hose or similar device may be used to prevent water from washing down the sides of the hole. Automatic siphons or float valves may be employed to automatically maintain the water level during the soaking period. It is extremely important that the soil be allowed to soak for a sufficiently long period of time to allow the soil to swell if accurate results are to be obtained.

   In sandy soils with little or no clay, soaking is not necessary. If, after filling the pipe twice with 12 inches of water, the water seeps completely away in less than 10 minutes, the test can proceed immediately.

4. Measurement of the Percolation Rate

Except for sandy soils, percolation rate measurements are made 15 hours but no more than 30 hours after the soaking period began. The water level is adjusted to 6 inches above the gravel (or 8 inches above the bottom of the hole). At no time during the test is the water level allowed to rise more than 6 inches above the gravel. Immediately after adjustment, the water level is measured from a fixed reference point to the nearest 1/16th-inch at 30 minute intervals. The test is continued until two successive water level drops do not vary by more than 1/16-inch within a 90-minute period. At least three measurements are to be made.

After each measurement, the water level is readjusted to the 6-inch level. The last water level drop is used to calculate the percolation rate.

In sandy soils or soils in which the first 6 inches of water added after the soaking period seeps away in less than 30 minutes, water level measurements are made at 10 minute intervals for a 1-hour period. The last water level drop is used to calculate the percolation rate.

5. Calculation of the Percolation Rate

The percolation rate is calculated for each test site by dividing the time interval used between measurements by the magnitude of the last water level drop. This calculation results in a percolation rate in terms of minutes/inch. To determine the percolation rate for the area, the rates obtained from each hole are averaged. (If tests in the area vary by more than 20 minutes/inch, variations in soil type are indicated. Under these circumstances, percolation rates should not be averaged.) **To compute the design infiltration rate (I_{design}), the final percolation rates must then be adjusted by the appropriate safety factors outlined previously.**

Example: If the last measured drop in water level after 30 minutes is five-eighths-inch, then:

percolation rate = (30 minutes)/(⅝ inch) = 48 minutes/inch. (At a minimum, a safety factor "$F_{testing}$" of 0.5 shall be applied to all field methods for determining infiltration rates.)

Alternative Washington Department of Ecology Infiltration Pit Method

Large-Scale Pilot Infiltration Test (PIT)

Large-scale in-situ infiltration measurements, using the Pilot Infiltration Test (PIT) described below is the preferred method for estimating the measured (initial) saturated hydraulic conductivity (K_{sat}) of the soil profile beneath the proposed infiltration facility. The PIT reduces some of the potential scale errors associated with relatively small-scale tests such as the Modified Falling Head Percolation Test, double ring infiltrometer or "stove-pipe" infiltration tests. It is not a standard test but rather a practical field procedure recommended by Ecology's Technical Advisory Committee.

Infiltration Test:

- Excavate the test pit to the depth of the bottom of the proposed infiltration facility. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be approximately 100 square feet.
- Accurately document the size and geometry of the test pit.
- Install a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom.
- Use a rigid 6-inch diameter pipe with a splash plate on the bottom to convey water to the pit and reduce side-wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates.
- Add water to the pit at a rate that will maintain a water level between 6 and 12 inches above the bottom of the pit. A rotameter can be used to measure the flow rate into the pit.

Note: For infiltration facilities serving large drainage areas, designs with multiple feet of standing water can have infiltration tests with greater than 1 foot of standing water. The depth must not exceed the proposed maximum depth of water expected in the completed facility.

Every 15 to 30 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point on the measuring rod.

Add water to the pit until 1 hour after the flow rate into the pit has stabilized (constant flow rate; a goal of 5 percent variation or less variation in the total flow) while maintaining the same pond water level (usually 6 hours). The total of the pre-soak time plus one hour after the flow rate has stabilized should be no less than 6 hours.

After the flow rate has stabilized for at least 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty. Consider running this falling head phase of the test several times to estimate the dependency of infiltration rate with head.

