APPENDIX D

Subsurface ~~Characterization~~Investigation and Infiltration Testing for Infiltration ~~Facilities~~BMPs

D-1. Subsurface Characterization Report

All projects shall prepare a subsurface characterization report documenting results of

Contents

D-1. Roles and Responsibilities of Licensed Professionals

This appendix provides the geotechnical explorations andminimum investigation requirements for infiltration tests described in this Appendix. Note that some geotechnical explorations and tests must be performed bybest management practices (BMPs). This information does not preclude the use of professional judgment to evaluate and manage risk associated with design, construction, and operation of infiltration BMPs.

Recommendations that deviate from the minimum investigation requirements specified in this appendix shall be contained in a stamped and signed letter from a State of Washington licensed professional engineer, geologist, engineering geologist, geologist, or professional hydrogeologist licensed with the State of Washington (, herein referred to as "licensed professional" and experienced, who has experience in infiltration and groundwater testing and infiltration facility design, and must provide rationale and specific data supporting their professional judgment. For more information on the role of the licensed professional, refer to City of Seattle Director's Rule 18-2011, *General Duties and Responsibilities of Geotechnical Engineers*.

D-2. Subsurface characterization reports shall include the following information:Investigation

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.			✓

D-3. Geotechnical Explorations

D-2.1. Geotechnical explorationsDescription

Subsurface investigations 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. ExplorationsThis section includes general subsurface investigation requirements followed by specific information regarding four types of subsurface investigations:

- Simple subsurface investigation
- Standard subsurface investigation
- Comprehensive subsurface investigation
- Deep infiltration subsurface investigation

D-2.2. General Subsurface Investigation Requirements

This section include requirements for subsurface investigation locations, timing, alternatives, investigation depth and vertical separation requirements, and subsurface reports.

D-2.2.1 Subsurface Investigation Locations

For Single-Family Residential (SFR) and Parcel-based projects, the site is defined as the project area. For Trail, Sidewalk, or Roadway projects, the site is defined by one intersection to the other and blocks may vary in length. In many cases, subsurface investigations should be performed at the site of the infiltration 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.information. Subsurface investigations can be conducted at the same location as the infiltration tests (*Section D-3*).

D-2.2.2 If possible, explorationsSubsurface Investigation Timing

Subsurface investigations should be performed in the wet season (November through March) if possible, when soils are more saturatedmay have a higher water content and groundwater levels are typically higher. Refer to *Sections D-2.3* through *D-2.5* for wet season and non-wet season requirements for the different types of subsurface investigations.

D-2.2.3 Alternatives to Subsurface Investigation

In some cases, available data and the licensed professional's interpretation of subsurface material characteristics can be used to demonstrate that infiltration is infeasible on a site and precludes the need for all of the subsurface investigation or infiltration testing. Examples of these instances include, but are not limited to:

- Groundwater monitoring data, that meets the requirements of the groundwater monitoring section (*Section D-5*), at the site of the proposed facility showing groundwater elevations not meeting the vertical separation requirements (*Section D-2.2*).
- Identification by the licensed professional of hydraulically-restrictive materials beneath the proposed facility and within the vertical separation requirements (*Section D-2.2*). Examples of materials that may be interpreted as hydraulically-restrictive include:
    - Glacially consolidated soils that have greater than 50 percent fines
    - Glacially unconsolidated soils that have greater than 70 percent fines
    - Bedrock

To support these instances, the licensed professional must submit a stamped and signed letter that provides rationale and specific data supporting their professional judgment for each area deemed infeasible for infiltration.

D-2.2.4 Investigation Depth and Vertical Separation Requirements

Investigation depth is measured below the bottom of the proposed infiltration BMP. The bottom of the infiltration facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into the underlying soil.

The vertical separation requirements depend upon the type of subsurface investigation required and the seasonal timing of the geotechnical exploration conducted to evaluate clearance and are typically one foot less than the minimum investigation depths summarized in *Sections D-2.3* through *D-2.5*. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation depth, then no further investigation is required.

D-2.2.5 Subsurface Report

Projects that are required to perform subsurface investigations per *Volume 3*, *Section 3.2*, shall prepare a report documenting results of the subsurface investigations described in *Sections D-2.3* through *D-2.6* and infiltration tests described in *Section D-3*.

