Green Stormwater Infrastructure **Geotechnical Guidelines**

Version 2.0 January 2021

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What's New

Effective Date: January 2021

Revisions History: Listed below are the major changes that occurred between the 2016 version of the GSI Geotechnical Guidelines and this most recent 2021 version.

- Improved organization of Part 1.0.
- Increased frequency of test borings to provide one test boring for every infiltration test.
- Specified factor of safety of two (2) for design rates for all infiltration testing methodologies.
- Clarified spacing between the infiltration test and representative test boring.
- Added requirement for descriptions of lithology to identify seams or pathways that could allow preferential lateral flow.
- Increased allowable field offset for test borings or infiltration tests from 10 to 20 feet before requiring PWD approval, provided they are within the proposed system footprint.
- Updated or clarified guidance to align testing methodologies with requirements for private development in Philadelphia Stormwater Management Guidance Manual.
- Updated presoak and rate measurement requirements for infiltration tests.
- Clarified test method procedures for borehole infiltration tests.
- Clarified laboratory testing requirements.

1.0 General Guidelines

These guidelines are a resource for designers and consultants performing geotechnical testing work for green stormwater infrastructure (GSI) projects for the Philadelphia Water Department (PWD). Typical testing includes drilling test borings and conducting infiltration testing within the footprint of each GSI system. The objectives of geotechnical testing include:

- Determine infiltration potential at proposed GSI system locations.
- Evaluate the lithology at depths sufficient to identify any hydraulically limiting layers that would inhibit vertical infiltration.
- Identify lithology that might encourage preferential lateral flow at depths that would compromise adjacent infrastructure.
- Identify seasonal high groundwater table and bedrock depth that may affect GSI system placement.

1.1 Overview

In general, the geotechnical investigation will consist of drilling one or more 20-foot deep continuously sampled borehole(s) within the footprint of each proposed GSI system in order to understand the subsurface lithology. Lithological and blow count data will be collected before conducting the infiltration testing. This data can be used to refine the design of the infiltration tests and target testing of layers with greater permeability, as well as evaluate potential limiting layers within depths consistent with the conceptual design for the system. Below are examples of how the testing data can be utilized:

- A borehole may show a thin hydraulically restrictive layer immediately below the bottom of a proposed system. If more permeable material is observed below that restrictive layer, designs could call for removal of the restrictive layer through over-excavation and backfill, allowing the proposed system to connect to the more permeable layers found during testing.
- Designs could incorporate infiltration column SMPs to promote infiltration into the more permeable subgrades.
- Restrictive layers and seams or pathways that would encourage preferential lateral flow may also be identified, informing appropriate design to mitigate against unwanted lateral infiltration to adjacent structures.

Qualified field personnel (Professional Engineer, Professional Geologist or their representative) will be present to evaluate the lithological and blow count data. If a limiting layer is detected and a higher permeability layer is also detected, the field personnel will notify the corresponding project manager to determine if a change in the original infiltration testing depth is warranted. Additional mobilizations should be avoided in order to keep fieldwork cost-effective and to minimize disruption to the community where the work is being performed.

1.2 Number of Tests

Geotechnical investigative testing will be conducted within the footprint of each GSI system.

- A minimum of one (1) infiltration test and one (1) test boring will be completed within the footprint of each proposed system, with one (1) test boring generally being conducted for every infiltration test.
- Due to the variability in subsurface lithology, particularly in an urban environment, more than one infiltration test and test boring will be conducted for larger systems.

- A detailed layout of proposed boring locations and infiltration testing sites will be submitted to the PWD and approved prior to any field activities.
- Borings and infiltration test locations will be grouped in proximity, such that the boring is representative of the infiltration test location. Infiltration tests will not be located within five (5) feet of the test boring, with borings backfilled prior to infiltration testing. Test borings should not be more than ten (10) feet from the infiltration test whenever possible, in order to be considered representative.
- The specified locations may be shifted in the field up to 20 feet within the proposed system footprint to avoid marked utilities or other obstructions such as parked cars or dumpsters.
- Any adjustments greater than 20 feet require the approval from the PWD and will be located within the limits of the utility mark-outs.
- Changes to test locations will be submitted in the final location map.