Data Analysis:

Calculate and record the infiltration rate in inches per hour in 30 minutes or 1-hour increments until 1 hour after the flow has stabilized.

Note: Use statistical/trend analysis to obtain the hourly flow rate when the flow stabilizes. This would be the lowest hourly flow rate.

To compute the design infiltration rate (I_{design}), apply appropriate safety factors outlined previously.

Example:

The area of the bottom of the test pit is 8.5-feet by 11.5-feet.

Water flow rate was measured and recorded at intervals ranging from 15 to 30 minutes throughout the test. Between 400 minutes and 1,000 minutes, the flow rate stabilized between 10 and 12.5 gallons per minute or 600 to 750 gallons per hour, or an average of (9.8 + 12.3) / 2 = 11.1 inches per hour.

To compute the design infiltration rate (Idesign), the infiltration rate must then be adjusted by the appropriate safety factors outlined previously.

Small-Scale Pilot Infiltration Test

A smaller-scale PIT can be used in any of the following instances:

- The drainage area to the infiltration site is less than one acre
- The testing is for bioretention areas or permeable pavement surfaces that either serve small drainage areas and/or are widely dispersed throughout a project site
- The site has a high infiltration rate, making a large-scale PIT difficult, and the site geotechnical investigation suggests uniform subsurface characteristics.

Infiltration Test

- Excavate the test pit to the estimated surface elevation of the proposed infiltration facility. In the case of bioretention, excavate to the estimated elevation at which the imported soil mix will lie on top of the underlying native soil. For permeable pavement, excavate to the elevation at which the imported subgrade materials, or the pavement itself, will contact the underlying native soil. If the native soils (road subgrade) will have to meet a minimum subgrade compaction requirement, compact the native soil to that requirement prior to testing. Note that the permeable pavement design guidance recommends compaction not exceed 90 – 92 percent. Finally, lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.

- The horizontal surface area of the bottom of the test pit should be 12 to 32 square feet. It may be circular or rectangular, but accurately document the size and geometry of the test pit.
- Install a vertical measuring rod adequate to measure the ponded water depth and that is marked in half-inch increments in the center of the pit bottom.
- Use a rigid pipe with a splash plate on the bottom to convey water to the pit and reduce side-wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates. Use a 3 inch diameter pipe for pits on the smaller end of the recommended surface area, and a 4 inch pipe for pits on the larger end of the recommended surface area.
- Pre-soak period: Add water to the pit so that there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
- At the end of the pre-soak period, add water to the pit at a rate that will maintain a 6-12 inch water level above the bottom of the pit over a full hour. The depth should not exceed the proposed maximum depth of water expected in the completed facility.
- Every 15 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point (between 6 – 12 inches) on the measuring rod. The specific depth should be the same as the maximum designed ponding depth (usually 6 – 12 inches).
- After one hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty.
- A self-logging pressure sensor may also be used to determine water depth and drain-down.

Data Analysis

See the explanation under the guidance for large-scale pilot infiltration tests.

Method 2 – USDA Soil Textural Classification

Infiltration rates may be estimated from soil grain size distribution (gradation) data using the USDA textural analysis approach. Conduct the grain size distribution test in accordance with the USDA test procedure (Soil Survey Manual, USDA, October 1993, page 136). This manual only considers soil passing the US #10 sieve to determine percentages of sand, silt, and clay for use in Figure A.1. **This method may only be applied to projects sites that trigger Minimum Requirement #1 through #5 and that are underlain by Spanaway soils (as defined by the Soils Survey of Pierce County Area, 1979, and field verified by a qualified professional).**

Short-term (field) infiltration rates, required correction factors, and design (long-term) infiltration rates based on gradations from soil samples and textural analysis are summarized in Table A.1. With prior approval by the City of Gig Harbor, the correction factors may be reduced (to a minimum of 2.0) if there is little soil variability, there will be a high degree of long-term facility maintenance, and there is adequate pretreatment to reduce total suspended solids in influent stormwater.

