12: SOIL TESTING CRITERIA

Introduction

Understanding the character and saturated hydraulic conductivity of surface and subsurface soils at a proposed land development site is crucial to the design of stormwater best management practices (BMPs) that meet the requirements of the New Jersey Stormwater Management rules at N.J.A.C. 7:8. In particular, how a soil responds to rainfall, measured by its ability to absorb and infiltrate some of that rainfall, is a required input parameter when computing both pre- and post-development runoff and recharge rates. Similarly, soil saturated hydraulic conductivity is a critical parameter in the design of stormwater BMPs that rely upon infiltration.

When Soil Testing is Needed:

There are five ways soil testing is used in the design of stormwater management BMPs:

1. Determining Hydrologic Soil Group (HSG) for calculating stormwater runoff,
2. Determining the soil series for groundwater recharge calculations,
3. Determining the Seasonal High Water Table (SHWT) to meet the BMP design separation standard,
4. Determining the soil hydraulic conductivity for BMP design and as-built testing and
5. Determining the input parameters for a groundwater mounding analysis.

The chapter is therefore divided into five sections in order to provide guidance on proper testing and the default values that must be used when testing is not performed. Each section begins on the page number listed in the table on the following page. Basic definitions are provided on Page 3.

In addition, the chapter includes an Addendum on the testing procedures listed in the table below:

Definitions

The following terms, which are used throughout this chapter, have the meaning specified below.

"soil profile" - a vertical cross-section of undisturbed soil showing the characteristic horizontal layers or horizons of the soil which have formed as a result of the combined effects of parent material, topography, climate, biological activity and time.

"soil profile pit" - an excavation made for the purpose of exposing a soil profile which is to be described.

"soil log" - a description of the soil profile which includes the depths, thickness, color, texture, coarse fragment content, mottling, structure and consistency of each soil horizon or substratum.

"**permeability**" – a quantitative measure of the ability of a saturated soil to transmit water vertically downward through a soil horizon or substratum. In this BMP Manual, soil permeability is assumed to be the vertical saturated hydraulic conductivity when the hydraulic gradient remains as one throughout stormwater routing calculations and the groundwater mounting analysis.

General Note and Disclaimer

It is the responsibility of the company or persons performing or witnessing subsurface investigations and soil hydraulic conductivity tests to comply with all applicable Federal, State and local laws and regulations governing occupational safety, including, but not limited to, the requirements of N.J.A.C. 7:9A-5.2(e)3. All soil profile pits, soil borings and soil hydraulic conductivity tests, along with any associated documentation, shall be conducted under the direct supervision of licensed New Jersey professional engineer. During all subsurface investigations and soil test procedures, adequate measures shall be taken to ensure personnel safety and prohibit unauthorized access to the excavations at all times. Entering a soil pit excavated below the water table can be extremely dangerous and should be avoided unless the pit is relatively shallow and the sides of the pit have been stepped and sloped to eliminate the likelihood of sudden and severe cave-in of the pit.

Disclaimer: This guidance cannot be construed to indicate that it contains the required soil testing to assess hydraulic impacts on groundwater from infiltration. Additional soil information may be necessary depending on the type of mounding analysis and the specific site being assessed. The design engineer shall ensure that there is no adverse impact to other properties due to infiltration.

Section 1: Methods for Identifying HSGs and Soil Series

For drainage area runoff computations using the Natural Resources Conservation Service (NRCS) methodology, knowledge of the Hydrologic Soil Group (HSG) to which the soil, or soils, present on a site belongs is required, particularly for soils with pervious land cover. HSG is a measure of the runoff potential of the surface soil layer. NCRS classifies soils into four HSGs, which are arranged alphabetically, i.e., 'A' through 'D,' in order from least to most likely to generate stormwater runoff. The soil series and HSG impact the computations to establish the groundwater recharge and runoff conditions necessary to evaluate compliance with the recharge and quantity control criteria of the Stormwater Management Rules.

- In accordance with NRCS recommendations, HSG is typically determined through information available from the NRCS Web Soil Survey, which, as its name indicates, is available on the internet. The Web Soil Survey is used to establish the existing soils condition and the associated HSG for the soil series.
- However, at certain locations, an HSG determination is not available, either because the site contains fill or sufficient information was not available to determine the HSG present. These lands may be labeled with a soil series designation of *Urban Land*, *Cut and Fill Land* or *Made Land*, among others, and have no HSG designation and/or are accompanied with a qualifying statement such as, "The properties and characteristics of these soils differ greatly from place to place. Onsite investigation and evaluation are needed for most uses."
- For other locations, direct soil observations and tests may indicate that a soil has an HSG classification that is different than the one provided by the Web Soil Survey.

As a result, a methodology is needed to associate these areas, or other indeterminately and previously altered areas in the State, with an applicable soil series and HSG, as well as for instances where map classifications do not represent field conditions.

Subsection 1a: HSG and Soil Series Designations from the NRCS Soil Survey

NRCS provides two forms of soil information:

1. archived PDF files for New Jersey's counties available at:

   https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=NJ.

   The New Jersey Groundwater Recharge Spreadsheet (NJGRS) requires knowledge of a soil's series name, which is used by the NJGRS to compute the soil's infiltration and recharge capabilities. Soil series names are typically derived from the published NRCS County Soil Surveys.

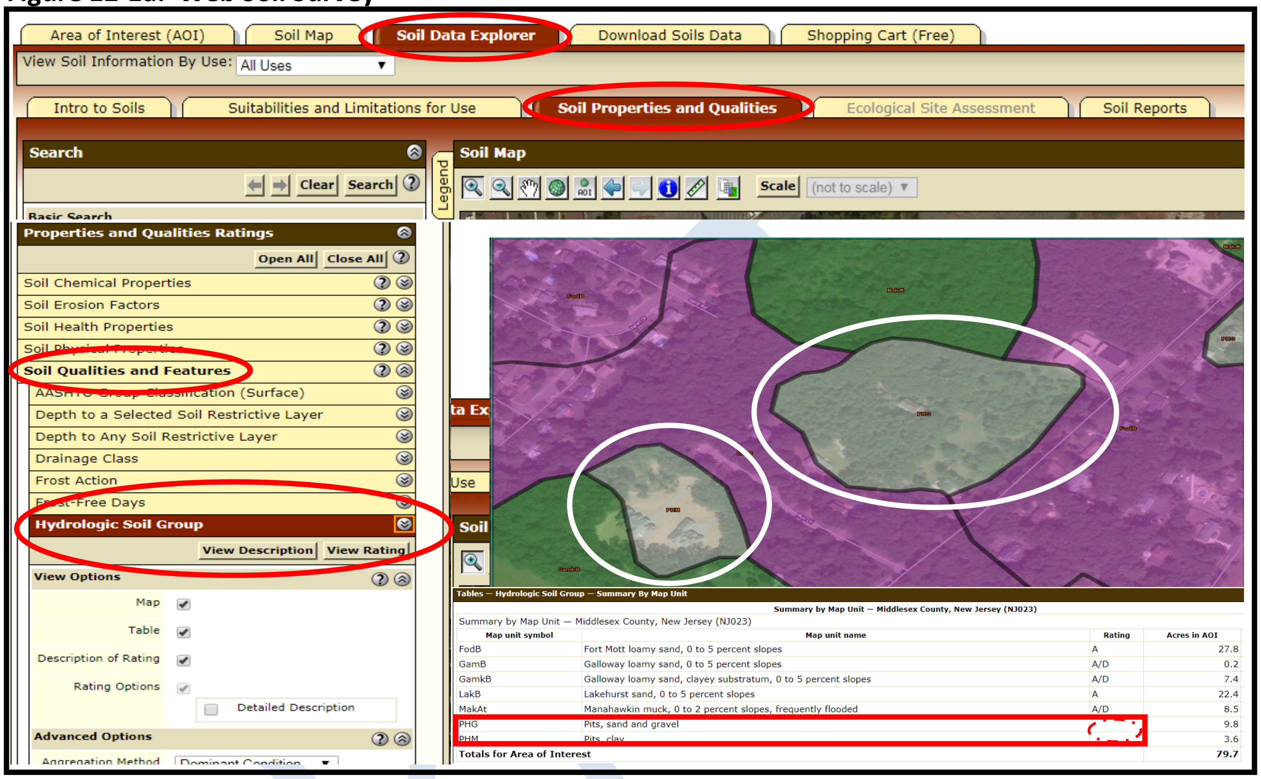
2. the interactive Web Soil Survey accessed from:

   https://websoilsurvey.nrcs.usda.gov/app/, for which the user's guide is found online at:

   https://websoilsurvey.nrcs.usda.gov/app/Help/WSS_HomePage_HowTo.pdf.

On the main page of the Web Soil Survey site, click on the circular shape labeled "Start WSS." The HSG and soil series designations are found under the tab "Soil Data Explorer" and subtab "Soil Properties and Qualities," and under the drop-down menu "Soil Qualities and Features," followed by "Hydrologic Soil Group" shown in Figure 12-1a, each of which are circled in red in the image below.

Figure 12-1a: Web Soil Survey



A close up of the lower right legend is provided in Figure 12-1b below. The column titled "Map unit name" contains the information on the soil series and the soil types for each soil unit depicted as a shape on the map in Figure 12-1a. HSG information in shown under column titled "Rating". The two areas highlighted in gray, within the white ovals, are those map units identified by the red rectangle for which HSG and soil series have not been determined. The soils in the undetermined HSG and soil series may be determined by the methods in Subsections 1b and 1c, which are discussed on Pages 6 and 8, respectively. Information on dual-rated soils shown above and below, i.e., those with a rating of 'A/D,' is provided at the bottom of Page 8.

Figure 12-1b: Web Soil Survey Summary by Map Unit Legend

Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Middlesex County, New Jersey (NJ023)

Summary by Map Unit — Middlesex County, New Jersey (NJ023)

Map unit symbol	Map unit name	Rating	Acres in AOI
FodB	Fort Mott loamy sand, 0 to 5 percent slopes	A	27.8
GamB	Galloway loamy sand, 0 to 5 percent slopes	A/D	0.2
GamkB	Galloway loamy sand, clayey substratum, 0 to 5 percent slopes	A/D	7.4
LakB	Lakehurst sand, 0 to 5 percent slopes	A	22.4
MakAt	Manahawkin muck, 0 to 2 percent slopes, frequently flooded	A/D	8.5
PHG	Pits, sand and gravel		9.8
PHM	Pits, clay		3.6
Totals for Area of Interest			**79.7**

Subsection 1b: Default HSG and Soil Series Designations

Where HSG information from a published or online NRCS Soil Survey is either unavailable or inconsistent with conditions in the field, the runoff computations for pre- and post-developed drainage area conditions may be based upon default HSGs. These default HSGs are shown in Table 12-1 below for drainage areas within and outside New Jersey's coastal plain, which is depicted in the graphic provided as Figure 12-2 on the next page. If the designer engineer does not wish to utilize these assumed hydrologic soil groups, a process is outlined in the remainder of this chapter to establish the HSG based on a site-specific investigation.

Table 12-1: Default Hydrologic Soil Group for Runoff Computation

Site Condition	Site location (see Figure 12-2)	
	In Coastal Plain	**Outside Coastal Plain**
Pre-construction	HSG A	HSG B
Post-construction	HSG D	HSG D

Figure 12-2: Physiographic Provinces of NJ

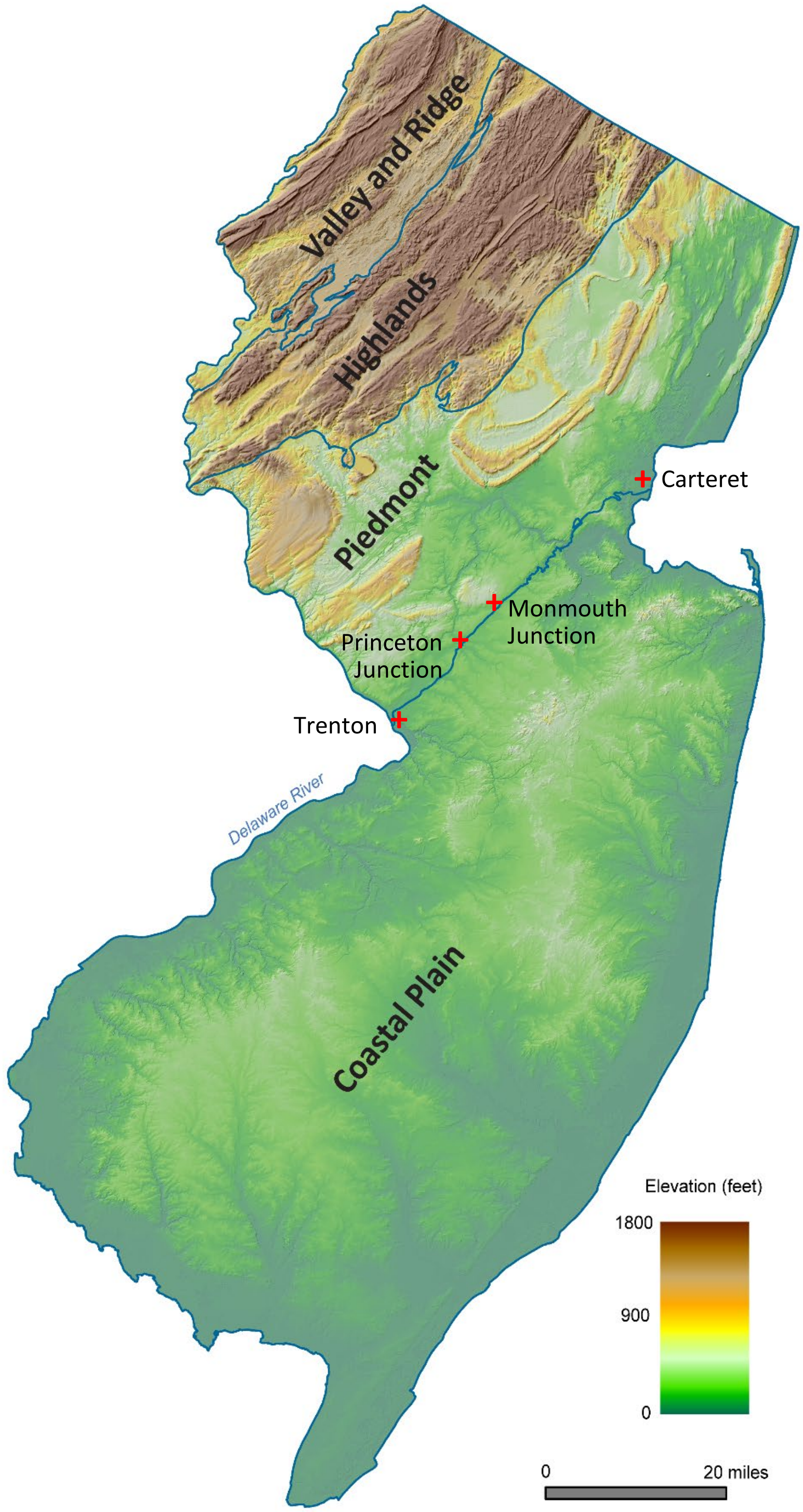


Image modified from the New Jersey Geological Survey Information Circular, "Physiographic Provinces of New Jersey, 2006" and used with permission.

