Appendix A

Infiltration and Soil Texture Testing Methods

Infiltration and Soil Texture Testing Methods

A.1 General Description

Sites can be defined as unsuitable for infiltration SCMs and soil-based SCMs due to natural or built site limitations (see Chapter 3). However, if suitable areas exist, these areas must be identified early in the Stormwater Management Concept Plan phase (see Chapter 2) and utilized to the greatest extent practicable.

This soil testing protocol describes the necessary field testing procedures to:

- Understand and evaluate site soil conditions: soil compaction (soil porosity) and missing soil components (including microorganisms and organic matter) needed to reestablish the soil's long-term capacity for infiltration, storage, and pollutant removal;
- Obtain the required data for infiltration SCM design; and
- Help determine which SCMs are suitable at a site and at what locations.

Qualified professionals who can substantiate by qualifications/experience their ability to carry out the evaluation (such as soil scientists, agronomists, civil engineers with appropriate experience, geotechnical engineers, and trained technicians) should evaluate the soil test pits and soil samples. A professional experienced in observing and evaluating soil conditions is necessary to ascertain conditions that might affect SCM performance (e.g., clay layers, groundwater movement, etc.).

As with all field work and testing, attention should be given to all applicable Occupational Safety and Health Administration (OSHA) regulations and local guidelines related to earthwork and excavation. Digging and excavation should never be conducted without adequate notification through the Tennessee One Call system (phone 811). Excavations should never be left unsecured or unmarked, and all applicable authorities should be notified prior to any work.

Detailed soil testing for compaction and soil fertility is described in Section III, after infiltration testing.

A.2 Infiltration Testing: A Four-Step Process

Infiltration testing is a four-step process to obtain the necessary data for the design of the Stormwater Management Plan. The four steps include:

1. Desktop analysis – conducted prior to Stormwater Management Concept Plan Submittal
    - Based on available published site-specific data
    - Includes consideration of proposed development plan
    - Used to identify potential SCM locations and testing locations
    - Prior to field work, onsite screening test may be conducted (visual observation of site conditions)

2. Test pit observation or soil boring
    - Includes multiple testing locations
    - Provides an understanding of subsurface conditions
    - Identifies limiting conditions

3. Infiltration testing
    - Must be conducted onsite
    - Different testing methods available
    - Alternate methods for additional screening and verification testing

4. Consideration of infiltration rate in design and modeling application
    - Determination of a suitable infiltration rate for design calculations
    - Consideration of SCM drawdown
    - Consideration of peak rate attenuation

Step 1. Desktop Analysis

Step 1, Desktop Analysis, should be conducted early in the Stormwater Management Concept Plan phase of the project (and prior to concept stormwater management plan submission to the local stormwater program). Information developed in the desktop analysis will focus on information gathering during site visits and inform the Concept Stormwater Management Plan. Following the Desktop Analysis, the design team should have a preliminary understanding of potential SCM locations prior to detailed soil testing. The design team should conduct detailed testing as early as possible during the Preliminary Stormwater Management Plan phase. If indicated by the testing results, adjustments to the design should be made. The designer may need to adjust the site layout and grading to incorporate the results of detailed soil testing and to achieve necessary infiltration results.

Prior to performing testing and developing a detailed site plan, existing conditions at the site should be inventoried and mapped including, but not limited to:

- Existing mapped individual soils and USDA hydrologic soil group classifications, which can be found on USDA Web Soil Survey website (websoilsurvey.sc.egov.usda.gov);
- Existing geology, including the locations of any dikes, faults, fracture traces, solution cavities, landslide prone strata, or other features of note;
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains, alluvial soils, stream classifications, headwaters, and first-order streams;
- Existing topography, slope, and drainage patterns;
- Existing and previous land uses; and
- Other natural or manmade features or conditions that may impact design, such as past uses of site, existing nearby structures (buildings, walls), etc.