1.3 Pre-Testing Clearance

Prior to conducting any geotechnical borings, all boring and testing locations will be cleared for subsurface utilities by the contractor. In addition, all applicable permits and approvals will be obtained, and community notifications will be completed (as discussed further below). Photographs will be taken of the pre-drilling conditions at each proposed borehole location. Photographs will show site context so the locations can be discerned from the photographs. Where PECO overhead wires are located above proposed testing locations, consultants will coordinate with PECO (1-800-454-4100) to have “blanket shielding” installed. This protection will remain in place through design and construction.

1.4 Pre-Testing Public Notification

In advance of geotechnical testing, consultants will notify residents in the adjacent areas. Approximately one week prior to drilling, the *Survey Work & Soil Testing* flyer or door hanger provided by PWD will be distributed to all households and businesses on the block where testing will occur. At the same time, consultants will send notification to PWD Public Affairs that testing will commence the following week.

1.5 Report Requirements

Results from geotechnical investigations will be documented in a geotechnical report, stamped and signed by a Pennsylvania State Licensed Professional Engineer or Professional Geologist, and submitted to PWD. The geotechnical report will include, but is not necessarily limited to, the following:

1. Project and site description
    a. Topographic and hydrogeological setting
    b. Relevant site information (water bodies, nearby structures, etc.)
2. Method of Investigation
    a. Boring method and diameter
    b. Drilling method and equipment
    c. Infiltration testing method (borehole, double ring infiltrometer, well permeameter)
    d. Samples collected for laboratory testing
3. Weather Information at time of testing and during previous 24 hours, including temperature and rainfall data.
4. Results (Test boring logs and infiltration test results); summary table that includes:
    a. Test ID
    b. Test date
    c. Test type (in conformance with types in *GreenIT Design Report Definitions*)
    d. Test depth (ft)

   e. Infiltration rate (if relevant)
   f. Percolation rate (if relevant)
   g. Depth to bedrock (if encountered)
   h. Depth to groundwater (if encountered)
   i. Soil description summary
5. Conclusions, including interpretation of testing results
6. Attachments
   a. Final location map showing as-drilled boring and infiltration testing locations
   b. Boring logs including:
      I. Blow counts
      II. Lithology – description of each individual split spoon sample in accordance with ASTM D2487-17 and D2488-17 and a brief verbal description with a particular focus on observed lensing or bedding
      III. Depth to groundwater
      IV. Depth to bedrock
      V. Percent passing 200 sieve for all laboratory grain size analysis results
      VI. Hydraulic conductivity where calculated based upon laboratory grain size analysis results for drainage wells (see item e. below)
   c. Infiltration test results, including:
      I. All time and volume measurements
      II. Infiltration rate calculations
   d. Well permeameter test construction diagram (4-inch PVC), complete with all relevant dimensions (for drainage well and infiltration column tests only)
   e. Laboratory results - Grain size analyses and calculation of hydraulic conductivity (for sandy sediments where d_{10} is between 0.1 and 3.0 mm) using the equation:

      $$K = C \times (d_{10})^2$$

      Where:

      C = Hazens Empirical Coefficient (1.0 to 1.5)

      d_{10} = effective grain size, or the diameter of the 10^{th} percentile grain size of the material

   f. Photographic logs, including photographs of lithological profiles from test pits (if applicable) as well as photographs of pre- and post- testing conditions. Photographs of locations will show site context, so the location of testing locations can be discerned from the photographs.

2.0 Auger Boring Guidelines

For each system, a minimum of one (1) boring will be conducted for every infiltration test. Additional borings are required for larger systems and will be conducted every 50 feet the proposed GSI extends in any direction. Borings will be advanced to a depth of up to 20 feet or until bedrock is reached. If the proposed bottom of the infiltrating practice is deeper than 10 feet from the surface, the boring depth should extend to 10 feet below the bottom of the system. If bedrock is encountered prior to reaching the proposed termination depth, the boring should be terminated.

The purpose of the boring is to define the subsurface lithology, especially the presence of shallow clay units, and determine the depth to the water table and/or the depth to bedrock (if either is within 20 feet of the surface). Some projects may require that the water table and/or bedrock be reached and therefore borings may extend beyond 20 feet.

Lithological samples will be collected continuously to depth. A standard penetration test (SPT) will be conducted and each split spoon sample collected following ASTM Method D1586-18: "Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils". Borings are required even if a system is proposed to be fully lined.