Once the HSG is known as provided above, the default soil series shown in Table 12-2 may be used in the NJGRS.

Table 12-2: Default Soil Series for NJGRS Recharge Computation

HSG	Soil Series Name
A	Fort Mott
B	Nixon
C	Venango
D	Any 'D' soil

Subsection 1c: Hydrologic Soil Group Testing Procedures

Location and Number of Required Soil Explorations

When the HSG designation is either undetermined from the NRCS Soil Survey or inaccurate with respect to field conditions, field observations and soil testing must be performed. The classification of HSG is in accordance with the *NRCS National Engineering Handbook*, Part 630 – Hydrology (NEH), Chapter 7 Hydrologic Soil Groups, January 2009, available at:

> https://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch7.pdf.
>
> From Page 7-1 of the above-referenced document, the assignment of HSG "is determined by the water transmitting soil layer with the lowest saturated hydraulic conductivity and depth to any layer that is more or less water impermeable (such as a fragipan or duripan) or depth to a water table (if present)." Table 7-1 of NEH Chapter 7 lists the criteria for assignment of HSG.

In order to obtain the information needed for determining the appropriate HSG designation, one or more soil profile pits are needed to collect detailed information on groundwater conditions and soil morphology. Data recorded from one or more soil borings must then compared to the reference soil profile pit to confirm consistency between the profile pit and the boring. Where soil and/or groundwater properties vary significantly between soil boring and profile pit explorations, additional soil profile pits must be conducted, as necessary, to resolve such differences and accurately characterize the soil(s) present in the mapping unit.

Note that there are dual HSG classes 'A/D', 'B/D' and 'C/D' in Table 7-1 of NEH. The dual class designation means that a soil can be classified as the 'A,' 'B' or 'C' soil appearing to the left of the slash, but this soil group often has the SHWT within 24 inches of the ground surface. If the SHWT is within 24 inches of the ground surface the soil must be classified as HSG 'D' soil. For example, a sandy soil that has a hydraulic conductivity of 10 in/hr, for which the SHWT is determined to be 22 inches below the ground surface would be classified as HSG 'D' despite its high hydraulic conductivity.

Soil Boring and Profile Pit Locations and Allowable Substitutions

In all instances, a soil profile pit may be conducted in place of a required soil boring; however, **a soil boring cannot be used as a substitute for a soil profile pit except as stated below.** In areas where a soil profile pit would substantially disturb the existing area and create an undesirable condition or where significant environmental disturbance will occur in an area that is not intended for future development, two soil borings may be conducted in the place of a required soil profile pit with a soil profile pit located at the closest available location representative of the soil boring locations.

- Where soil and/or groundwater properties vary significantly between soil explorations, additional soil profile pits shall be conducted as necessary to resolve such differences and accurately.
- All soil explorations shall be located generally equidistant from each other and the boundaries of the mapping unit to maximize the ability to interpolate between test locations so as to provide adequate characterization of the mapping unit's soil.
- If the location of the soil profile pit is not representative of the soil borings taken, it is the responsibility of the design engineer to demonstrate the consistency of soil profile pit data to the soil characteristics at the location of the soil borings.

Number of Soil Explorations Required

The size of the soil mapping unit for which the HSG is either unknown or inaccurate determines the minimum number and types of soil explorations required. Examples of the number of required soil profile pits and soil borings are in Table 12-3 located on the following page.

a. **Soil Mapping Unit < 0.5 ac:** Where the HSG is unknown for a mapping unit of less than one half acre, as shown on the NRCS Web Soil Survey, a minimum of one soil profile pit and one soil boring shall be conducted within that mapping unit.

b. **Soil Mapping Unit ≥ 0.5 ac and ≤ 2 ac:** On those areas of the development parcel for which the HSG is either unknown or inaccurate with respect to field conditions, for a mapping unit greater than or equal to one half acre and less than or equal to two acres, as shown on the NRCS Web Soil Survey, a minimum of one soil profile pit and four soil borings shall be conducted within each soil mapping unit.

c. **Soil Mapping Unit > 2 ac:** Where the HSG is unknown for a mapping unit larger than two acres within the limits of the overall site, in addition to the required numbers in b., a minimum of one additional soil profile pit and two additional soil borings shall be conducted for each additional two acres.

Table 12-3: Example 1 - Soil Explorations vs. Map Unit Size

Map Unit Size	Number of Soil Profile Pits	Number of Soil Borings
0.45 ac	1	1
1.9 ac	1	4
2.6 ac	1+1 = 2	4+2 = 6

Depth of Soil Profile Pits and Boring:

Soil profile pits and soil borings performed for the purpose of determining HSG must extend to the depth of the SHWT or either six feet below existing grade or four feet below proposed grade, whichever is deeper, meaning lower in elevation. The determination of the soil HSG is based upon the depth to restrictions (i.e., the depth to the SHWT and soil morphological characteristics which restrict the vertical movement of water including, but not limited to, abrupt textural boundaries, fragipan, bedrock, dense or cemented soils) and the hydraulic conductivity of the most restrictive soil horizon above either the restriction or the SHWT. The presence and depth of these restrictions must be included in the soil log of both the soil profile pits and the soil borings.

Table 12-4: Example 2 - Soil Exploration Required Depth Determinations

	Elevation	Example 2-A	Example 2-B	Example 2-C
	Ex. Grade=	EL. 11	EL. 9	EL. 9
(a)	**6 ft. Below=**	EL. 5	EL. 3	EL. 3
	Prop. Grade =	EL. 8	EL. 8	EL. 8
(b)	**4 ft. Below Prop. Grade =**	EL. 4	EL. 4	EL. 4
	SHWT =	EL. 2	EL. 2	EL. 4.5
	Required Elevation of Soil Pit or Boring Excavation =	**Answer: EL. 4.** The resulting elevation in (b) is lower than the result in (a)	**Answer: EL. 3.** The resulting elevation in (a) is lower than the result for (b).	**Answer: EL. 4.5.** The excavation cannot be lower in elevation than the SHWT.

Note: "Ex." Denotes Existing, "Prop." Denotes Proposed and "EL." Denotes Elevation

Soil Series for NJGRS Recharge Computation

For the soil series determinations in the New Jersey Groundwater Recharge Spreadsheet (NJGRS), the user may input the default soil series name matching the HSG designation. Alternatively, the user may identify the soil series by the taxonomic class and soil series description. The first step is to identify the soil taxonomic class by using the NRCS publication, titled:

A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd edition. Natural Resources Conservation Service. 1999. U.S. Department of Agriculture *Handbook 436*, available online at:

https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/class/taxonomy/.