A Concept Site Layout Plan for development should be evaluated, including:

- The concept grading plan and areas of cut and fill;
- The locations of other features of note such as utility rights-of-way, water and sewer lines, etc.;
- Existing data such as structural borings, drillings, and geophysical testing; and
- The proposed locations of development features (buildings, roads, utilities, walls, etc.).

In step 1, the designer should determine the potential locations of infiltration SCMs. The approximate locations of these SCMs should be indicated on the proposed development plan and should serve as the basis for the location and number of tests to be performed onsite following Concept Stormwater Management Plan approval, where applicable.

Note: If the proposed development plan is located in areas that may otherwise be suitable for SCM location, or if the proposed grading plan is such that potential SCM locations are eliminated, the designer is strongly encouraged to revisit the proposed layout and grading plan and adjust the development plan as necessary. Full build-out of areas suitable for infiltration SCMs should not preclude the use of SCMs for runoff reduction.

Step 2. Test Pits

A test pit allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. A large number of test pit observations can be made across a site at a relatively low cost and in a short time period. The use of soil borings as a substitute for test pits may be necessary in areas where existing pavement or structure precludes a test pit excavation. Visual observation is narrowly limited in a soil boring and the soil horizons cannot be observed in-situ, but must be observed from the extracted borings. Borings and other procedures, however, may be substituted for test pits if necessary because of site constraints.

A test pit typically consists of a backhoe-excavated trench, 2½ to 3 feet wide, to a depth of between 72 inches and 90 inches, or until bedrock or fully saturated conditions are encountered. The trench should be benched at a depth of 2 to 3 feet for access and/or infiltration testing.

The recommended number of test pits or standard soil borings for a site is based on existing soil data availability and proposed infiltration SCM location, and has been listed below.

1. Sites where NRCS soil data is available:
   a. utilize NRCS soil data testing for site-wide design purposes;
   b. and soil testing on a twenty-five feet master-grid for locations of proposed infiltration SCM installations.
2. Sites where NRCS soil data is unavailable, or soils have either been classified as urban or have been disturbed since the NRCS survey:
   a. soil testing on a one hundred (100) feet master-grid system for site-wide design purposes;
   b. and soil testing on a twenty-five feet master-grid for site locations of proposed infiltration SCM installations.

At each test pit or boring, the following conditions shall be noted and described. Depth measurements should be described as depth below the ground surface:

- Identification and depth of soil horizons (upper and lower boundary)
- Soil texture and color for each horizon
- Color patterns (mottling) and observed depth
- Depth to water table
- Depth to bedrock
- Observance of pores or roots (size, depth)
- Estimated type and percentage of coarse fragments
- Hardpan or limiting layers
- Strike and dip of horizons (especially lateral direction of flow at limiting layers)
- Additional comments or observations

The sample soil log form at the end of this protocol may be used for documentation of each test pit.

At the designer's discretion, soil samples may be collected at various horizons for additional laboratory analysis. Following testing, the test pits should be refilled with the original soil and the surface replaced with the original topsoil. A test pit should never be accessed if soil conditions are unsuitable for safe entry, or if site constraints preclude entry. OSHA regulations must always be observed.

It is important that the test pit or boring provide information related to conditions at or near the bottom of the proposed infiltration SCM. If the SCM depth will be greater than 90 inches below existing grade, deeper excavation will be required. However, such depths are discouraged, as infiltration rates tend to decrease with depth until weathered bedrock is encountered. Except for surface discharge SCMs (filter strips, etc.), the designer is cautioned regarding the proposal of systems that are significantly lower than the existing topography. The suitability for infiltration may decrease, and risk factors are likely to increase. The designer should reduce grading and earthwork as needed to reduce site disturbance and compaction.

The recommendations above are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the site prior to construction are not recommended. Designers must also check with the local stormwater program for any additional requirements they may have related to the type, number and location of soil testing.