D-2.3. Simple Subsurface Investigation

This section summarizes the minimum requirements of a Simple Subsurface Investigation. Refer to Table 3.1 in *Volume 3*, *Section 3.2* to determine the minimum subsurface investigation requirements for a project.

A simple subsurface investigation report can be used to document the investigation and testing results. This report should include the following:

- Map of investigation and testing location
- Soil characteristics
- Depth to groundwater (if encountered)

Simple Subsurface Investigation Elements
Minimum Investigation Depth[a] • 2 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation requirement (1 foot below the bottom of the facility), no further investigation is required. • 4 feet below the bottom of the proposed facility for investigations conducted between April and October. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 1 foot below the bottom of the facility or groundwater within 3 feet below the bottom of the facility, no further investigation is required.
Soil Characteristics Type and texture of soil

[a] The bottom of the facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into the underlying soil.

D-2.4. Standard Subsurface Investigation

This section summarizes the minimum requirements of a Standard Subsurface Investigation. Refer to Table 3.1 in *Volume 3*, *Section 3.2* to determine the minimum subsurface investigation requirements for a project.

Standard Subsurface Investigation Elements

Minimum Investigation Depth[a, b]

Infiltration basins:

- 6 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation requirement (5 feet below the bottom of the facility), no further investigation is required.
- 8 feet below the bottom of the proposed facility for investigations conducted between April and October. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 5 feet below the bottom of the facility or groundwater within 6 feet below the bottom of the facility, no further investigation is required.

All other infiltration BMPs:

- 2 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation requirement (1 foot below the bottom of the facility), no further investigation is required.
- 4 feet below the bottom of the proposed facility for investigations conducted between April and October. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 1 foot below the bottom of the facility or groundwater within 3 feet below the bottom of the facility, no further investigation is required.

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

- USCS classification or textural class
- 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
- Iron oxide staining or mottling that may provide an indication of high water level
- Cation exchange capacity (refer to *Volume 3*, *Section 4.5.2*)

Detailed logs for each investigation

- Map showing the location of the test pits or borings
- Depth of investigations
- Investigation methods (hand augers, test pits, or drilled borings), material descriptions
- Depth to water (if present)
- Presence of stratification
- Existing boring or groundwater information

The report shall document how the information collected relates to the infiltration feasibility of the site based on the setbacks provided in *Volume 3*, *Section 3.2* and this appendix.

[a] The bottom of the facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into the underlying soil. For Small PITs, sampling of distinct materials below the bottom of the facility and within the vertical separation depth is required. Beyond this depth, samples should be collected every 2.5 feet.

[b] If more than 2,000 sf of the site infiltration will occur within a single facility, the Standard Subsurface Investigation report shall be stamped and signed by a licensed professional.

D-2.5. Comprehensive Subsurface Investigation

This section summarizes the minimum requirements of a Comprehensive Subsurface Investigation. Refer to Table 3.1 in *Volume 3*, *Section 3.2* to determine the minimum subsurface investigation requirements for a project. The comprehensive subsurface investigation report shall be stamped and signed by a licensed professional.

Comprehensive Subsurface Investigation Elements
Minimum Investigation Depth[a, b] **Infiltration basins:** • 6 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation requirement (5 feet below the bottom of the facility), no further investigation is required. • 8 feet below the bottom of the proposed facility for investigations conducted between April and October. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 5 feet below the bottom of the facility or groundwater within 6 feet below the bottom of the facility, no further investigation is required. **All other infiltration BMPs:** • 4 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or hydraulically-restrictive material is encountered within the vertical separation requirement (3 feet below the bottom of the facility), no further investigation is required. • 10 feet below the bottom of the proposed facility for investigations conducted between April and October that will not serve as groundwater monitoring wells. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 3 feet below the bottom of the facility or groundwater within 8 feet below the bottom of the facility, no further investigation is required. **Permeable pavement facility:** • 2 feet below the bottom of the proposed facility for investigations conducted between November and March. If groundwater or a hydraulically-restrictive material is encountered within the vertical separation requirement (1 foot below the bottom of the facility), no further investigation is required. • 4 feet below the bottom of the proposed facility for investigations conducted between April and October. If either of the following vertical separation depths are encountered: hydraulically-restrictive material within 1 foot below the bottom of the facility or groundwater within 3 feet below the bottom of the facility, no further investigation is required.
Characterization for each soil and/or rock unit (strata with the same texture, color/mottling, density, and type) Same as Standard Subsurface Investigation (*Section D-2.4*)
Detailed logs for each investigation Same as Standard Subsurface Investigation (*Section D-2.4*)