The second step is to look up the soil series name that matches the soil classification described in the taxonomic class. The Soil Science Division maintains the official soil series descriptions in a file-share storage system, which is available online at:

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053587

and the soil series classifications is in a database, which is available online at:

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053583.

For more details, see the *National Soil Survey Handbook*, Natural Resources Conservation Service, U.S. Department of Agriculture online at:

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242

Subsection 1d: Seasonal High Water Table (SHWT) Location

The upper limit of the zone of saturation, which is known as the Seasonal High Water Table, shall be determined by one of the following means:

1. Where mottling is observed, at any season of the year, the SHWT shall be taken as the highest level at which mottling is observed, except when the water table is observed at a level higher than the level of the mottling.

2. Where mottling is not observed, the SHWT shall be determined based upon either of the following methods:

    a. During the months of January through April, inclusive, water levels may be measured directly within soil profile pits or borings. Whenever the Department determines that there has been a significant departure from normal climatic conditions the Department may, with due notice to the administrative authority, lengthen or shorten the period allowed for direct measurement during any given year. In low lying coastal areas where groundwater levels fluctuate with the tides, measurements shall be taken at the time of highest groundwater elevation in response to tidal fluctuation or

    b. During other times of the year, the depth to the SHWT may be obtained from the Soil Conservation Service County Soil Survey Report provided that the soil series present at the site is identified based upon comparison of soil profile morphology observed within a soil profile pit and the soil profile description provided for the soil series in question within the County Soil Survey Report. In cases where SHWT is shown as a range of elevations in the County Soil Survey Report, the highest elevation of the range shall be used as the SHWT.

Below is an example of an Excel spreadsheet that may be used to calculate the number of soil profile pits and borings required for the determination of an HSG designation. The spreadsheet may be downloaded as part of an Excel workbook from the Department website at:

{*updated link to be inserted here upon chapter finalization – file is currently located on the Draft BMP Manual Chapters Available for Comment page at:* }
https://njstormwater.org/bmp_man_comments.htm.

Figure 12-3: Example of an HSG Soil Testing Worksheet

HSG Soil Testing Worksheet

Project Name: ______________________

Location: ______________________

Determination of Hydrologic Soil Group Worksheet

Determining No. of Test Pit for HSG				
Unknown Mapping Unit No.	**Size of Mapping Unit (acre)**	**# of Soil Profile Pit(s) Required**	**# of Soil Boring(s) Required**	1. mapping unit of less than 0.5 acre, a minimum of one soil profile pit and one soil boring shall be conducted within that mapping unit.
		1	1	
		1	1	2. a minimum of one soil profile pit and four soil borings shall be conducted within each soil mapping unit of 0.5 acre or more and less than or equal to 2 acres, as shown on the NRCS Web Soil Survey.
		1	1	
		1	1	3. a mapping unit larger than 2 acres within the limits of the overall site, a minimum of one additional soil profile pit and two additional soil borings shall be conducted for each additional 2 acres.
		1	1	
		1	1	
		1	1	

Determining Depth of Soil Profit Pit/Boring					
Test No.	**Existing Grade Elevation**	**Proposed Grade Elevation**	**SHWT Elevation**	**Depth of Test Pit/Boring from Existing Grade (in)**	**Required Depth Notes**
1	100	102	98	98	4 ft below Proposed Grade
2				-6	
3				-6	
4				-6	
5				-6	
6				-6	
7				-6	
8				-6	
9				-6	
10				-6	

Soil profile pits and soil borings performed for the purpose of determining HSG must extend to the depth of the SHWT or either six feet below existing grade or four feet below proposed grade, whichever is deeper, meaning lower in elevation.

Subsection 1e: Perched Water Table Requirements

The SHWT shall be considered to be perched if it is present immediately above a hydraulically restrictive horizon underlain by a layer of permeable unsaturated soil which is free of mottling and has a chroma of four or higher. In cases where a perched water table exists at the location of a BMP, additional soil testing is required to determine the extent of the hydraulically restrictive horizon within the area of the BMP, which is sometimes referred to as the "footprint." The following requirements must be followed:

- Soil profile pits separated by equal distances, must be conducted along the boundary of the footprint. The number of soil profile pits conducted must be sufficient to determine the extent of the hydraulically restrictive horizon in all directions.
- A hydraulic head test, as defined at N.J.A.C. 7:9A-5.9, shall be conducted in the soil that immediately underlies a perched water table to determine whether an artesian condition exists. An artesian condition is defined at N.J.A.C. 7:9A-5.8 (f).
- If the hydraulically restrictive horizon extends beyond the footprint, the infiltration BMP must be relocated to another location that is not affected by the perched water table or the highest elevation of the perched water table shall be assumed to be the SHWT for all aspects of design and soil testing.
- If the hydraulically restrictive horizon does not extend beyond the footprint, the hydraulically restrictive horizon may be excavated and replaced with sand.
- **Under no circumstances may a BMP be located in soils that exhibit artesian groundwater conditions. If artesian conditions exist, the hydraulically restrictive layer may not be excavated and replaced. The proposed BMP must be relocated to avoid the artesian aquifer.**

Section 2: Soil Tests for Infiltration BMPs

The design of a stormwater infiltration BMP, whether for groundwater recharge, stormwater quality or stormwater quantity purposes, requires specific knowledge of the soil hydraulic conductivity and related characteristics of each of the soil layers beneath the proposed BMP. Stormwater infiltration BMPs are those BMPs which rely on infiltration for groundwater recharge, stormwater runoff quality and/or stormwater runoff quantity control. Infiltration BMPs include, but are not limited to, a bioretention system without an underdrain, a dry well, an infiltration basin and a sand filter without an underdrain. As described in various other chapters of the BMP Manual, the soil permeabilities, as defined on Page 3, must meet or exceed certain minimum rates. This section presents soil testing guidelines to determine soil hydraulic conductivity at proposed stormwater infiltration BMPs.

Subsection 2a: Number of tests required plus details regarding the location(s) and depth of soil exploration

Required Quantity and Placement of Soil Explorations

Soil profile pits and soil borings are only required in the area of a BMP providing infiltration, which is also referred to as a BMP's infiltration area. The location and numbers of soil profile pits and soil borings must meet the requirements listed in Items 1 through 7 in the index on the following page and covered on the subsequent pages. Example 3, found in Table 12-5 on Page 17, illustrates the various requirements.

No.	Testing Requirement Applicability	Page No.
1	Requirements for any infiltration BMP	14
2	Requirements for a site with multiple infiltration BMPs, each less than five hundred square feet in area	14
3	Requirements for a site with multiple green infrastructure BMPs, where each green infrastructure BMP is greater than 500 square feet in area, exclusive of porous paving systems	15
4	Requirements for a linear BMP	15
5	Allowable substitutions	16
6	Proximity of soil exploration(s) to the actual location of a BMP	16
7	When additional soil profile pit(s) may be required	16

1. Requirements for any infiltration BMP:

   - Except as specified in items 2, 3 and 4 listed below, a minimum of two soil profile pits must be excavated within the infiltration area of any proposed infiltration BMP to determine the suitability and distribution of soil types and seasonal high water table present at location of the BMP.
   - Placement of the test pits must be sufficient to provide adequate characterization of the infiltration area.
   - For BMP infiltration areas larger than ten thousand square feet, a minimum of one additional soil profile pit shall must be conducted for each additional area of ten thousand square feet.
   - At least one test to establish the soil hydraulic conductivity must be conducted for each soil profile pit.