Step 3. Infiltration (Soil Absorption) Tests

A variety of field tests exist for determining the infiltration capacity of soil. Laboratory tests for infiltration are strongly discouraged, as a homogeneous laboratory sample does not represent field conditions. Tests should not be conducted in the rain or within 24 hours following significant rainfall events (greater than 0.5 inches), or when the temperature is below freezing. It is recommended that at least one infiltration test be conducted at the proposed bottom elevation of an infiltration SCM, and a minimum of two tests conducted per test pit. The designer may elect to test two different elevations to allow flexibility in SCM design. Based on observed field conditions, the designer may elect to modify the proposed bottom elevation of a SCM. Personnel conducting infiltration tests should be prepared to adjust test locations and depths depending on observed conditions.

Methodologies discussed in this protocol include:

- Double-ring infiltrometer tests
- Percolation tests

A double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil. A percolation test allows water movement through both the bottom and sides of the test area.

For infiltration basins, it is recommended that an infiltration test be carried out with a double-ring infiltrometer (not a percolation test) to determine the saturated hydraulic conductivity rate. This precaution is taken to account for the fact that only the surface of the basin functions to infiltrate, as measured by the test. In addition, tests should "not be conducted in the rain, within 24 hours of significant rainfall events (> 0.5 inches), or when the temperature is below freezing" (SEMCOG 2008).

a. Methodology for Double-Ring Infiltrometer Field Test

A double-ring infiltrometer consists of two concentric metal rings. The rings are driven into the ground and filled with water. The outer ring helps to prevent divergent flow. The drop in water level or volume in the inner ring is used to calculate an infiltration rate. The infiltration rate is determined as the amount of water per surface area and time unit that penetrates the soils. The diameter of the inner ring should be approximately 50 percent to 70 percent of the diameter of the outer ring, with a minimum inner ring size of 4 inches, preferably much larger. Double-ring infiltrometer testing equipment designed specifically for that purpose may be purchased. However, field testing for SCM design may also be conducted with readily available materials.

Equipment for double-ring infiltrometer test:

- Two concentric cylinder rings 6 inches or greater in height. Inner-ring diameter equal to 50 percent to 70 percent of outer-ring diameter (i.e., an 8-inch ring and a 12-inch ring). Material typically available at a hardware store may be acceptable.
- Water supply
- Stopwatch or timer
- Ruler or metal measuring tape
- Flat wooden board for driving cylinders uniformly into soil
- Rubber mallet
- Log sheets for recording data

Procedure for double-ring infiltrometer test:

- Prepare level testing area. This should be at or close to the proposed SCM location bed bottom.
- Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of 2 inches.
- Place inner ring in center of outer ring; place flat board on ring and drive ring into soil a minimum of 2 inches. The bottom rim of both rings should be at the same level.
- The test area should be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30-minute intervals for 1 hour. The minimum water depth should be 4 inches. The drop in the water level during the last 30 minutes of the presoaking period should be applied to the following standard to determine the time interval between readings:
  - If water level drop is 2 inches or more, use 10-minute measurement intervals.
  - If water level drop is less than 2 inches, use 30-minute measurement intervals.
- Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring shall be made from a fixed reference point and shall continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, shall represent the infiltration rate for that test location.

b. Methodology for Percolation Test

Equipment for percolation test:

- Post hole digger or auger
- Water supply
- Stopwatch or timer
- Ruler or metal measuring tape
- Log sheets for recording data
- Knife blade or sharp-pointed instrument (for soil scarification)
- Course sand or fine gravel
- Object for fixed-reference point during measurement (nail, toothpick, etc.)

Procedure for percolation test:

This percolation test methodology is based largely on traditional onsite sewage investigation of soils:

- Prepare level testing area.
- Prepare hole having a uniform diameter of 6 to 10 inches and a depth of 8 to 12 inches. The bottom and sides of the hole should be scarified with a knife blade or sharp-pointed instrument to completely remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Loose material should be removed from the hole.
- (Optional) Two inches of coarse sand or fine gravel may be placed in the bottom of the hole to protect the soil from scouring and clogging of the pores.
- Test holes should be presoaked immediately prior to testing. Water should be placed in the hole to a minimum depth of 6 inches over the bottom and readjusted every 30 minutes for 1 hour. Between June 1 and December 31, the presoak should be conducted for 2 hours to simulate saturated spring conditions.
- The drop in the water level during the last 30 minutes of the final presoaking period should be applied to the following standard to determine the time interval between readings for each percolation hole:
  - If water remains in the hole, the interval for readings during the percolation test should be 30 minutes.
  - If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.
  - After the final presoaking period, water in the hole should again be adjusted to a minimum depth of 6 inches and be readjusted when necessary after each reading. A nail or marker should be placed at a fixed reference point to indicate the water refill level. The water level depth and hole diameter should be recorded.
- Measurement to the water level in the individual percolation holes should be made from a fixed reference point and should continue at the interval determined from the previous step for each individual percolation hole until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the percolation hole during the final period, expressed as inches per hour, shall represent the percolation rate for that test location.

Step 4. Consideration of Infiltration Rate in Design and Modeling Application

Infiltration systems can be modeled similarly to traditional detention basins. The marked difference with modeling infiltration systems is the inclusion of the infiltration rate, which can be considered as another outlet. For modeling purposes, it is convenient to develop infiltration rates that vary (based on the infiltration area provided as the system fills with runoff) for inclusion in the Stage-Storage-Discharge table.

Alternate tests or investigations can be used for verification. For instance, if the final SCMs are not located precisely over the test locations, alternate testing or investigations can be used to verify that the soils are the same as the soils that yielded the earlier results. However, the design team should document these verification test results or investigations. Other testing methods are acceptable to assess a soil's suitability for infiltration for early screening and occasionally for verification. Only professionals with substantiated qualifications may carry out verification procedures.

A.3 General Description

Other soil tests are extremely useful when the design team needs to identify the better soils on a site – both for SCMS (structural, preventive, and restorative) and for landscape plantings. Tests for bulk density, contamination, texture class, organic matter content, and pH should be conducted before designing SCMs with vegetation or before specifying plants in restorative SCMs such as cover change, and before designing and planting ornamental landscapes.

A.3.1 Soil Compaction – Bulk Density Tests

A.3.1.1 Purpose of Bulk Density Tests

Bulk density tests can help determine the relative compaction of soils before and after site disturbance and/or restoration. These tests measure the level of compaction of a soil as an indicator of a soil's ability to absorb water. Disturbed and urbanized sites often have very high bulk densities. These soils have limited ability to absorb rainfall and therefore have high rates of stormwater runoff. Both the use of deep-rooted vegetation and the restoration of soil structure, missing chemical components, and living soil organisms can lower soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

Macropores occur primarily in the upper soil horizons and are formed by plant roots (both living and decaying), soil animals, bacteria and fungi, weathering processes caused by the movement of water, the freeze-thaw cycle, soil shrinkage due to desiccation of clays, chemical processes, and other mechanisms. These macropores are a critical method to infiltrate water and exchange atmospheric gases, both oxygen and carbon dioxide, under natural conditions. Good engineering and design should maintain or restore these macropores during construction of site SCMs.

A.3.1.2 Relationship of Soil Type to Bulk Density

A major indicator for compacted soil is bulk density, which is calculated as the dry weight of soil divided by its volume. Bulk density is important because it reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. In general, higher bulk density of a soil correlates to a lower infiltration rate and a higher stormwater runoff volume.

Different soil types have different bulk densities:

- Maximum allowable bulk densities for sustainable soil management are based on 95 percent of the bulk density value at which growth limitations are expected for an average range of plant material, as described by Daddow and Warrington (1983).
- While these requirements are expressed as maximum allowable bulk densities, it is important to note that densities that are too low can also cause problems, especially for lawn areas or steep slopes.

To calculate the maximum allowable bulk density for a soil:

- Obtain a laboratory analysis of the sand, silt, and clay percentages as well as existing bulk density.
- Refer to Table A.1 to determine the ideal bulk density for a determined soil texture.

Table A.1: Soil Textures and Bulk Densities.