Table A.1. Recommended Infiltration Rates Based on USDA Soil Textural Classification.

	Short-Term Infiltration Rate (in./hr)[1]	Correction Factor CF	Estimated Design (Long-term) Infiltration Rate (in./hr)
Clean sandy gravels and gravelly sands (i.e., 90% of the total soil sample is retained in the US #10 sieve)	20	2	10
Sand	8	4	2
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

Source: Stormwater Management Manual for Western Washington (Ecology 2005).
1 From WEF/ASCE (1998).

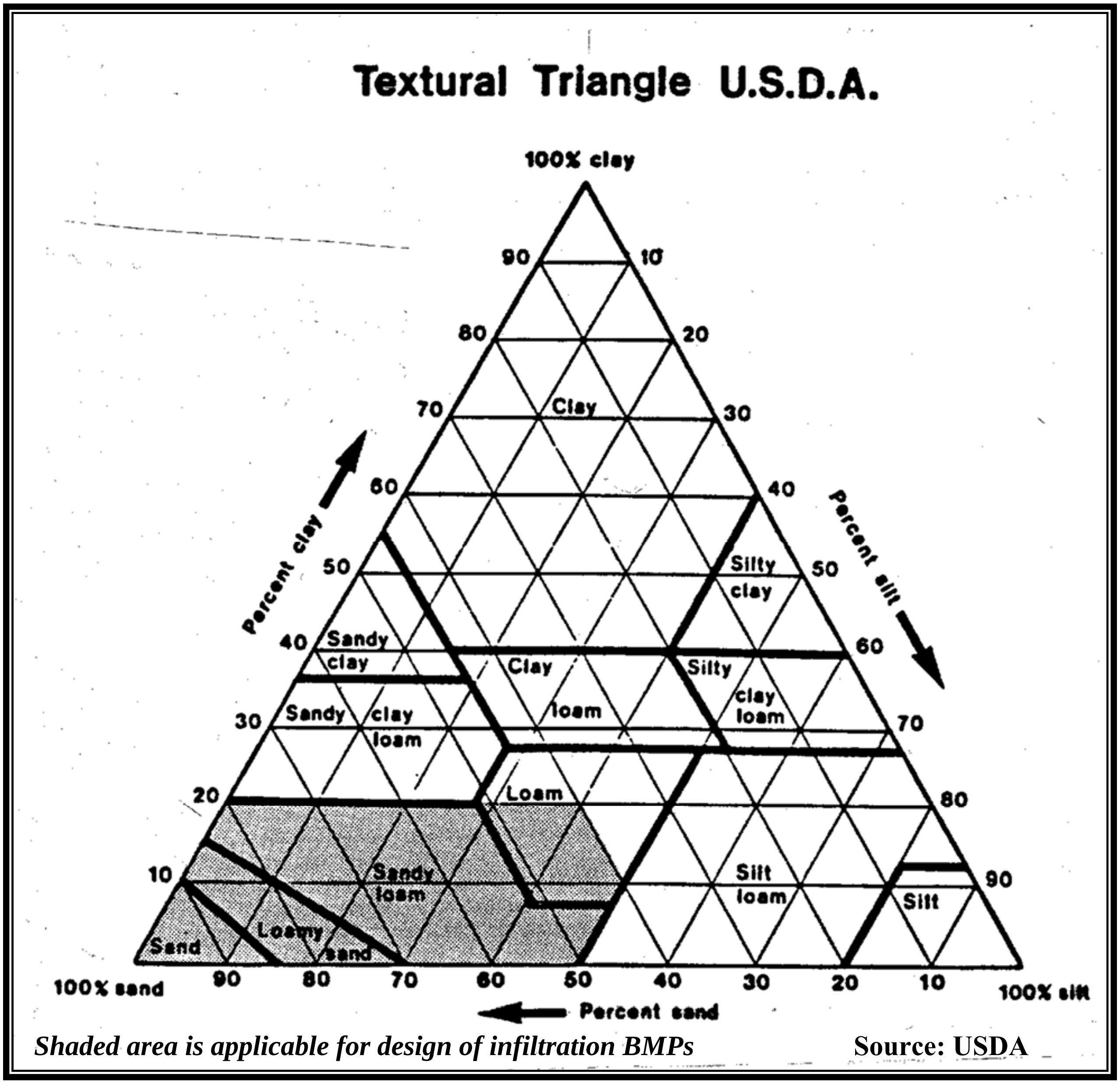

Figure A.1. USDA Textural Triangle.

Method 3 – Soil Grain Size Analysis Method

For each defined layer below the infiltration basin or trench to a depth below the facility bottom of 2.5 times the maximum depth of water in the pond, but not less than 6 feet, estimate the initial saturated hydraulic conductivity (K_{sat}) in cm/sec using the following relationship (see Massmann 2003). **This method may only be applied to project sites that are underlain by type A soils. See Appendix III-B Table B.5 Major Soil Groups in Gig Harbor.**

For large infiltration facilities serving drainage areas of 10 acres or more, soil grain size analyses shall be performed on layers up to 50 feet deep (or no more than 10 feet below the water table).

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

Where, D_{10}, D_{60}, and D_{90} are the grain sizes in mm for which 10 percent, 60 percent, and 90 percent of the sample is more fine and f_{fines} is the fraction of the soil (by weight) that passes the US #200 sieve (K_{sat} is in cm/s).

For bioretention areas, analyze each defined layer below the top of the final bioretention area subgrade to a depth of at least 3 times the maximum ponding depth, but not less than 3 feet (1 meter). For permeable pavement, analyze for each defined layer below the top of the final subgrade to a depth of at least 3 times the maximum ponding depth within the base (reservoir) course, but not less than 3 feet (1 meter).