2. Requirements for a site with multiple infiltration BMPs, each equal to or less than five hundred square feet in area:

   - For sites with multiple infiltration BMPs, each with infiltration areas equal to or less than five hundred square feet, a minimum of one soil profile pit per soil mapping unit where the multiple BMPs will be located is required for the site. If the multiple infiltration BMPs are to be located in different soil mapping units, each soil mapping unit must have one soil profile pit. The location of the soil profile pit shall be at or near to the geographic center of all soil borings of the infiltration BMPS within the same soil mapping unit.
   - One soil boring is required for each infiltration BMP.
   - At least one test to establish the soil hydraulic conductivity must be conducted for each soil profile pit and soil boring.

3. Requirements for a site with multiple green infrastructure BMPs, where each green infrastructure BMP is greater than 500 square feet in area, excluding porous paving systems:

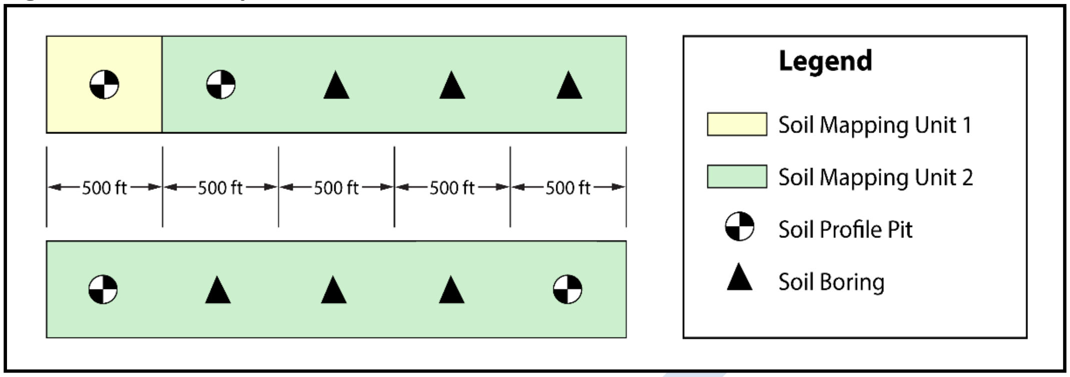
   - A soil profile pit is required for each soil mapping unit where a green infrastructure BMP is to be located. The location of the soil profile pit shall be at or near to the geographical center of all of the soil borings within the same soil mapping unit for a given green infrastructure BMP.
   - Two soil borings are required for each green infrastructure BMP.
   - For multiple green infrastructure BMPs located linearly along a roadway, one additional soil profile pit is required for every 2,000 linear feet.
   - The total number of required soil profile pits shall be placed generally equidistant from each other so as to provide adequate characterization of the infiltration area.
   - At least one test to establish the soil hydraulic conductivity must be conducted for each soil profile pit and soil boring.

4. Requirements for a linear BMP:

   - A linear BMP is defined as a BMP with all of the following characteristics:
     - The length of the infiltration area is at least four times the width of the infiltration area, i.e., the minimum length to width ratio is equal to or greater than 4:1,
     - The maximum width of the bottom of the infiltration area is twenty-five feet and
     - The maximum width of the top of the infiltration area is forty feet.
   - A minimum of one soil profile pit must be conducted within each soil mapping unit. In each soil mapping unit, the soil profile pit must be conducted within the first 500 linear feet of a linear BMP.
   - Where the length of a linear BMP exceeds 500 linear feet, one additional soil profile pit must be conducted for every 2,000 linear feet and one soil boring must be conducted at every 500-feet interval and similarly.
   - The total number of required soil explorations shall be placed generally equidistant from each other so as to provide adequate characterization of the infiltration area.

   See Figure 12-4 on the following page for a graphical representation of the required placement discussed above for a linear BMP. Take note that soil profile pits from different soil mapping units may be more distant from each other in order to obtain more information about the geomorphology characteristics of the project.

Figure 12-4: Soil Exploration Locations for Linear Infiltration BMPs



5. Allowable substitutions

   - In all cases, a soil profile pit may be conducted in place of a required soil boring; however, **a soil boring cannot be used as a substitute for a soil profile pit except as stated below.**

   - In areas where a soil profile pit would substantially disturb the existing area and create an undesirable condition or where significant environmental disturbance will occur in an area that is not intended for future development, two soil borings may be conducted in the place of a required soil profile pit and a soil profile pit located at the closest available location representative of the soil boring locations.

6. Proximity of soil exploration(s) to the actual location of a BMP

   The final location of a proposed BMP can differ from the location of a soil exploration. As long as the proposed BMP is within the same soil mapping unit, a new soil exploration is not required under the following circumstances:

   - If the soil explorations that have been performed are still within the infiltration area of the BMP at new location or

   - If the new location of the BMP is within 25 feet, in any direction, of all of the original soil exploration location(s).

7. When additional soil profile pit(s) may be required

   - Where soil and/or groundwater properties vary significantly between soil explorations, additional soil profile pits shall be conducted as necessary to resolve such differences and accurately characterize the subsurface conditions below the infiltration BMP.

Table 12-5: Example 3 - Required Number of Soil Profile Pits and Soil Borings

Type of Soil Exploration and Number Required:	Example BMPs					
	9,000 sf Infiltration Basin	**25,450 sf Infiltration Basin**	**35,000 sf Porous Paving System**	**10 Rain Gardens Each = 400 sf**	**4 Small-Scale Infiltration Basins, Each = 1,500 sf**	**2,500 ft Linear Infiltration Trench**
Soil Profile Pit(s)	**2**	**4 Total:** 2 (1st 10,000 sf) + 1 (2nd 10,000 sf) + 1 (add'l. 5,450 sf)	**5 Total:** 2 (1st 10,000 sf) + 1 (2nd 10,000 sf) + 1 (3rd 10,000 sf) + 1 (add'l. 5,000 sf)	**1**	**1**	**2 Total:** 1 (1st 500 ft) + 1 (2,000 ft)
Soil Boring(s)	**None Required**	**None Required**	**None Required**	**10 Total:** 1 per each *GI* BMP	**8**	**3 Total:** 1 per each 500 ft of length after the first 500 feet

Note: "*GI*" Denotes Green Infrastructure

Depth of Soil Exploration

Soil profile pits and soil borings performed for the purpose of designing an infiltration BMP must extend to either a **minimum** depth of eight feet below the lowest elevation of the basin bottom or to a depth that is at least twice the maximum potential water depth generated by the largest design storm, whichever is greater.

Example 4 - Calculate the required depth and bottom elevation of the soil exploration for an infiltration basin

An infiltration basin is proposed at a location where the existing grade is at EL. 50 ft. The proposed elevation of the top of the 6 inch deep sand layer comprising the basin bottom is 5 ft below the existing grade. The infiltration basin is proposed to infiltrate the Water Quality Design Storm (WQDS), which produces a maximum depth of stormwater runoff equal to 2 ft, measured above the sand layer.

In this example, the lowest elevation of the basin bottom is the lower physical limit of the sand layer, which is at EL. 50 - 5 - 0.5 = EL. 44.5 ft. The maximum potential depth of runoff to be infiltrated was stated above to be 2 ft. Twice this depth is 4 ft; however, this depth is less than the 8 ft minimum depth requirement stated above. Therefore, the soil exploration for the soil profile pit and/or soil boring must extend down to EL. 44.5 - 8 = EL. 36.5 ft.