[a] The bottom of the facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into the underlying soil. For Small PITs, sampling of distinct materials below the bottom of the facility and within the vertical separation depth is required. Beyond this depth, samples should be collected every 2.5 feet.

[b] If the bottom of the facility is not known, the minimum investigation depth shall be 16 feet below grade. Investigations that will also serve as groundwater monitoring wells shall not be less than 20 feet below the bottom of proposed facility and the criteria for vertical separation to groundwater or hydraulically-restrictive materials listed above shall apply.

D-2.6. Deep Infiltration Subsurface Investigation

This section summarizes the minimum requirements of a Deep Infiltration Subsurface Investigation. Refer to Table 3.2 in *Volume 3*, *Section 3.2*, to determine the minimum subsurface investigation requirements for a project. The deep infiltration subsurface investigation report shall be stamped and signed by a licensed professional.

Deep Infiltration Subsurface Investigation Elements
Minimum Investigation Depth[a]
At least 10 feet below regional groundwater table or into aquitard underlying target soil
Characterization for each soil and/or rock unit (strata with the same texture, color/mottling, density, and type)
Same as Standard Subsurface Investigation (*Section D-2.4*)
Detailed logs for each investigation
Same as Standard Subsurface Investigation (*Section D-2.4*)

[a] The bottom of the facility is defined as the deepest portion of proposed facility where infiltrating water is expected to move into the underlying soil.

D-3. Infiltration Tests

D-3.1. Description

~~D-4.D-1.~~ Step 4 in *Volume 3, Section 3.2*, is Conduct Infiltration Testing. ~~Infiltration Tests~~

This section provides procedures for the following infiltration testing methods:

- Simple Infiltration Test (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~~refer to Table 3.1 and Table 3.2 in *Volume 3*, ~~Table 5.11~~*Section 3.2*.

~~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 infiltration facility. Infiltration testing results from a nearby location within 50 feet of the proposed infiltration 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~~) and greater than 5,000 sf is infiltrated on the site, then acceptance testing is required (~~see~~refer to *Section* ~~5.4.1.4~~*D-8*).

If ~~discontinuous~~variable 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~~"~~ infiltration rate used for BMP sizing (refer to ~~"Infiltration rate Correction Factors" section below~~*Section D-4*).

The test method may be modified due to site conditions if recommended by the licensed professional and the reasoning is documented in the report. Any modifications to the proposed test method should be approved by the City.

~~D-4.1.~~D-3.2. Simple Infiltration Test

~~Procedure~~

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

Procedure

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 sh~~ou~~al~~d~~l be 4 feet ~~in depth~~deep.
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. 7. 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.

D-4.1.2 Data Analysis

8. Mark test locations on site map.
9. Calculate measured infiltration rate. Refer to Table 3.3 in *Volume 3*, *Section 3.2*, for minimum infiltration rates for each type of infiltration BMP. 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:

Data Analysis

Design Infiltration Rate = Measured Infiltration Rate X 0.5

In locations where the measured infiltration rate is less than 0.3 inches per hour, no further subsurface investigation is required to meet the on-site stormwater management, flow control, or water quality treatment requirements, but is allowed if an underdrain is used. Infiltration BMPs may be required to meet project point of discharge or Peat Settlement Prone Critical Area requirements.

D-4.2. D-3.3. Small Pilot Infiltration Test (Small PIT)

The testing procedure and data analysis requirements for the Small PIT are provided below. The report for this test shall include documentation of the testing procedure, analysis and results to assess infiltration feasibility and an explanation of the correction factor used to determine the design infiltration rate.