If the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, soil layers at greater depths must be considered when assessing the site's hydraulic conductivity characteristics. 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 only the layers near and above the water table or low permeability zone (e.g., a clay, dense glacial till, or rock layer) need to be considered, as the layers below the groundwater table or low permeability zone do not significantly influence the rate of infiltration. Also note that this equation for estimating K_{sat} assumes minimal compaction consistent with the use of tracked (i.e., low to moderate ground pressure) excavation equipment.

If the soil layer being characterized has been exposed to heavy compaction (e.g., due to heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires) the hydraulic conductivity for the layer could be approximately an order of magnitude less than what would be estimated based on grain size characteristics alone (Pitt, 2003). In such cases, compaction effects must be taken into account when estimating hydraulic conductivity.

For clean, uniformly graded sands and gravels, the reduction in K_{sat} due to compaction will be much less than an order of magnitude. For well-graded sands and gravels with moderate to high silt content, the reduction in K_{sat} will be close to an order of magnitude.

For soils that contain clay, the reduction in K_{sat} could be greater than an order of magnitude.

If greater certainty is desired, the in-situ saturated conductivity of a specific layer can be obtained through the use of a pilot infiltration test (PIT). Note that these field tests generally provide a K_{sat} combined with a hydraulic gradient. In some of these tests, the hydraulic gradient may be close to 1.0; therefore, in effect, the test infiltration rate result is the same as the hydraulic conductivity. In other cases, the hydraulic gradient may be close to the gradient that is likely to occur in the full-scale infiltration facility. The hydraulic gradient will need to be evaluated on a case-by-case basis when interpreting the results of field tests. It is important to recognize that the gradient in the test may not be the same as the gradient likely to occur in the full-scale infiltration facility in the long-term (i.e., when groundwater mounding is fully developed).