Location for soil samples or in-situ tests of the soil hydraulic conductivity

Soil hydraulic conductivity tests must be conducted on the most hydraulically restrictive horizon or substratum above the SHWT or nonfractured bedrock but located below the lowest elevation of a BMP and above whichever of the following depths is greater:

- eight feet below the lowest elevation of the BMP or
- to a depth equal to twice the maximum potential water depth in the BMP measured from the lowest elevation of the BMP.

  Take note: The lowest elevation of a BMP is bottom of the excavation of the BMP. Where a BMP has a sand or soil layer, the lowest elevation is the bottom of the sand or soil layer. If soil replacement is proposed beyond the required layers in the BMP, the depth is measured from the elevation of the bottom of the required sand or soil layer.

Stormwater infiltration BMPs must not be installed in soils that exhibit artesian groundwater conditions.

Stormwater infiltration BMPs relying on fractured bedrock for exfiltration must not be installed without a minimum of 2 feet between the bottom of the infiltration basin and the bedrock. In such a situation, the design engineer must demonstrate that appropriate testing methods, as discussed in Section 3, are utilized to establish the hydraulic conductivity of the infiltration BMP. The number of permeability tests performed shall be no less than the number of tests required for determining the permeability in the soil.

Table 12-6, located on the following page, provides a number of examples illustrating these requirements.

Table 12-6: Example 5 – Required Depth for Locating the Most Hydraulically Restrictive Layer

	Example BMPs				
	Bioretention Basin	**Infiltration Basin**			
		w/ 6 in Sand Layer	**w/ 6 in Sand Layer**	**w/ 5 ft Sand Replacement Below Basin Bottom***	**w/ 10 ft Sand Replacement Below Basin Bottom***
Maximum Standing Water Depth (ft)	1	2	2	2	2
SHWT (ft) Below the Basin Bottom	12	12	4**	12	18
Depth range to locate the most hydraulically restrictive layer(s)	0 to 8 ft below the bottom of the basin	0 to 8 ft below the bottom of the sand layer	0 to 4 ft below the bottom of the sand layer	5 to 12 ft below the bottom of the basin	10 to 18 ft below the bottom of the basin

*The depth of sand replacement specified does not include the required 0.5 ft deep sand layer comprising the surface of the basin infiltration area.

**The location of the SHWT is the limiting factor in this case

On the following page is an example of an Excel spreadsheet that may be used to calculate the number of soil profile pits and borings, plus the depth(s), required for an infiltration BMP as part of soil hydraulic conductivity testing. The workbook including this spreadsheet may be downloaded from the Department website at:

{*updated link to be inserted here upon chapter finalization – file is currently located on the Draft BMP Manual Chapters Available for Comment page at:* }
https://njstormwater.org/bmp_man_comments.htm.

Figure 12-5: Example of a Soil Testing Worksheet for Infiltration BMPs

Hydraulic Conductivity Test Worksheet for Infiltration BMPs

Project Name: ______________________________

Location:

No. of Tests Required to Determine Hydraulic Conductivity (Single, Non-GI, Large BMP, Linear BMP)				
Type (select one)	**Size of Infiltration Area (square feet)**	**Length of Linear BMP (ft)**	**# of Soil Profile Pits Required**	**# of Soil Borings Required**
Single BMP	6,500	--	2	0
Single BMP	25,600	--	4	0
Linear BMP	--	450	1	0
	--	--	--	--
	--	--	--	--
	--	--	--	--
	--	--	--	--

No. of Test Required to Determine Hydraulic Conductivity (Multiple BMPs)				
Type (select one)	**# of Soil Mapping Unit**	**# of BMPs**	**# of Soil Profile Pits Required**	**# of Soil Borings Required**
Small BMPs <= 500 sf	1	5	1	5
GI BMPs > 500 sf	2	9	2	18
	--	--	--	--
	--	--	--	--
	--	--	--	--
	--	--	--	--
	--	--	--	--

Subsection 2b: Soil Log Requirements

A soil log must be prepared for each soil profile pit and soil boring. The soil boring log must be legible and, at a minimum, provide all of the following:

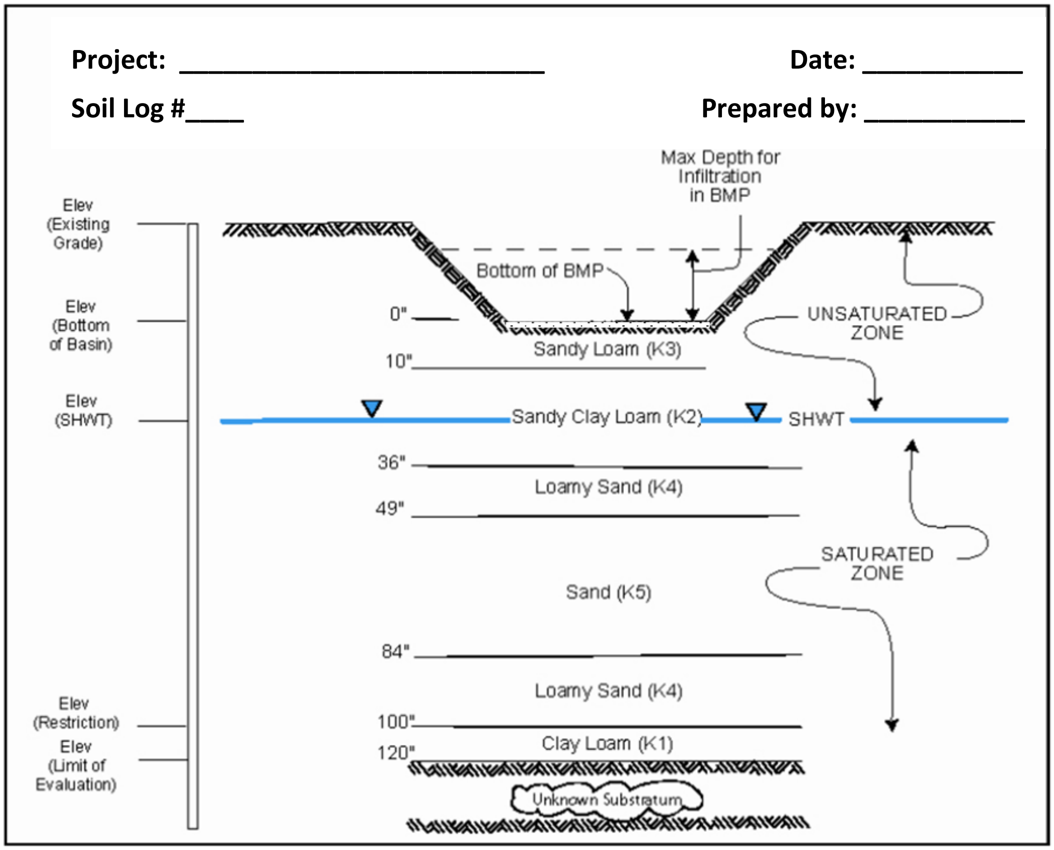
- the date of the soil exploration,
- the elevation of the existing ground surface at the location of the soil exploration,
- the elevation of the proposed grade and/or elevation of the lowest level in the bottom of the proposed BMP,
- the elevations of the permeability test or sample location(s),
- the depth and thickness of each soil horizon and the depth to the substratum,
- the dominant matrix or background and mottle colors using the Munsell system of classification for hue, value and chroma,
- the appropriate textural class as shown on the USDA textural triangle,
- the volume percentage of coarse fragments larger than two (2) millimeters in diameter,
- the abundance, size and contrast of mottles,
- the soil moisture condition, using standard USDA classification terminology,
- the presence of any soil horizon, substratum or other feature that exhibits an in-place soil hydraulic conductivity less than 1 inch per hour,
- the depth and occurrence of soil restrictions including, but not limited to, abrupt textural boundaries likely to restrict the movement of water, e.g., fragipans, dense materials, bedrock and ortstein horizons,
- the depth to the seasonally high ground water level, either perched or regional,
- the static (stabilized) water level, presence of soil mottles or other redoximorphic features and
- any observed seepage or saturation.