Procedure

1. Excavate the test pit to the estimated surface elevation depth of the bottom of the proposed infiltration facility. In the case of bioretention, excavate to the lowest estimated elevation at which the imported soil mix will lie on top of contact 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 underlying soils (road subgrade) will be compacted, compact the native soil underlying soils 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 shoualdl be betweena minimum of 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:
   a. At the end of the pre-soak period, add water to the pit at a rate that will maintain the design pondinga depth of 12 inches 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.
   b. 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 or pressure transducer readout.
8. 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 every 15 minutes using the pressure transducer or measuring rod data, for a minimum of 1 hour or until the pit is empty.
9. At the conclusion of testing, over-excavate the pit to seedetermine if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The investigation depth of excavation varies depending on soilthe type of subsurface investigation required (refer to Table 3.1 in *Volume 3, Section 3.2*) and depth to hydraulic restricting layer, and is determined by the licensedthe seasonal timing of the geotechnical engineer or hydrogeologistexploration conducted to evaluate clearance. Minimum investigation depths are provided in *Section D-2*.

Data Analysis

Refer to the guidance for large PITs.

Using the established steady state flow rate, calculate and record the measured infiltration rate in inches per hour. Use the falling head data to confirm the measured infiltration rate estimated from the steady state data.

In locations where the measured infiltration rate is less than 0.3 inches per hour, no further subsurface investigation is required to meet the on-site stormwater management, flow control, or water quality treatment requirements, but is allowed if an underdrain is used.

Infiltration BMPs may be required to meet project point of discharge or Peat Settlement Prone Critical Area requirements.

Adjust the measured infiltration rate using the correction factor (CF) described in *Section D-4* to estimate the design infiltration rate.

D-4.3.D-3.4. Large Pilot Infiltration Test (Large PIT)

A lLarge PIT will more closely simulate actual conditions for the infiltration facility than a sSmall PIT and may be preferred at the discretion of the licensed professional. if not already required per Table 3.1 in *Volume 3, Section 3.2*. The testing procedure and data analysis requirements for the Large PIT are provided below. The report for this test shall include documentation of the testing procedure, analysis and results to assess infiltration feasibility and an explanation of the correction factor used to determine the design infiltration rate.

The Large PIT report shall be stamped and signed by a licensed professional. The test method may be modified due to site conditions if recommended by the licensed professional and the reasoning is documented in the report.

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.

Refer to Steps 4 through 10 as described in the Small PIT procedure above.

Data Analysis

Refer to the data analysis guidance for small PITs.

D-4.4.D-3.5. Deep Underground Injection Control (UIC) Infiltration Test

The design infiltration rate for UIC wellsdeep infiltration shall be determined by performing a constant-rate infiltration test followed by a falling-head infiltration test as explained below. The Deep Infiltration Test report shall include documentation of the testing procedure, analysis and results to assess infiltration feasibility and an explanation of the correction factor used to determine the design infiltration rate.

The Deep Infiltration Test report shall be stamped and signed by a licensed professional. The test method may be modified due to site conditions if recommended by the licensed professional and the reasoning is documented in the report.

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 1/2half the thickness of the unsaturated infiltration receptor soil layer.
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~~required wells, monitor groundwater elevations in ~~all project~~nearby monitoring wells ~~located within 100 feet of the test well~~as available.

Data Analysis

The test data shall be evaluated by a licensed ~~professional~~hydrogeologist 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.~~

~~D-5.~~D-4. Infiltration Rate Correction Factor~~s~~

~~Infiltration~~Measured infiltration rates ~~measured using the field tests~~ described in ~~this appendix are measured (initial) rates and must be~~ *Section D-3* shall 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~~ design infiltration rates. The determination of a design infiltration rate from in-situ infiltration test data involves a considerable amount of engineering judgment. Therefore, when determining the final design infiltration rate, 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~~	~~$CF_V \times CF_T$ = 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~~ shall consider the results of both soil subsurface material conditions and in~~ providing recommendations for designing~~-situ infiltration ~~projects and the approval by the City of Seattle~~tests results. In no case shall the design infiltration rate exceed 10 inches per hour.

Design Infiltration Rate = Measured Infiltration Rate x CF

A correction factor (CF) is applied to the measured infiltration rate to calculate the design infiltration rate. The design infiltration rate shall be used when sizing infiltration BMPs using the design criteria outlined in *Volume 3, Section 5.4*.

