Protecting Seattle's Waterways

Appendix D

Subsurface Investigation and Infiltration Testing for Infiltrating BMP's

CITY OF SEATTLE
STORMWATER MANUAL

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Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

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D-1. Roles and Responsibilities of Licensed Professionals

This appendix provides the minimum investigation requirements for infiltration best 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, engineering geologist, geologist, or hydrogeologist, herein referred to as licensed professional, 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 Investigation

D-2.1. Description

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.

This 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 includes 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 information. Subsurface investigations can be conducted at the same location as the infiltration tests (*Section D-3*).

D-2.2.2 Subsurface Investigation Timing

Subsurface investigations should be performed in the wet season (November through March) if possible, when soils may contain a higher water content and groundwater levels are typically higher. Refer to *Sections D-2.3* through *D-2.5* for wet season and dry 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-2.2.4)*.
- Identification by the licensed professional of hydraulically-restrictive materials beneath the proposed facility and within the vertical separation requirements *(Section D-2.2.4)*.
- 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.

Examples of materials that may be interpreted as hydraulically-restrictive include:

- o Glacially consolidated soils that have greater than 50 percent fines
- o Glacially unconsolidated soils that have greater than 70 percent fines
- o Bedrock

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. The Simple Subsurface Investigation is conducted approximately 5 feet from the test hole.

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 and Vertical Separation Requirements

All BMPs			
Season	Minimum Investigation Depth (ft)[a]	Minimum Vertical Separation, ft[a]	
		Groundwater	Hydraulically-Restrictive Layer
Wet Season (November – March)	2	1	1
Dry Season (April – October)	3	2	1

Soil Characteristics

Type and texture of soil

[a] The minimum investigation depth and vertical separation shall be measured from the bottom of the facility. 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 and Vertical Separation Requirements

Season	Minimum Investigation Depth (ft)[a]	Minimum Vertical Separation (ft)[a]	
		Groundwater	Hydraulically-Restrictive Layer
Infiltration Basins			
Wet Season (November – March)	6	5	5
Dry Season (April – October)	7	6	5
All Other Infiltration BMPs			
Wet Season (November – March)	2	1	1
Dry Season (April – October)	4	3	1

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. If more than 2,000 sf of the site infiltration will occur within a single facility, the Standard Subsurface Investigation report shall be prepared by a licensed professional.

[a] The minimum investigation depth and vertical separation shall be measured from the bottom of the facility. 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.

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 prepared by a licensed professional.

Comprehensive Subsurface Investigation Elements

Minimum Investigation Depth and Vertical Separation Requirements

Season	Minimum Investigation Depth (ft)[a, b]	Minimum Vertical Separation (ft)[a]	
		Groundwater	Hydraulically-Restrictive Layer
Infiltration Basins			
Wet Season (November – March)	6	5	5
Dry Season (April – October)	10	8	5
Permeable Pavement Facilities			
Wet Season (November – March)	2	1	1
Dry Season (April – October)	4	3	1
All Other Infiltration BMPs			
Wet Season (November – March)	4	3	3
Dry Season (April – October)	10	8	3

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 minimum investigation depth and vertical separation shall be measured from the bottom of the facility. 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 prepared by a licensed professional.

Deep Infiltration Subsurface Investigation Elements
Minimum Investigation Depth 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)*

D-3. Infiltration Tests

D-3.1. Description

Step 4 in *Volume 3, Section 3.2*, is Conduct Infiltration Testing. This section provides procedures for the following infiltration testing methods:

- Simple Infiltration Test (Small-scale infiltration test)
- Small Pilot Infiltration Test (PIT)
- Large PIT
- Deep infiltration test

To determine which infiltration test method is required for a project, refer to Table 3.1 and Table 3.2 in *Volume 3*, *Section 3.2*.

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) and greater than 5,000 sf is infiltrated on the site, then acceptance testing is required (refer to *Volume 3, Section 3.2*).

If variable soil conditions are observed at the site, multiple infiltration tests are recommended in the different soil types.

After the measured 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 *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-3.2. Simple Infiltration Test

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

The Simple Infiltration Test does not require a licensed professional.

The Simple Infiltration Test is not allowed for projects with no off-site point of discharge (*Volume 3*, *Section 4.3.2.1*). These projects shall use a Small PIT.

Procedure

If testing is performed during the wet season (November through March), only one test is required. If the test is performed during the dry season (April through October), two tests must be performed in same hole within 2 days, with the beginning of each test spaced 24 hours apart.