Once the K_{sat} for each layer has been identified, determine the effective average K_{sat} below the pond. K_{sat} estimates from different layers can be combined using the harmonic mean:

$$K_{equiv} = \frac{d}{\sum \frac{d_i}{K_i}} \tag{2}$$

Where, d is the total depth of the soil column, d_i is the thickness of layer "*i*" in the soil column, and K_i is the saturated hydraulic conductivity of layer "*i*" in the soil column. The depth of the soil column, d, typically would include all layers between the pond bottom and the water table. However, for sites with very deep water tables (>100 feet) where groundwater mounding to the base of the pond is not likely to occur, it is recommended that the total depth of the soil column in Equation 2 be limited to approximately 20 times the depth of pond, but not more than 50 feet. This is to ensure that the most important and relevant layers are included in the hydraulic conductivity calculations. Deep layers that are not likely to affect the infiltration rate near the pond bottom should not be included in Equation 2.

Equation 2 may over-estimate the effective K_{sat} value at sites with low conductivity layers immediately beneath the infiltration basin. For sites where the lowest conductivity layer is within five feet of the base of the pond, it is suggested that this lowest K_{sat} value be used as the equivalent hydraulic conductivity rather than the value from Equation 2. Using the layer with the lowest K_{sat} is advised for designing bioretention areas or permeable pavement surfaces. The harmonic mean given by Equation 2 is the appropriate effective hydraulic conductivity for flow that is perpendicular to stratigraphic layers, and will produce conservative results when flow has a significant horizontal component such as could occur due to groundwater mounding.

Recommended Modifications to ASTM D 2434 When Measuring Hydraulic Conductivity for Bioretention Soil Mixes

Developed by the City of Seattle in cooperation with local soils laboratories.

Proctor method ASTM D1557 Method C (6-inch mold) and ASTM D2434 shall be used to determine the hydraulic conductivity of bioretention soil samples with a compaction rate of 85 percent. Sample preparation for the Proctor test (ASTM D1557 Method C) shall be amended in the following ways:

1) Maximum grain size within the sample shall be no more than 0.5 inches in size.
2) Snip larger organic particles (if present) into 0.5 inch long pieces.
3) When adding water to the sample during the Proctor test, allow the sample to pre-soak for at least 48 hours to allow the organics to fully saturate before compacting the sample. This pre-soak ensures the organics have been fully saturated at the time of the test.

ASTM D2434 shall be used and amended in the following ways:

1) Apparatus:
    a. 6-inch mold size shall be used for the test
    b. If using porous stone disks for the testing, the permeability of the stone disk shall be measured before and after the soil tests to ensure clogging or decreased permeability has not occurred during testing
    c. Use the confined testing method, with 5- to 10-pound force spring
    d. Use de-aired water.
2) Sample:
    a. Maximum grain size within the sample shall not be more than 0.5inch in size.
    b. Snip larger organic particles (if present) into 0.5inch long pieces.
    c. Pre-soak the sample for at least 48 hours prior to loading it into the mold. During the pre-soak, the moisture content shall be higher than optimum moisture but less than full saturation (i.e., there shall be no free water). This pre-soak ensures the organics have been fully saturated at the time of the test.
3) Preparation of Sample:
    a. Place soil in cylinder via a scoop.

b. Place soil in 1-inch lifts and compact using a 2-inch-diameter round tamper. Pre-weigh how much soil is necessary to fill 1-inch lift at 85 percent of maximum dry density, then tamp to 1-inch thickness. Once mold is full, verify that density is at 85 percent of maximum dry density (+ or – 0.5 percent). Apply vacuum (20 inches Hg) for 15 minutes before inundation.

c. Inundate sample slowly under a vacuum of 20 inches Hg over a period of 60 to 75 minutes.

d. Slowly remove vacuum (> 15 seconds).

e. Sample shall be soaked in the mold for 24 to 72 hours before starting test.

1) Procedure:

a. The permeability test shall be conducted over a range of hydraulic gradients between 0.1 and 2

b. Steady state flow rates shall be documented for four consecutive measurements before increasing the head

c. The permeability test shall be completed within 1 day (1-day test duration).