For drainage wells and infiltration columns, split spoon samples will be taken continuously throughout the depth of the borehole, or until bedrock is reached. Split spoon samples will be collected at least five (5) feet beyond the water table depth or until bedrock is reached. It is possible that the borings will exceed 20 feet for these projects. Qualified field personnel (Professional Engineer, Professional Geologist, or their representative) will be present to evaluate the lithological and blow count data.

Special attention will be paid to any indications of the following:

- Materials unsuitable for infiltration such as coal ash, slag, miscellaneous fill that contains brick or debris, or loose granular soils (N value < 5)
- Restrictive layers and seams or pathways that would encourage lateral flow, such as seams of granular soils in native soils, horizontal bedding of micaceous sands, sharp changes in stratigraphy, or dense soils
- Presence of groundwater or indications of seasonally high groundwater evidenced by descriptions of oxidation and mottling
- Spoon and/or auger refusal

General testing procedures are highlighted below. All specified ASTM standards should be referenced for additional detail.

Testing Procedure

1. Perform test borings using the Hollow Stem Auger method (ASTM D6151-15) and as follows: Use a machine-driven, continuous flight, helical, hollow-stem auger, with an inside diameter not less than four (4) inches. Use truck-mounted equipment unless otherwise directed by the Engineer.

2. Take split spoon samples in accordance with ASTM D1586-18 and the following:

   a. Use a split spoon sampler with inside diameter not less than 1-3/8 inches.
   b. Drive sampler into undisturbed material below bottom of auger to secure sample.
   c. Drive sampler with 140-pound hammer dropping 30 inches and record the number of blows required to drive the sampler in six (6)-inch increments.
   d. Take samples continuously throughout the borehole depth, five (5) feet beyond the water table or until bedrock is encountered, to a maximum of 20 feet.
   e. Lithological descriptions including, but not necessarily limited to, the following:
      - Lithology using ASTM D2488-17 classification and brief verbal description
      - Texture and thickness (include indication of any fill materials such as brick, etc.)
      - Composition of larger-grained sediments
      - Color (including mottles, etc.)
      - Structure (if possible)

- Degree of consolidation and cementation
- Moisture content
- Evidence of bioturbation
- Description of contacts
- Evidence of soil structure or gradation that may influence lateral flow, such as granular lenses, horizontal layering or bedding, etc.

f. Samples collected within the split spoon immediately below the infiltration test depth should be sent to a geotechnical laboratory for grain size analysis. The testing should be conducted to determine the percent passing the No. 200 sieve (i.e., to determine sand vs silt/clay content) following ASTM D422-63 (2007). No hydrometer testing is required. The number of tests will be a function of the lithology within the two (2)-foot split spoon, but at least one (1) test will be conducted. Additional tests will be based on a clear change in lithology within the profile (coarse sand to fine sand or silt, for example).

3. Record the depth at which groundwater is first encountered, if encountered within the first 20 feet (or beyond, if it is a project requirement). Also, measure and record the depth to groundwater at the completion of boring.

4. Upon completion of the borehole and all relevant logs, the borehole will be backfilled with the cuttings and plugged to the surface with a concrete or asphalt patch for paved surfaces. In unpaved areas covered with grass, hay and grass seed should be applied. Borings will be backfilled prior to infiltration testing.

5. Photographs will be taken of the post-drilling conditions at each borehole location. Photos will show site context so that the location of the borehole can be discerned from the photograph.

3.0 Infiltration Testing

Infiltration testing will be conducted during the design phase as well as during construction. Five (5) types of infiltration testing are outlined:

1. Double Ring Infiltrometer
2. Modified Borehole Percolation Test
3. Borehole Infiltration Test (Bentonite Casing)
4. Borehole Infiltration Test (Direct Push Casing)
5. Drainage Well/Infiltration Column Permeability Test

Multiple testing methods are presented within these guidelines. The preferred method for infiltration testing is the double ring infiltrometer test. These tests are primarily used for unpaved and open excavation areas where surface disturbance is not problematic. Double ring infiltrometer testing will also be utilized during the construction phase (following excavation) and results compared with those obtained during pre-construction. In areas of existing sidewalk or pavement, or populated areas where surface disturbance should be minimized during pre-construction activities, a borehole infiltration test may be performed. Borehole infiltration methods may also be preferred during winter months when freezing temperatures could preclude exposed double ring testing, but below grade borehole testing is still feasible. They may also be preferred when testing deeper than five (5) necessitates a benched or braced excavation and there is insufficient space to excavate safely. The selection of a cased vs. uncased borehole will be made based on whether lateral infiltration from the system is considered acceptable based on proximity to structures. The infiltration testing method for drainage wells and infiltration columns is also described. For those projects, a slotted PVC casing (well screen) is used to evaluate lateral infiltration through the well screen. Infiltration testing is not required if a system is proposed to be fully lined.