1. Dig a hole a minimum of 2 feet deep. Preferably, the depth of the hole should be measured from the bottom of the facility but at a minimum shall be measured from the proposed site finished grade. The hole shall be at least 2 feet in diameter.
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. At the same time that you dig your test hole, check for high groundwater by using a post hole digger to excavate a hole to the minimum subsurface investigation depth, as provided in *Section D-2.3*, approximately 5 feet from the test hole. If standing water or seeping water is observed in the hole, measure the depth to the standing water or seepage.
4. Pre-soak period: Add 12 inches of water to the hole. This can be measured using a ruler, scale, or tape measure. Be careful to avoid splashing, which could erode the sides of the hole or disturb the soil at the base of the hole.
5. Record the depth of water in the hole in inches.
6. Record the time water was added to the hole.
7. Check and record the time and depth of water in the hole on an hourly basis for up to two hours. Estimate the infiltration rate in inches per hour by calculating the drop in water level in inches for each hour. Based on the lowest of these measurements, determine which time interval to use for the infiltration test by following these guidelines:

    - > 3 inch per hour fall, check at 15 minute intervals
    - 3 inch to 1 inch per hour fall, check at 30 minute intervals
    - < 1 inch per hour fall, check at hourly intervals

8. Infiltration Test: Fill the hole back up to a depth of 12 inches. Check and record the time and depth of water in the hole at regular intervals based on the time interval determined during the presoak period for a total of six measurements. If the hole empties prior to the six measurements, refill and continue recording until you have recorded six measurements.
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 measured infiltration rate in inches per hour by calculating the drop in water level in inches for each hour data was collected during the infiltration test. There should be a total of six values. The lowest calculated value is the measured infiltration rate in inches per hour
10. Mark test locations on site map.

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.

The Small PIT report shall be prepared 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. In the case of bioretention, excavate to the lowest estimated elevation at which the imported soil mix will contact the underlying soil. For permeable pavement, excavate to the elevation at which the imported subgrade materials, or the pavement itself, will contact the underlying soil. If the underlying soils (road subgrade) will be compacted, compact the 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 shall be a minimum of 12 square feet (sf). 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. 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 a depth of 12 inches above the bottom of the pit over a full hour.
    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. Within 24 hours after the falling head period, over-excavate the pit to determine if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The investigation depth varies depending on the type of subsurface investigation required (refer to Table 3.1 in *Volume 3*, *Section 3.2*) and the seasonal timing of the geotechnical exploration conducted to evaluate clearance. Minimum investigation depths are provided in *Section D-2*.

Data Analysis

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 calculated from the steady state data.

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

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

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 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 prepared 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.

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 in *Section D-3.3*.

D-3.5. Deep Infiltration Test

The design infiltration rate for deep infiltration shall be determined by performing a constant-rate infiltration test followed by a falling-head infiltration test. 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 prepared 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

4. Perform the test by adding water (obtained from a potable water source) to the test well to maintain a hydraulic head in the well equal to approximately half the thickness of the unsaturated infiltration receptor soil layer.
5. 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.
6. Monitor water levels in the test well with a pressure transducer and datalogger on a maximum of 5-minute intervals.
7. Add water until the rate of water added is constant, or for a minimum of 4 hours.
8. 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.
9. In addition to the required wells, monitor groundwater elevations in nearby monitoring wells as available.

Data Analysis

The test data shall be evaluated by a licensed hydrogeologist experienced in the analysis of well hydraulics and well testing data. As a result of the likely variability in soil conditions, specific methods for analysis of the data are not provided. It is the responsibility of the professional analyzing the data to select the appropriate methodology.

D-4. Infiltration Rate Correction Factor

Measured infiltration rates described in *Section D-3* shall be reduced using correction factors to determine 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 shall consider the results of both soil subsurface material conditions and in-situ infiltration 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, as recommended and documented by a licensed professional, 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

<u>Site variability and number of locations tested</u> **-** 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 following are examples of how site variability and number and locations of the tests may affect uncertainty:

- The subsurface conditions are known to be uniform based on previous exploration and site geological factors, one PIT may be adequate to justify that the uncertainty for that site is low.
- High variability may exist due to subsurface conditions (such as 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.
- 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 – This criterion represents the accuracy of the infiltration test method used. Larger scale tests are assumed to produce more reliable results (i.e., the Large PIT is more certain than the Small PIT).

Degree of influent control to prevent siltation and bio-buildup – 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 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 low uncertainty may be justified for this criterion.

D-5. Groundwater Monitoring

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 prepared 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 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 10 feet below the bottom of the proposed infiltration facility or if the initial groundwater measurement is more than 15 feet below the bottom 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 and Seepage Analysis

Infiltration 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).

The software program MODRET is considered a standard tool for evaluating infiltration facilities, and is recommended in Ecology's Stormwater Management Manual for Western Washington. Although 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.

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.

Licensed hydrogeologists with formal training and experience in developing groundwater flow models should conduct these analyses. It should also be noted that groundwater models do not provide specific answers, 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:

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

Many of the data inputs for the groundwater mounding model should be available in the vicinity of the infiltration facilities from the subsurface investigation and infiltration testing 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 the model do not influence the data 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.

Aquifer parameters shall be estimated based on knowledge of local soil types and from grain size distribution of the soil samples collected as part of the subsurface 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 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 a range of values to evaluate the potential impact on the mounding results. The range values shall be based on known variability in the parameter and experience with similar soils in the area by the licensed professional developing the model.

The following ranges of aquifer parameters shall 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 0.05 to 0.2

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 scenario is required:

- A typical wet season (November through April) based on average monthly precipitation followed by a single-event rainfall modeling of the back-loaded long-duration storm for the 100-year recurrence interval, using data from the closest rain gage.

The licensed hydrogeologist performing the mounding analysis should use professional judgment and experience to potentially modify the above scenario 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 re-evaluated. The re-evaluation should include simulation of the precipitation events prior to the observed groundwater monitoring data.