APPENDIX D

Subsurface Characterization and Infiltration Testing for Infiltration Facilities

Subsurface Characterization Report

All projects shall prepare a subsurface characterization report documenting results of the geotechnical explorations and infiltration tests described in this Appendix. Note that some geotechnical explorations and tests must be performed by a professional engineer, geologist, engineering geologist or professional hydrogeologist licensed with the State of Washington (herein referred to as "licensed professional" and experienced in infiltration testing.

Subsurface characterization reports shall include the following information:

Subsurface Characterization Report Information	Impervious Area Infiltrated On-site		
	<5,000 sf	>5,000-<10,000 sf	>10,000 sf
Underlying subsurface material characterization beneath the site, implementing a subsurface exploration program to supplement existing information, if any. Subsurface exploration methods are hand-augers, test pits, or drilled borings	✓	✓	✓
Detailed logs for each exploration and a map showing the location of the test pits or borings. Logs must include depth of explorations, material descriptions, depth to water (if present), and presence of stratification.	✓	✓	✓
Stratigraphy should be assessed for hydraulically-restrictive and – unrestrictive materials, evidence of groundwater, and other structure variability necessary to assess subsurface flow patterns.		✓	✓
The results of infiltration tests to assess infiltration capability and the feasibility of Infiltration facilities.	✓	✓	✓
If on-site infiltration may result in shallow lateral flow (interflow), the conveyance and possible locations where that interflow may re-emerge should be assessed by licensed a hydrogeologist.			✓

Geotechnical Explorations

Geotechnical explorations consist of any type of excavation that allows for the collection of soil samples and the observation of subsurface materials and groundwater conditions, including hand-auger holes, test pits, and drilled boreholes.

Characterization for each soil and/or rock unit (strata with the same texture, color/mottling, density, and type) should include:

- Material texture, color/mottling, density and type
- Relative moisture content
- Grain size distribution, including fines content determination
- Presence of stratification or layering

- Presence of groundwater
- USCS classification or textural class
- Iron oxide staining or mottling that may provide an indication of high water level
- Cation exchange capacity (refer to Section 5.4.1.7)

For projects with greater than 5,000 sf impervious area infiltrated on-site, the geotechnical explorations shall be performed by a licensed professional. Explorations should be performed at the site of the facility or as close as possible, but no more than 50 feet away to obtain relevant subsurface characterization. The seasonal timing, number, and depth of geotechnical explorations required are presented in Volume 3, Table 5.11.

If possible, explorations should be performed in the wet season (November through March) when soils are more saturated and groundwater levels are typically higher.

Infiltration Tests

This section provides procedures for the following infiltration testing methods:

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

To determine which infiltration test method is required for a project, see Volume 3, Table 5.11.

Test reports for Small PITs, Large PITs, and UIC Infiltration tests shall be stamped by a professional engineer, geologist, engineering geologist or professional hydrogeologist licensed with the State of Washington (herein referred to as “licensed professional” and experienced in infiltration testing.

If possible, perform infiltration testing at the location of the proposed facility. Infiltration testing results from a nearby location within 50 feet of the proposed facility may be approved at the discretion of the licensed professional. If the infiltration testing is performed more than 50 feet from the final infiltration facility location due to existing site conditions (e.g., existing structure at location of proposed facility), verification testing is required (see Section 5.4.1.4).

If discontinuous soil conditions are observed at the site, multiple infiltration tests are recommended in the different soil types. If multiple infiltration facilities are planned for a site, additional infiltration testing is required at each of the facility locations. When more than one infiltration test is required, evenly distribute the testing locations across the proposed facility area as outlined in Table 5.11 in Volume 3.

After the measured (initial) infiltration rates are determined using the procedures provided in this section, correction factors must be applied to calculate the "design" rate used for BMP sizing (refer to "Infiltration rate Correction Factors" section below).

Simple Infiltration Test

Procedure

The Small-Scale Infiltration Test procedure is adapted from the 2013 Rain Garden Handbook for Western Washington – Washington State Department of Ecology (Ecology) (https://fortress.wa.gov/ecy/publications/SummaryPages/1310027.html).