As mentioned in Part 1.0, more than one (1) infiltration test should be conducted for larger systems and should be conducted every 50 feet the proposed GSI extends in any direction. Infiltration test rates are averaged using the geometric mean if there is more than one test per GSI system. To determine the design infiltration rate, a factor of safety of two (2) must be applied to the field rate, reduced rate, or geometric means (as applicable per testing program).

3.1 Double Ring Infiltrometer Testing Guidelines

A double ring infiltrometer consists of two (2) concentric metal rings. The outer ring serves to mitigate divergent flow while the water level drop in the inner ring is used to calculate the infiltration rate. This test requires excavating an area large enough to accommodate the double ring apparatus (test pit), to the depth of the proposed system bottom. Test pits should also be constructed so that they are benched for access and should not be accessed if soil conditions are unstable. All relevant OSHA regulations must be adhered to and utility mark-outs must be conducted prior to any excavation.

Since test pits extend several feet in the horizontal and vertical directions, they allow for a more representative analysis of shallow subsurface lithology than a geotechnical boring. The lithology within the test pit will be logged using ASTM D2488-17 in a similar fashion as the borings (Section 2). Lithological descriptions will be in accordance with ASTM D2488-17 and should include, but are not necessarily limited to, the following:

- Lithology using ASTM D2488-17 and brief verbal description
- Texture and thickness of strata (include indication of any fill materials such as brick, etc.)
- Composition of larger-grained sediments
- Color (including mottles, etc.)
- Structure
- Degree of consolidation and cementation
- Moisture content
- Evidence of bioturbation
- Description of contacts
- Evidence of soil structure or gradation that may influence lateral flow, such as granular lenses, horizontal layering or bedding, etc.

An approximate strike and dip of hydraulically limiting layers should be obtained if possible. Provide photographic documentation of the lithological section (include scale) and include with the geotechnical report. Following the infiltration test, at least one (1) sample will be collected immediately below the test pit (using a hand auger, for example) and sent to a geotechnical laboratory for grain size analysis to determine the percent passing a No. 200 sieve (no hydrometer) following ASTM D422-63 (2007). The number of tests will be a function of the lithology, but at least one (1) test will be conducted. Additional tests will be based on a clear change in lithology (coarse sand to fine sand or silt, for example). For pre-design investigations, upon completion of the test (and sample collection), the pit shall be over-excavated to a depth four (4) feet below the depth of the test to evaluate lithology at greater depth.

Testing Procedure

The double ring infiltrometer test will be conducted based on a slightly modified version of ASTM D3385-18 as described below. The ASTM standard should be referenced for complete details, although the method below is the alternative that should be followed.

1. All technical precautions will be applied where appropriate to minimize interference of the test from the public or potential vandals. Precautions to account for evaporation, direct sunlight and significant temperature variations will also be considered.

2. The diameter of the inner ring will be approximately 50% of the diameter of the outer ring, with a minimum inner ring diameter of six (6) inches. After preparing a level testing area, the outer ring of the infiltrometer will be placed and driven into the soil to a depth of six (6) inches, or at least two (2) inches deeper than the inner ring, using a flat board (or drive cap) across the top of the ring. The inner ring will then be placed in the center of the outer ring and driven into the ground in the same manner to a depth of two (2) to four (4) inches.

3. If soil along the inner ring is excessively disturbed, reset the ring. If the soil along the inside of either ring is slightly disturbed, tamp the soil lightly until soil is as firm as it was prior to disturbance.

4. A constant head will be maintained within the inner ring and the annular space between the two rings, as described below. Manually controlling the flow is sufficient; however, the testing professional can consult the ASTM standard for additional methods. If manually controlling the level, depth gages will be installed such that the reference head is between one (1) and six (6) inches. Place the depth gages toward the center of the inner ring and midway between the inner and outer rings.