D-4.1. Simple Infiltration Test

A CF of 0.5 shall be applied to the measured infiltration rate to calculate the design infiltration rate.

D-4.2. Small and Large PITs

A CF of 0.5 must be used for all projects unless a lower value is warranted by site conditions, and shall not be less than 0.2. In determining an appropriate CF, the following criteria shall be considered and are described below:

- Site variability and number of locations tested
- Uncertainty of test method
- Degree of influent control to prevent siltation and bio-buildup

Site variability and number of locations tested ~~**(CF$_v$)**~~ ~~:~~**:** This criterion depends on the level of uncertainty that adverse subsurface conditions may exist. 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~~following are examples of how site variability and number and locations of the tests may affect uncertainty ~~that adverse~~:

- The 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~~that the uncertainty for that site is low.
- ~~If the level of uncertainty is high, a partial correction factor near the low end of the range~~High variability may ~~be appropriate. This might be the case where the site~~ exist due to subsurface conditions ~~are highly variable due to conditions~~ (such as ~~a deposit of ancient landslide debris, or~~ buried stream channels) identified on previous explorations and site geological factors. 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~~High uncertainty could also 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~~criterion represents the accuracy of the infiltration test method used. ~~The assumption is that the larger the~~Larger scale ~~of the test, the~~tests are assumed to produce more reliable ~~the result~~results (i.e., the

Large PIT ~~has a higher correction factor~~is more certain than the Small~~-Scale Infiltration Test~~ PIT).

Degree of influent control to prevent siltation and bio-buildup ~~**(CF_m)**: A partial correction factor near the low end of the range~~**:** High uncertainty for this criterion 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~~total suspended solids (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~~low uncertainty may be justified for this criterion.

~~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.~~

~~D-6.~~D-5. 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 wells (including the minimum subsurface investigation depth) shall be installed as determined in *Sections D-2.3* through *D-2.6* under the direct supervision of a licensed professional. The minimum number of groundwater monitoring wells, duration of monitoring, and frequency of monitoring are summarized in Table 3.1 and Table 3.2 in *Volume 3*, *Section 3.2*. A report shall be developed that is signed and stamped by a licensed professional and includes a map detailing the locations of the monitoring wells relative to the project site and a description of the groundwater levels relative to the investigation depth and vertical separation requirements provided in *Section D-2*.

Groundwater monitoring is not required ~~if available piezometer~~ in the following situations:

- Elevation data measured at project monitoring wells shows groundwater levels within the investigation depth and vertical separation requirements summarized in *Section D-2*
- Available groundwater elevation data within 50 feet of the proposed infiltration facility shows the highest measured groundwater level to be at least 20 10 feet below the lowest elevationbottom of the proposed infiltration facility

In these situations, no further investigation is required to meet on-site, flow control, or water quality treatment requirements. These exceptions do not apply to deep infiltration BMPs.

D-6. Characterization of Infiltration Receptor

The infiltration receptor is the unsaturated and saturated soil receiving stormwater from an infiltration facility. Thresholds for triggering characterization of the infiltration receptor are summarized in Table 3.1 and Table 3.2 in *Volume 3*, *Section 3.2*).

Assessment and documentation by a licensed hydrogeologist characterizing the infiltration receptor shall include the following elements:

- Depth to groundwater and to hydraulically-restrictive material
- Seasonal variation of groundwater table based on well water levels and observed mottling of soils
- Existing groundwater flow direction and gradient
- Approximation of the lateral extent of infiltration receptor
- Volumetric water holding capacity of the infiltration receptor soils. The volumetric water holding capacity is the storage volume in the soil layer directly below the infiltration facility and above the seasonal high groundwater mark, or hydraulically-restrictive material.
- Horizontal hydraulic conductivity of the saturated zone to assess the aquifer's ability to laterally transport the infiltrated water

Note: As part of the infiltration receptor characterization for deep infiltration wells, the pretreatment requirements shall be evaluated as in the UIC Guidance Manual (Ecology 2006).