If testing is performed during the wet season (November through March), only one test is required. If the test is performed outside of the wet season (April through October), three tests must be performed in same hole within 3 days, with the beginning of each test spaced 24 hours apart.

1. Dig a hole a minimum of 2 feet deep and 2 feet in diameter. If testing is performed outside of the wet season, the hole should be 4 feet in depth.
2. Record the type and texture of the soil. If the soil is primarily fine-grained such as silt or clay, or is glacial till, infiltration may not be feasible.
3. Add 6 to 12 inches of water to the hole. Be careful to avoid splashing which could erode the sides of the hole or disturb the soil at the base of the hole.
4. Record the depth of water in the hole in inches using a ruler, scale, or tape measure.
5. Record the time water was added to the hole.
6. Check and record the time and depth of water in the hole on an hourly basis until the water has drained from the hole, or for a total of 8 hours.
7. If the test is performed in the dry season (April through October), a total of three tests should be performed.
8. The day after the test, check for high groundwater by using a post hole digger to excavate a 3-foot deep hole approximately 5 feet from the test hole. If water is observed seeping into the hole, measure the depth to the seepage. If the depth is 2.5 feet or less, high groundwater conditions may reduce the effectiveness of the infiltration facility and a different location is recommended with additional testing.

Data Analysis

Using the collected data, estimate the infiltration rate in inches per hour by calculating the drop in water level in inches for each hour data was collected. For an 8-hour test, there should be a total of eight values. The lowest calculated value is the measured infiltration rate in inches per hour. A correction factor of 0.5 shall be applied to the measured infiltration rate to calculate the design infiltration ate as shown below:

Design Infiltration Rate = Measured Infiltration Rate X 0.5

Small Pilot Infiltration Test

The testing procedure and data analysis requirements for the Small PIT are provided below.

Procedure

1. 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 pavements, 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 be compacted, compact the native soil prior to testing. Note that the permeable pavement design guidance recommends compaction not exceed 90 to 92 percent.

2. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.

3. The size of the bottom of the test pit should be between 12 and 32 square feet. Accurately document the size and geometry of the test pit.

4. Install a device capable of measuring the water level in the pit during the test. This may be a pressure transducer (automatic measurements) or a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom (manual measurements).

5. Use a rigid pipe with a splash plate or some other device on the bottom to convey water to the bottom of the pit and reduce side-wall erosion and excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance may result in clogging of the infiltration receptor and yield lower than actual infiltration rates.

6. 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.

7. Steady state period: At the end of the pre-soak period, add water to the pit at a rate that will maintain the design ponding depth 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.

8. Every 15 minutes during the steady state period, record the cumulative volume and instantaneous flow rate (in gallons per minute) necessary to maintain the water level at the same point (the design ponding depth) on the measuring rod.

9. Falling head period: After 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour using the pressure transducer or measuring rod data, until the pit is empty.

10. At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface.

The depth of excavation varies depending on soil type and depth to hydraulic restricting layer, and is determined by the licensed geotechnical engineer or hydrogeologist.

Data Analysis

Refer to the guidance for large PITs.

Large Pilot Infiltration Test

A large PIT will more closely simulate actual conditions for the infiltration facility than a small PIT and may be preferred at the discretion of the licensed professional. The testing procedure and data analysis requirements for the Large PIT are provided below.