5. Appropriate measures will be taken to avoid scouring and/or siltation of the native sediment. Install a one (1)-inch layer of clean-washed coarse sand or fine gravel, use splash guards.

6. The test area will be presoaked for one (1) hour immediately prior to testing. Fill both rings with water to water level indicator mark. The water depth will be 6 to 12 inches. Refill to the water level indictor mark after 30 minutes or when entire depth infiltrates. Record the drop in water level over the second 30-minute interval of the presoak. The drop in the water level during the last 30 minutes of the presoaking period will be applied to the following standard to determine the time interval between readings:

   a. If water level drop is two (2) inches or greater, use 10-minute measurement intervals.
   b. If water level drop is less than two (2) inches, use 30-minute measurement intervals.

7. Refill to the water level indictor mark and begin testing. Obtain a reading of the drop in water level in the center ring at appropriate time intervals based on drop observed during the presoak. After each reading, refill both rings to the water level indicator mark. Measurement to the water level in the center ring will be made from a fixed reference point and will continue at the interval determined until a minimum of eight (8) readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop is a difference of 0.25 inch or less of drop between the highest and lowest readings of four (4) consecutive readings. The drop that that occurs in the center ring during the final period or the average stabilized rate over the last hour of testing, expressed as inches per hour, represents the infiltration rate for that test location.

8. Upon conclusion of the test, remove the equipment from the test pit and over-excavate the test pit to a depth four (4) feet below the depth of the infiltration test. Note any observed stratigraphic contacts at depth. Depending on the dimensions of the original pit, the over-excavation may make entry to the pit unsafe, and observations may need to be made from the surface. As an alternative to extending the excavation, a hand auger boring may be performed to characterize the four (4) feet below the infiltration depth.
9. Once all testing and inspection is completed, backfill the excavation. Straw and grass seed will be placed on open areas. If paving was disturbed, new pavement may be required, depending on the project site.

3.2 Borehole Infiltration Testing Guidelines

In paved areas or other areas where surface disturbance during testing should be minimized, double ring infiltrometer testing may not be feasible and borehole infiltration testing will be required. There are a number of methods that can be utilized to collect borehole infiltration data, three of which are highlighted here:

1. Modified Borehole Percolation Test – Pennsylvania Stormwater BMP Manual
2. Borehole Infiltration Test (Bentonite Casing Method) – Standard Test Method for Field Measurement of Hydraulic Conductivity Using Borehole Infiltration (ASTM D6391-20), referenced below as the “ASTM Method”
3. Borehole Infiltration Test (Direct Push Casing Approach) – Maryland Stormwater Manual (2009)

The appropriate method will be determined based on project requirements and conditions. For projects in relatively open areas that are not adjacent to buildings, sewers, or other structures, and partial lining of the trench is not anticipated, the modified percolation test may be appropriate. In areas where buildings or sensitive infrastructure are within 10 feet of the GSI and protection of those structures may be required by impermeable liner, either the bentonite casing or the direct push casing method will be utilized.

ASTM Standard D6391-20 notes that a borehole must be drilled and the annulus between the casing and the borehole sealed with bentonite. However, the bentonite requires time for hydration before the infiltration test can begin. If hydration time is an issue and if the borehole data indicate limited obstructions in the fill layer (if present), the direct push casing method can be applied as described below.

3.2.1 Modified Borehole Percolation Test (PA Stormwater BMP Manual)

The infiltration test method is presented in detail in the Pennsylvania Stormwater BMP Manual and should be referenced for additional information. Conduct infiltration testing at the depth specified by PWD project manager, or as modified by the team based on the field conditions and limiting layers encountered in the test borings, as discussed above.

Testing Procedure

The following procedure is derived from ASTM Standard 6391-20 and the Pennsylvania Department of Environmental Protection (PADEP) criteria for on-site sewage investigation of soils as specified in Chapter 73 of the Pennsylvania Code:

1. Boreholes for percolation testing will be 6 to 10 inches in diameter. The bottom and sides of each hole will be scarified to remove any smeared surfaces and two (2) inches of clean-washed coarse sand or fine gravel will be placed in the bottom of the hole to prevent scour.