In addition to all of the above the soil profile pit log must also provide the soil structure and soil consistence using standard USDA classification terminology.

The results and locations of all soil profile pits, borings and soil hydraulic conductivity tests, both passing and failing, must be included in the Stormwater Management Report submitted to the appropriate review agency.

A simple version of a sample soil log is depicted in Figure 12-6 on the following page.

Figure 12-6: Sample Soil Log (For Direct Observation of SHWT)



On Page 23, Figure 12-7 depicts a soil profile cross-section example obtained from the Pinelands Commission, which is available online at:

https://www.state.nj.us/pinelands/appli/tools/new%20forms/Pinelands%20Stormwater%20BMP%20Cross%20Section%20Design%20Example.pdf.

On Page 24, Figure 12-8 depicts an example of an Excel spreadsheet created to serve as a template for a soil profile report. The workbook including this spreadsheet may be downloaded from the Department website at:

{updated link to be inserted here upon chapter finalization – file is currently located on the Draft BMP Manual Chapters Available for Comment page at: }
https://njstormwater.org/bmp_man_comments.htm.

Figure 12-7: Pineland Commission Soil Cross-Section Design Example

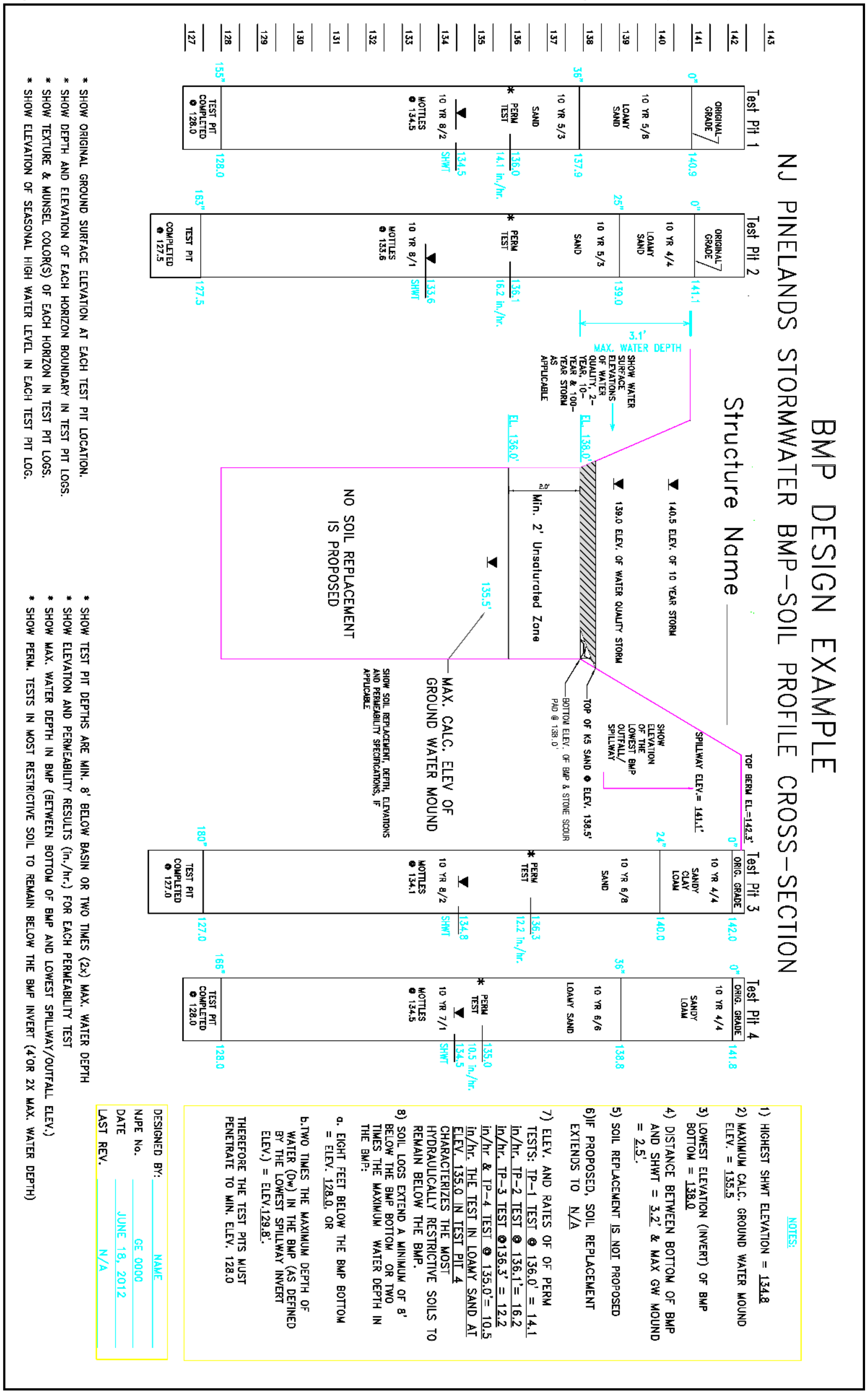


Figure 12-8: Soil Profile Report Template

Soil Profile Report

Project Name:		**Municipality:**	
Project Location:		**Block/Lot Info:**	

Date of Observation of SWHT:		**Lowest point in BMP (ft) =**	5
Prepared by:		**Max Water Depth (ft) =**	4
		Required Soil Profile Pit Depth (ft) =	13

Test Pit No.:

Observation Reported:	**Elevation (ft)**
Ground Level:	100
Seasonal Hight Water Table:	
Pit bottom:	87

Soil type (select one)	**Check box if most hydraulically restrictive**	**Top Elevation/Bottom Elevation**
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/

Test Pit No.:

Observation Reported:	**Elevation (ft)**
Ground Level:	120
Seasonal Hight Water Table:	
Pit bottom:	107

Soil type (select one)	**Check box if most hydraulically restrictive**	**Top Elevation/Bottom Elevation**
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/

Test Pit No.:

Observation Reported:	**Elevation (ft)**
Ground Level:	100
Seasonal Hight Water Table:	
Pit bottom:	87

Soil type (select one)	**Check box if most hydraulically restrictive**	**Top Elevation/Bottom Elevation**
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/
	☐	/

Locating the Seasonal High Water Table, if determined by direct observation, must be performed between January 1 and April 30

Generally, most soil types listed below are arranged from most to least hydraulically restrictive; if unsure of the soil type present, multiple soil layers may need to be tested.