D-7. Groundwater Mounding Analysesand Seepage Analysis

A number of differentInfiltration of large volumes of water may result in a rise in the water table or development of a shallow water table on hydraulically-restrictive materials that slow the downward percolation of water. If this mounding of water is excessive, the infiltration facility may become less effective and/or adjacent structures or facilities may be impacted by the rising water table. In addition, if the infiltration facility is adjacent to a slope, slope stability may be decreased.

Thresholds for triggering groundwater mounding and seepage analysis are summarized in Table 3.1 and Table 3.2 in *Volume 3*, *Section 3.2*).

The mounding analysis shall evaluate the impact of the infiltration facility on local groundwater flow direction and water table elevations and determine whether there would be any adverse effects caused by seepage zones on nearby building foundations, basements, roads, parking lots or sloping sites. If the results of the mounding analysis indicate that adverse conditions could occur, as determined by a licensed professional, the infiltration facility shall not be built.

If infiltration on the site may result in shallow lateral flow (interflow), the conveyance and possible locations where that interflow may re-emerge should be assessed by a licensed hydrogeologist.

For deep infiltration BMPs, the following shall also be evaluated:

- Extent of groundwater mounding under the design flow rate
- Potential impacts from the groundwater mounding to:
  - Deep infiltration BMP performance
  - Surrounding infrastructure, including, but not limited to, infiltration facilities, drainage facilities, foundations, basements, utility corridors, or retaining walls
  - Off-site slope stability
  - Down-gradient existing contamination plumes

Several 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~~Ecology's Stormwater Management Manual for Western Washington. Although ~~technically~~MODRET is 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~~Licensed hydrogeologists with formal training and experience in ~~constructing~~developing groundwater flow models should conduct these analyses. It should also be noted that groundwater models do not provide specific answers, ~~and instead~~but 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.

D-7.1. Data Requirements

Data requirements for development of a groundwater mounding model include~~ information on soil~~:

- Soil and groundwater conditions~~, a~~
- Aquifer parameters (e.g., hydraulic conductivity and specific yield)~~, a~~
- Aquifer geometry~~, pre~~
- Pre-infiltration hydraulic gradient~~, and flow~~
- Flow rate from ~~the ~~infiltration facilities~~.~~

Many of the data inputs for the groundwater mounding model should be available in the vicinity of the infiltration facilities from the ~~geotechnical exploration~~subsurface investigation 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~~Aquifer parameters~~, including hydraulic conductivity and specific yield~~ shall be estimated based on knowledge of local soil types and from grain size distribution ~~obtained for~~of the soil samples collected as part of the subsurface ~~exploration~~investigation 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.

D-7.2. Analysis Procedures

The initial step for any groundwater modeling ~~project~~analysis is the 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 toshall be used in the parametric analysis:

- **Hydraulic conductivity –:** one order of magnitude (e.g., + and - a power of 10) for each receptor soil
- **Aquifer thickness –:** plus or minus 50 percent of the known values
- **Specific yield –:** minimum range of 0.105 to 0.32

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 arescenario is 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-event rainfall modeling of the back-loaded long-duration storm for the 100-year recurrence interval using data from the closest rain gage.
- 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.

D-8. Acceptance Testing

Thresholds for acceptance testing are summarized in Table 3.1 and Table 3.2 in *Volume 3, Section 3.2*). Acceptance testing may be required for infiltration facilities receiving runoff from a smaller contributing area if the City determines there may be a risk of infiltration facility failure. Site conditions that may justify acceptance testing include, but are not limited to:

- Soil and groundwater conditions observed during construction that are different than those observed at the infiltration test locations
- Presence of hydraulically-restrictive subsurface materials
- History of infiltration failure in the project area
- High groundwater levels
- Risk of flooding in the event of system failure
- Indications of sediment loads to the facility during construction
- Indications of soil compaction during construction
- New information gained during construction with regards to infiltration facility design and performance (e.g., better subsurface characterization, groundwater data, etc.)

Acceptance testing procedures for shallow infiltration BMPs shall be developed by the licensed professional responsible for design of the infiltration facility. At a minimum, the acceptance testing shall demonstrate that the infiltration facility performs at the design infiltration rate.

Acceptance testing of deep infiltration BMPs shall consist of the infiltration testing procedures for deep infiltration wells described in *Section D-4*.