2. Test holes will be presoaked immediately prior to testing with the intent of simulating saturated conditions and minimizing unsaturated flow. Water will be placed in the hole to a depth of 6 to 12 inches and readjusted every 30 minutes for an hour. The drop in the water level during the last 30 minutes of the presoaking period will be applied to the following standard to determine the time interval between readings:

    a. If water level drop is two (2) inches or greater, use 10-minute measurement intervals.
    b. If water level drop is less than two (2) inches, use 30-minute measurement intervals.

3. After the final presoaking period, the water level will be measured over time as a falling head test. Initial water level will be approximately 12 inches above the bottom of the borehole and readjusted as necessary. If initial measurements indicate a high infiltration rate, then the casing can be filled so that the water is up to 18 inches from the bottom of the hole, as appropriate. All additions of water (volume) will be recorded.

4. Measurement of water level in the percolation holes will be made from a fixed reference point and will continue at the interval determined until a minimum of eight (8) readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop is a difference of 0.25 inch or less of drop between the highest and lowest readings of four (4) consecutive readings.

5. Upon completion of the test, remove the casing and backfill the borehole with cuttings. For paved areas, plug the hole with a bentonite plug and seal the surface with concrete or asphalt. For open areas, lay grass seed onto the surface.

6. The drop that occurs in the percolation hole during the final testing interval, expressed in inches per hour, will represent the percolation rate for that test location. The percolation rate must be reduced according to the formula provided in the Pennsylvania Best Management Practices Manual Appendix C–Site Evaluation and Soil Testing, Protocol 1.

3.2.2 Borehole Infiltration Test (Bentonite Casing Method)

The following procedure is modified from ASTM Standard D6391-20. This description serves as a summary only and the ASTM Standard should be reviewed for further detail and clarification.

Testing Procedure

1. Advance a borehole to the depth of the proposed system bottom using hollow stem auger methods. Drilling mud should not be utilized. Boreholes for infiltration testing will have a diameter at least two (2) inches larger than the outside diameter of the casing.

2. Casing will be a minimum four (4)-inch Schedule 40 PVC. The bottom of the casing must be smooth and square.

3. Casing will be lowered into the borehole and firmly set into the bottom of the borehole. The borehole bottom will be scarified to remove any smeared surfaces. Measure the depth from the top of casing to the bottom of the hole to the nearest 0.01 ft.

4. Two (2) inches of clean-washed coarse sand or fine gravel will be placed in the bottom of the hole to prevent scour during filling of the casing. The sand or gravel will be uniformly placed so

that is of equal thickness throughout the hole. Re-measure the depth from the top of casing to the sand or gravel surface to the nearest 0.01 ft.

5. The annular space between the casing and borehole will be sealed with sodium bentonite, in layers. The bottom layer will consist of a bentonite paste, having a thickness of one (1) to two (2) inches. This will be tamped in place using a wooden dowel or equivalent. The remainder of the annulus will be filled with powdered or granular sodium bentonite in layers no more than two (2) inches thick. Bentonite chips or pellets may also be used. Each layer will be moistened with water and tamped with a wooden dowel. If granules are used, the granular diameter will be less than one fifth of the annular spacing. Bentonite can be either poured from grade or installed using a tremie pipe. Do not add water such that the bentonite becomes a thin slurry. Only add enough water for hydration.

6. Allow the bentonite to hydrate for a period of at least two (2) hours. Install a cap or cover over the top of the casing and borehole to prevent desiccation and prevent rainfall from entering the hole. Block off the area as appropriate. The seal will be checked prior to testing to ensure that it has set.

7. Test holes will be presoaked immediately prior to testing with the intent of simulating saturated conditions and minimizing unsaturated flow. Fill the casing with water at a very low rate so as not to disturb the bottom sediments. Water will be placed in the hole to a depth of at least 6 to 12 inches above the bottom and readjusted every 30 minutes for an hour. Alternatively, a constant head can be applied in which water level is maintained in a graduated container at the ground surface. The drop in the water level during the last 30 minutes of the presoaking period will be applied to the following standard to determine the time interval between readings:

    a. If water level drop is two (2) inches or greater, use 10-minute measurement intervals.
    b. If water level drop is less than two (2) inches, use 30-minute measurement intervals.