Procedure

1. Excavate the test pit to the depth of the bottom of the proposed infiltration facility.
2. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
3. The size of the bottom of the test pit should be as close to the size of the planned infiltration facility as possible, but not less than 32 square feet in area (100 square feet is recommended). Where water availability is an issue, smaller areas may be considered, as determined by the licensed professional. Accurately document the size and geometry of the test pit.
4. Install a device capable of measuring the water level in the pit during the test. This may be a pressure transducer (automatic measurements) or a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom (manual measurements).
5. Use a rigid pipe with a splash plate or some other device on the bottom to convey water to the bottom of the pit and reduce side-wall erosion and excessive disturbance of the pit bottom. Excessive erosion and bottom disturbance may result in clogging of the infiltration receptor and yield lower than actual infiltration rates.
6. Add water to the pit at a rate that will maintain a water depth between 3 and 4 feet above the bottom of the pit. At no time shall the depth exceed the proposed maximum depth of water expected in the completed facility.
7. 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 (between 3 and 4 feet) on the measuring rod. Flow rate measurement can best be accomplished with an in-flow meter.
8. Add water to the pit until 1 hour after the flow rate into the pit has stabilized (constant flow rate) while maintaining the same pond water level (usually 17 hours).
9. Falling head period: After the flow rate has stabilized, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour using the pressure transducer or measuring rod, until the pit is empty.

10. At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation varies depending on soil type and depth to hydraulic restricting layer, and is determined by the licensed geotechnical engineer or hydrogeologist.

Data Analysis

Calculate and record the infiltration rate in inches per hour until 1 hour after the flow has stabilized. Use the falling head data to confirm the infiltration rate estimated from the stabilized data. Adjust the measured infiltration rate using the correction factors described in this appendix to estimate the design infiltration rate.

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

Deep Underground Injection Control (UIC) Infiltration Test

The design infiltration rate for UIC wells shall be determined by performing a constant-rate infiltration test followed by a falling-head infiltration test as explained below.

Procedure

1. Perform the test by adding water (obtained from a potable water source) to the test UIC well to maintain a hydraulic head in the well equal to approximately 1/2 the thickness of the unsaturated infiltration receptor soil.

2. Monitor the flow rate with a flow meter or other method that is capable of measuring flow to within 5 percent of the total flow rate.

3. Monitor water levels in the test UIC well with a pressure transducer and datalogger on a maximum of 5 minute intervals.

4. Add water until the rate of water added is constant, or for a minimum of 4 hours.

5. Once a constant rate is achieved, the test is complete. Begin the falling head portion of the test. Monitor water levels during the falling until the water level has fallen to a minimum of 5 percent of the total head targeted during the constant rate portion of the test.

6. In addition to the test well, monitor groundwater elevations in all project monitoring wells located within 100 feet of the test well.

Data Analysis

The test data shall be evaluated by a licensed professional experienced in analysis of well hydraulics and well testing data. Because of the likely variability in soil conditions, specific methods for analysis of the data are not provided and it is the responsibility of the professional analyzing the data to select the appropriate methodology. Adjust the measured infiltration rate using the correction factors described in this appendix to estimate the design infiltration rate.

Infiltration Rate Correction Factors

Infiltration rates measured using the field tests described in this appendix are measured (initial) rates and must be reduced using correction factors to determine the "long-term" or "design" rates. Correction factors account for site variability, the number of tests conducted, uncertainty of the test method, and the potential for long-term clogging due to siltation and bio-buildup. Table D-1 summarizes the range of "partial" correction factors that account for these issues. Correction factors shall be within the ranges provided in Table D-1 unless soil and groundwater conditions warrant a lower correction factor, as determined and documented by the licensed professional responsible for the design recommendations of the facility.

Table D-1. Correction Factors to be Used With Measured (Initial) Infiltration Rates of the Native Soil to Estimate Design Rates

Applicability	Site Analysis Issue	Partial Correction Factor
All facilities	Includes site variability, number of locations tested, and uncertainty of the test method	CF_v x CF_T = 0.20 to 0.50
All facilities except bioretention and permeable pavement	Degree of influent control to prevent siltation and bio-buildup	CF_m = 0.2 to 0.9
Permeable pavement	Quality of pavement aggregate base material	CF_m = 0.9 to 1

Total Correction Factor, $CF_T = CF_v \times CF_T \times CF_m$
CF_T is used to adjust the measured infiltration rate to calculate the design infiltration rate.
Design Infiltration Rate = Measured Infiltration Rate X CF_T

Determining the appropriate correction factor requires the use of best professional judgment by the licensed professional who is experienced in providing recommendations for designing infiltration projects and the approval by the City of Seattle. In no case shall the design infiltration rate exceed 10 inches per hour.