Soil Texture	Ideal Bulk Densities (g/cm^3)	Bulk Densities that may affect root growth (g/cm^3)	Bulk Densities that restrict root growth (g/cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

A.3.1.3 Procedures for Bulk Density Tests

Various procedures are available to conduct bulk density tests, including a procedure developed by USDA. website:

http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050957.pdf

The density measurements should be carried out in conjunction with a soil texture analysis. Sandy soils infiltrate well, but tend to have a somewhat higher bulk density than finer soils. Experienced personnel can perform the texture analysis manually onsite.

A.3.2. Soil Contamination

Contaminated sites have a wide range of complexity, primarily dependent on previous, existing, and proposed land use. Land development at brownfield sites normally occurs in three stages:

1. Site assessment
2. Site remediation
3. Redevelopment

Step 1. Site Assessment

a. Develop a preliminary survey to determine the presence of contaminants.
b. Develop a plan to sample, measure, and monitor the site.
c. Conduct special tests to determine the type and degree of contamination.
d. Specialists such as soil scientists, geologists, chemists, hydrologists, and engineers should be consulted. The design team with expert help can then develop a Site Remediation Plan.

Step 2. Site Remediation

Typical site remediation uses earth-moving solutions to address soil and groundwater contamination. How stormwater is managed depends largely on how the site was remediated. Contaminated soil can be completely removed from the site, isolated and capped, or blended with clean soil so that it meets state standards for public health and safety. Assessment and cleanup of properties must conform to the requirements of both U.S. Environmental Protection Agency (USEPA) and Tennessee state requirements.

For more information on site remediation, go to the TDEC Division of Remediation website:

http://www.tn.gov/environment/dor/

Step 3. Redevelopment

After the environmental concerns are addressed through cleanup or institutional controls, assessment is complete, and the appropriate actions taken, plans must be developed for resolving unacceptable environmental risks and integrating solutions into the development plans. Contact economic development staff of local, state, and federal agencies to determine possible financial and technical resources available to help with planning and financing brownfield redevelopment.

A.3.3. Soil Texture, Organic Matter Content, Nutrient Levels, and pH

It is recommended that soils be amended based on information provided by the results of soil tests for the following parameters - texture class, organic matter content, nutrient deficiencies, and pH:

- Take soil samples from representative areas on the site.
- Do not mix these soils together.
- Test each individual sample for texture class, organic matter content, nutrient levels, and pH.
- Send samples to your local University of Tennessee Extension Office for analysis. Website:

  https://extension.tennessee.edu/Pages/Office-Locations.aspx

  Also see the Soil, Plant and Pest Center for soil testing information:

  https://ag.tennessee.edu/spp/Pages/soiltesting.aspx

- Results should be interpreted by a professional soil scientist or USDA Extension Service expert. (Laboratory tests often include professional interpretation of results and recommendations.)

Please note: Sands and soils based off of limestone parent material are calcareous and therefore basic. You cannot permanently amend limestone-based soils with sulfur to reduce pH. Some soils are amendable, but calcareous soils are not. Elemental sulfur, with the help of bacteria, will work to decrease the pH for a little while (+/-5 years), but the pH will increase again and plants will turn yellow and die unless more sulfur is added in perpetuity. Helpful hint: know if local soils are limestone based and make sure plant material can handle the high pH. This is easier than playing soil alchemy.

A.4 Sample Soil Log

Tested by: ____________________

Test Pit: ____________ Date: ____________ Elevation: ____________ Equipment Used: ____________

Geology: ____________ Soil Type: ____________ Land Use: ____________ Weather: ____________

Additional comments: ____________________

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Horizon	Upper Boundary	Lower Boundary	Soil Textural Class	Type, Size, Coarse Fragments, etc.	Soil Color	Color Patterns	Pores, Roots, Rock Structure	Depth to Bedrock	Depth to Water	Comments

REFERENCES

Daddow and Warrington. 1983. Growth-limiting Soil Bulk Densities as influenced by Soil Texture, USDA Forest Service, Fort Collins, Colorado.

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University of Tennessee Institute of Agriculture: Soil, Plant and Pest Center. https://ag.tennessee.edu/spp/Pages/soiltesting.aspx