8. After the final presoaking period, the water level will be measured over time as a falling head test. Initial water level will be approximately 12 inches above the bottom of the borehole and readjusted as necessary. If initial measurements indicate a high infiltration rate, then the casing can be filled so that the water is up to 18 inches from the bottom of the hole, as appropriate. All additions of water (volume) will be recorded.

9. Measurement of water level in the casing will be made from the top of the casing and will continue at the interval determined until a minimum of eight (8) readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop is a difference of 0.25 inch or less of drop between the highest and lowest readings of four (4) consecutive readings.

10. Upon completion of the test, remove the casing and backfill the borehole with cuttings. For paved areas, plug the hole with a bentonite plug and seal the surface with concrete or asphalt. For open areas, lay grass seed onto the surface.

11. Report the rate measured during the final period or the average stabilized rate over the last hour of testing, expressed in inches per hour, as the field infiltration rate for the test location.

3.2.3 Borehole Infiltration Test (Direct Push Cased Approach)

An alternative approach to utilizing the ASTM standard is a method involving hydraulically driving casing through an augered borehole. The method is similar to the approach outlined in the Maryland Stormwater Manual (2009).

Testing Procedure

1. Advance a borehole to the depth of the proposed system bottom using hollow stem auger methods. Drilling mud should not be utilized. Boreholes for infiltration testing should have a diameter at least two (2) inches larger than the outside diameter of the casing.

2. Lower a minimum four (4)-inch schedule 40 PVC casing through the borehole and push the casing 12 inches through the bottom of the borehole.

3. Clear out the sediments within the casing using a hand auger.

4. Once the sediment within the casing has been removed, measure the depth to the bottom of the hole from the top of the casing. The depth will correspond with the planned depth of the system.

5. Two (2) inches of clean-washed coarse sand or fine gravel will be placed in the bottom of the hole to prevent scour during filling of the casing with water. Sand or gravel will be uniformly placed so that is of equal thickness throughout the hole. Measure the depth from the top of casing to the sand or gravel surface to the nearest 0.01 ft.

6. Test holes will be presoaked immediately prior to testing with the intent of simulating saturated conditions and minimizing unsaturated flow. Fill the casing with water at a very low rate so as not to disturb the bottom sediments. Water will be placed in the hole to a depth of 6 to 12 inches from the bottom of the hole and readjusted every 30 minutes for an hour. The drop in the water level during the last 30 minutes of the presoaking period will be applied to the following standard to determine the time interval between readings:

    a. If water level drop is two (2) inches or more, use 10-minute measurement intervals.
    b. If water level drop is less than two (2) inches, use 30-minute measurement intervals.

7. After the final presoaking period, the water level will be measured over time as a falling head test. Initial water level will be approximately 12 inches above the bottom of the borehole and readjusted as necessary. If initial measurements indicate a high infiltration rate, then the casing can be filled so that the water is up to 18 inches from the bottom of the hole, as appropriate. All additions of water (volume) will be recorded.

8. Measurement of water level in the casing will be made from the top of casing and will continue at the interval determined until a minimum of eight (8) readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop is a difference of 0.25 inch or less of drop between the highest and lowest readings of four (4) consecutive readings.

9. Upon completion of the test, remove the casing and backfill the borehole with cuttings. For paved areas, plug the hole with a bentonite plug and seal the surface with concrete or asphalt. For open areas, lay grass seed onto the surface.

10. Report the rate measured during the final period or the average stabilized rate over the last hour of testing, expressed in inches per hour, as the field infiltration rate for the test location.

3.3 Drainage Well/Infiltration Column Permeability Testing Guidelines

For projects that include drainage well or infiltration column SMPs, deeper investigations of the depth of the water table and/or bedrock are required. Four (4)-inch PVC slotted well screen will be installed to the same depth as the proposed drainage well and an infiltration test conducted. A full set of data (borings, infiltration rates) will be collected for each drainage well location. Ideally, the geotechnical borings will provide information on the water table depth and the depth to bedrock. If the water table is within the bedrock, completing the boring to the surface of the bedrock is permitted. As drainage wells will be located in the street, all necessary safety precautions must be taken and all relevant permits obtained.

The test involves installing a PVC well screen and performing an infiltration test. The testing procedure is modified from the United States Bureau of Reclamation (USBR) Procedure 7300, *Performing Field Permeability Testing by the Well Permeameter Method*.