Site variability and number of locations tested (CF_v): The number of locations tested must be sufficient to represent the conditions throughout the facility site. The partial correction factor (CFv) used depends on the level of uncertainty that adverse subsurface conditions may exist. For example, if the range of uncertainty is low and conditions are known to be uniform based on previous exploration and site geological factors, one PIT may be adequate to justify a partial correction factor at the high end of the range.

If the level of uncertainty is high, a partial correction factor near the low end of the range may be appropriate. This might be the case where the site conditions are highly variable due to conditions such as a deposit of ancient landslide debris, or buried stream channels. In these cases, even with many explorations and several PITs, the level of uncertainty may still be high.

A partial correction factor near the low end of the range could be assigned where conditions have a more typical variability, but few explorations and only one PIT is conducted. That is, the number of explorations and tests conducted do not match the degree of site variability anticipated.

Uncertainty of test method (CFt): This partial correction factor represents the accuracy of the infiltration test method used. The assumption is that the larger the scale of the test, the more reliable the result (i.e., the Large PIT has a higher correction factor than the Small-Scale Infiltration Test).

Degree of influent control to prevent siltation and bio-buildup (CF_m): A partial correction factor near the low end of the range may be justified under the following circumstances:

- If the infiltration facility is located in a shady area where moss buildup or litter fall buildup from the surrounding vegetation is likely and cannot be easily controlled through long-term maintenance
- If there is minimal pre-treatment, and the influent is likely to contain moderately high TSS levels

If influent into the facility can be well controlled such that the planned long-term maintenance can easily control siltation and biomass buildup, then a partial correction factor near the high end of the range may be justified. The maintenance schedule calls for removing sediment when the facility is infiltrating at only 90 percent of its design capacity. Therefore, the nominal correction factor is 0.9 for CF_m.

The determination of long-term design infiltration rates from in-situ infiltration test data involves a considerable amount of engineering judgment. Therefore, when determining the final long-term design infiltration rate, the licensed professional shall consider the results of both soil subsurface material conditions and in-situ infiltration tests results.

Groundwater Monitoring

Groundwater monitoring is required when runoff from more than 5,000 square feet of impervious surface is infiltrated on site (see Volume 3 Table 5.11). For projects infiltrating runoff from more than 5,000 and less than 10,000 square feet of impervious area, one monitoring well is required to establish groundwater elevations near the facility. For these site, monitor groundwater through at least one wet season (November through March) with groundwater levels measured on a monthly basis. If the project site is within 200 feet of Lake Union, Lake Washington, or the Ship Canal, monitor for at least one calendar year.

For projects infiltrating runoff from 10,000 square feet or more of impervious area, a minimum of three groundwater monitoring wells are required per site to establish groundwater flow direction and gradient. For these projects, monitor groundwater levels on a monthly basis for a minimum of one calendar year.

Groundwater monitoring is not required if available piezometer data within 50 feet of the proposed facility shows the highest groundwater level to be at least 20 feet below the lowest elevation of the facility.

Groundwater Mounding Analyses

A number of different analytical tools are available to evaluate potential groundwater mounding beneath infiltration facilities. These include both analytical and numerical

groundwater flow software. In general, public domain software programs shall be used (such those initially authored by the United States Geological Survey (USGS) or the Environmental Protection Agency); proprietary computer programs are not allowed.

The software program MODRET is considered a standard tool for evaluating infiltration facilities, and is recommended in the Ecology Stormwater Management Manual for Western Washington. Although technically a proprietary computer program, it is readily available for purchase and is based on USGS software. However, MODRET is limited to evaluation of a single facility at a time, and generally will not be suitable for evaluating clustered facilities, such as areas with multiple infiltration facilities.