Prior to testing, lithological samples will be collected continuously to depth. Standard penetration tests (SPT) will be conducted and each split spoon sample collected following ASTM Method D1586-18: “Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils”. Split spoon sampling, logging, and photo documentation will be in accordance with Section 2.0. At least one (1) sediment sample representative of the soil infiltration depth will be sent to a geotechnical laboratory for grain size analysis. The testing should be conducted using a full set sieve analysis (down to No. 200 sieve) following ASTM D422-63 (2007). The number of tests will be a function of the lithology, but at least one (1) test will be conducted. Additional tests will be based on a clear change in lithology (coarse sand to fine sand or silt, for example).

Testing Procedure

1. Advance a borehole to the depth of the proposed system bottom using hollow stem auger methods. Boreholes for infiltration testing will have a diameter at least two (2) inches larger than the outside diameter of the casing. The lithology sequence of the borehole will be logged by continuously collecting split spoon samples (as described above).

2. Install a PVC well cap on one end of a four (4)-inch inside diameter Schedule 40 PVC well screen and lower into the borehole. The cap will be securely attached, making a positive seal. Sections of well screen will be added corresponding to the proposed length of perforated pipe of the planned drainage well or infiltration column. A three (3)-foot section of solid PVC casing will be connected to the slotted well screen section and extended to the surface, depending on the proposed design. If fill containing coal slag, ash and/or extensive debris (brick, concrete, glass, etc.) is encountered, the solid casing will extend through that layer to a depth of at least three (3) feet below. Infiltration in these deposits is prohibited.

3. PVC well screen will be new and flush threaded as per ASTM standards (ASTM F480-14). The slot size of the well screen will be 0.060 inches (60 slot). The annulus between the well screen and the borehole will be filled with gravel pack, U.S. Silica FilPro #4 or equivalent.

4. Infiltration testing will be conducted by measuring the flow rate that is needed to maintain a constant head in the well. Use of a reservoir and float valves as described in USBR 7300 is suitable, but not required. Variations to the reservoir set up and the maintenance of the constant head are permitted as long as measurement of flow can be accurately made. Constant head will be maintained at least one (1) foot above the slotted screen interval, but at least one (1) foot below fill containing slag, ash, or debris. Once the water level has stabilized, record the volume loss from the constant head reservoir over time. Specific increments are not provided in the USBR 7300 procedure, but regular increments should be used, at least every 15 minutes. As per USBR 7300, the test should be continued for at least four (4) hours without letting the reservoir completely empty.

5. Upon completion of the infiltration test and all relevant logs, the well screen should be removed (if possible) and the hole backfilled with the cuttings. The surface will be restored using a concrete or asphalt patch. If the PVC materials cannot be retrieved, the casing extension should be removed or should be cut to at least 6 inches below the surface. The screen will then be backfilled with cuttings and the surface restored.

6. The permeability coefficient will be computed as follows:
   a. If the depth to the water table or impervious layer is greater than three (3) times the depth of the water in the test well:

$$k_{20} = \frac{qV}{2\pi h^2}\left\{ln\left[\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1}\right] - \frac{\sqrt{1 + \left(\frac{h}{r}\right)^2}}{\frac{h}{r}} + \frac{\frac{1}{h}}{r}\right\}$$

   b. If the depth to the groundwater table or impermeable unit is less than three (3) times the depth of water in the well,

$$k_{20} = \frac{qV}{2\pi h^2}\left[\frac{ln\left(\frac{h}{r}\right)}{\frac{1}{6} + \frac{1}{3}\left(\frac{h}{T_u}\right)^{-1}}\right]$$

   Where:

   k_{20} = coefficient of permeability at 20 deg C
   h = height of water in the well
   r = radius of the well
   q = discharge rate of water from the well for steady-state constant head condition (determined from the straight line of a graph of total volume vs. time (see Figure 7 in USBR 7300).

$$V = \left(\frac{\mu T}{\mu 20}\right)$$

   Where:

   μ20 = viscosity of water at 20 deg C
   μT =viscosity of water at temp T
   T_u = unsaturated distance between the water surface in the well and the water table

7. In addition to the permeability coefficient, an alternative infiltration rate will be calculated using the discharge rate of water from the well for steady-state constant head condition divided by

the open area of the well screen. This rate will be converted to inches per hour and reported along with the coefficient of permeability calculated using the USBR Procedure 7300 method.

4.0 References

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