The preferred program for simulating groundwater mounding beneath infiltration facilities is the USGS-based program MODFLOW. MODFLOW can be used to simulate a wide range of aquifer conditions and geometries. The primary limitation with MODFLOW is that most versions of the program do not simulate the movement of water through the unsaturated zone, which would normally be expected to slow the downward movement of water and allow for lateral spreading of water before reaching the water table. Instead, infiltrating water is input directly to the water table. For a shallow water table or perching layer this limitation should not greatly influence the overall results of the mounding simulation and represents a more conservative approach to simulating mounding.

Only licensed hydrogeologists with formal training and experience in constructing groundwater flow models should conduct these analyses. It should also be noted that groundwater models do not provide specific answers, and instead are tools to help understand the behavior of groundwater systems under a variety of conditions. The results of any model should be used in the context of the overall goal of the project and be applied as warranted by the risk tolerance of the owner.

Data Requirements

Data requirements for development of a mounding model include information on soil and groundwater conditions, aquifer parameters (e.g., hydraulic conductivity and specific yield), aquifer geometry, pre-infiltration hydraulic gradient, and flow rate from the infiltration facilities.

Many of the data inputs for the mounding model should be available in the vicinity of the infiltration facilities from the geotechnical exploration and infiltration testing program performed for design of the facilities. Outside the area of the infiltration facilities, data may be sparse and may need to be interpolated from regional data. The extent of the modeled area should be such that the edges of model do not influence unless an actual boundary exists, such as Elliott Bay or Lake Washington.

In the absence of local information regarding the groundwater gradient and/or the distribution of hydraulic restrictive layers, mounding analyses should consider the general slope of the site and surrounding sites, as the general slope is likely indicative of the direction of interflow originating from infiltration facilities, and the regional hydraulic gradient.

Estimate aquifer parameters, including hydraulic conductivity and specific yield based on knowledge of local soil types and from grain size distribution obtained for soil samples collected as part of the subsurface exploration and testing program. In general, groundwater flow models tend to be most sensitive to variations in hydraulic conductivity values. Obtain hydraulic conductivity values from field testing of the infiltration receptor soils using standard industry methods.

Analysis Procedures

The initial step for any groundwater modeling project is development of a conceptual model of the groundwater system. The conceptual model should describe the anticipated groundwater flow system including the data requirements described above, direction and rate of groundwater flow, potential model boundaries, and approach for simulating infiltration. The conceptual model provides the basis for constructing the computer model.

Because of the limited available data necessary for model inputs, a parametric analysis shall be performed whereby model inputs, especially aquifer parameters, are varied over range of values to evaluate the potential impact on the mounding results. The range values should be based on known variability in the parameter and experience of the licensed professional with similar soils in the area.

The following minimum ranges of aquifer parameters are to be used in the parametric analysis:

- **Hydraulic conductivity** – one order of magnitude for each receptor soil
- **Aquifer thickness** – plus or minus 50 percent of the known values
- **Specific yield** – minimum range of 0.1 to 0.3

If known field conditions warrant, increase the above ranges as necessary.

In general, multiple infiltration scenarios will need to be simulated to evaluate potential mounding below the infiltration facilities. For example, both short-term peak storm events and long-term seasonal precipitation should be evaluated. Additional scenarios may include a series of short-term high precipitation events. Although the actual events that need to be simulated will depend on subsurface conditions, number and types of infiltration facilities, and potential risk factors, as a minimum the following scenarios are required:

- A single 24-hour, 100-year precipitation event
- A typical wet season (November through April) based on average monthly precipitation followed by a single 24-hour, 25-year event
- A typical wet season based on average monthly precipitation followed by a series of 24-hour, 1-year, and 2-year events (total of four events over a 2-week period)

The licensed hydrogeologist performing the mounding analysis should use professional judgment and experience to potentially modify the above scenarios or add additional scenarios on a project specific basis, as needed.

As additional soil and groundwater information is collected during construction, testing, and operation of the infiltration facility, the mounding analysis should be revised and refined to incorporate any new information. If groundwater monitoring indicates results inconsistent with the findings of the mounding analysis, in the opinion of a licensed hydrogeologist, the model should be reevaluated. The reevaluation should include simulation of the precipitation events prior to the observed groundwater monitoring data.