	Notes
Clay	
Clay Loam	
Loam	
Silty Clay	
Silty Clay Loam	
Silt Loam	
Silt	
Sandy clay	
Sandy clay loam	
Loamy Sand	
Sandy Loam	
Sand	

Section 3: Soil Hydraulic Conductivity Testing

Acceptable Soil Hydraulic Conductivity Test Methods

A minimum of one soil hydraulic conductivity test must be performed at each soil profile pit and soil boring location. Soil hydraulic conductivity can be determined as described in the Addendum, which begins on Page 28, using a tube permeameter test, a percolation test, a cased borehole infiltration test, a single ring infiltration test, or a basin flooding test (for fractured bedrock). Additional methods of establishing the soil hydraulic conductivity, such as ASTM D 3385 - Double-Ring infiltrometer, and USBR 7300-89 - Well Permeameter Method, or other soil hydraulic conductivity tests that utilize in-situ conditions and are accompanied by a recognized published source reference can be used. When performing a soil boring during the soil exploration, the borings must be performed and reported in accordance with ASTM D 1452 - Practice for Soil Investigation and Sampling Auger Borings and ASTM D 1586 - Test Method for Penetration Test and Split-Barrel Sampling of Soils. Sampling must be continuous for the entire depth of the boring to fully characterize the soil profile.

Hydraulic Conductivity Testing in Fractured Bedrock

The number of hydraulic conductivity tests for fractured bedrock shall be no less than the tests required for hydraulic conductivity in the soil. The design hydraulic conductivity of 0.5 in/hr can be used for fractured bedrock when the basin drains completely within 12 hours during a basin flooding test performed as described in the Addendum. To use a hydraulic conductivity greater than 0.5 in/hr, more detailed testing is required. USBR 7300-89 or pump tests shall be utilized for detailed investigation.

Section 4: Construction and Post-Construction Oversight and Soil Hydraulic Conductivity Testing

Subsection 4a: Construction and Post-Construction Oversight Requirements

During construction, regular oversight must be provided by the professional engineer responsible for ensuring the effectiveness of infiltration BMPs to establish that the basin will function as designed. Oversight includes, but is not limited to, the following:

- Participation in a pre-construction meeting with the contractor to ensure all parties are familiar with the special care necessary in constructing an infiltration BMP.
- Confirmation of the proper use of construction equipment, especially to minimize the compaction of the infiltration area.
- Ensuring that the earthwork does not occur within the BMP area when the soil moisture content is above the lower plastic limit and that the specifications of any replacement soil(s) is/are met.
- Testing each soil layer where the hydraulic conductivity is critical, prior to the placement of a new layer, to ensure that the hydraulic conductivity has been protected. For example, in bioretention-infiltration basins, the subsoil must be tested prior to the placement of the soil filter media.

- Ensuring that proper precautions are taken to prevent sediment entering the infiltration area during construction or where unavoidable, if the basin is used as a sedimentation basin, excavation for the sediment basin is at least 2 feet above the final design elevation of the basin bottom.

Subsection 4b: Post-Construction Hydraulic Conductivity Testing

Post-construction soil hydraulic conductivity tests must be conducted to ensure that the installed BMP functions as designed. Such testing must be carefully undertaken when all BMP construction that may affect soil hydraulic conductivity has been completed. This includes the use of all construction equipment and the placement of all construction material that may affect soil hydraulic conductivity. In addition, hand tools and manual permeability test procedures must be used to avoid affecting soil hydraulic conductivity.

Required Number of Tests

The number of soil hydraulic conductivity tests must follow the same requirements as the requirements for the pre-construction soil hydraulic conductivity tests.

Required Test Depth

The post-construction hydraulic conductivity test must the conducted at the bottom of the excavation of the BMP before the sand layer or soil bed is placed into the BMP.

Permitted Test Methods

Only the single ring infiltration test, the basin flooding test, and the double ring infiltration test or a similar test that does not require a test hole in the soil layer are allowed. The tested soil hydraulic conductivity from the post-construction hydraulic conductivity test must be equal or greater than the tested soil hydraulic conductivity of the most restrictive soil layer that was tested in the pre-construction condition.

All post-construction soil hydraulic conductivity test results must be certified by a licensed professional engineer, submitted to the review agency, and recorded in the as-built documents.

Section 5: Determination of the Input Parameters in Groundwater Mounding Analyses

Subsection 5a: Input parameters in Groundwater Mounding Analyses

In accordance with *Chapter 13: Groundwater Table Hydraulic Impact Assessments for Infiltration BMPs*, a groundwater mounding analysis, when performed using the *Hantush Spreadsheet,* requires the user to input the appropriate soil and geological parameters, which include the recharge rate, specific yield, horizontal hydraulic conductivity and the initial thickness of the saturated zone. These parameters are discussed on the following page.

Recharge Rate

The recharge rate, R, is the design hydraulic conductivity of the most restrictive soil layer below the proposed infiltration BMP as described in Section 2, and in particular on Page 18, of this chapter.

Specific Yield

The default value for specific yield, S_y, is 0.15, but other values equal or less than 0.2 can be used if testing of the soil within the proposed infiltration BMP is conducted. No value greater 0.2 can be used, regardless of whether a higher value for specific yield is obtained from the soil testing results.

In the soil science field, specific yield is what remains when the field capacity is subtracted from the porosity of a particular soil, i.e.:

Specific yield = porosity – field capacity

The acceptable soil testing methods for determining the porosity and the field capacity are in the *Soil Survey Investigations Report No. 42, Kellogg Soil Survey Laboratory Methods Manual*, published by NRCS. The manual is available online at:

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054247.

Note that the specific yield values obtained from literature reviews or textbooks cannot be substituted for the value obtained from soil testing conducted within the proposed infiltration BMP.

Horizontal Hydraulic Conductivity

Horizontal hydraulic conductivity, K_h, is an essential parameter affecting the volume and speed of stormwater runoff that has infiltrated to move away from the center of the infiltration BMP during the infiltration period. However, horizontal conductivity may be affected by factors other than the soil types, e.g., the stratification of soil layers. The determination of horizontal hydraulic conductivity requires several test wells to observe horizontal flows in various directions under the aquifer test and also requires analysis through complicated analytic models. Therefore, conducting field tests in a proposed development site to determine horizontal hydraulic conductivity is not recommended. The default values listed in *Chapter 13* are to be used.

Initial Thickness of Saturated Zone

The initial saturated zone thickness, hi(0), is also an essential factor affecting the mounding height. The thickness of the unsaturated zone (not accounting for the capillary fringe) can also be described as the thickness of the water table below the land surface. If a value greater than 10 ft is used, it must be accompanied by on-site testing results that demonstrate the value used is appropriate. The input value must never exceed 75 ft, which is based on the preliminary results of research conducted by the USGS. The exact maximum allowed value may be subject to revision based on the final results of the research. Any on-site boring used to justify a value greater than 10 ft must be a continuous sampling boring for the entire drilled depth.

ADDENDUM

This addendum provides the Department summary of the NRCS guidance documents to establish hydrologic soil group based on hydraulic conductivity and the procedures for a percolation test, a tube permeameter test and a basin flooding test mentioned in Section 3 above.

Part A: Procedures for Soil Hydraulic Conductivity Testing

Test procedures for each of the testing methods cited in Section 3 above are found beginning on the pages specified in Table 12-8 below.

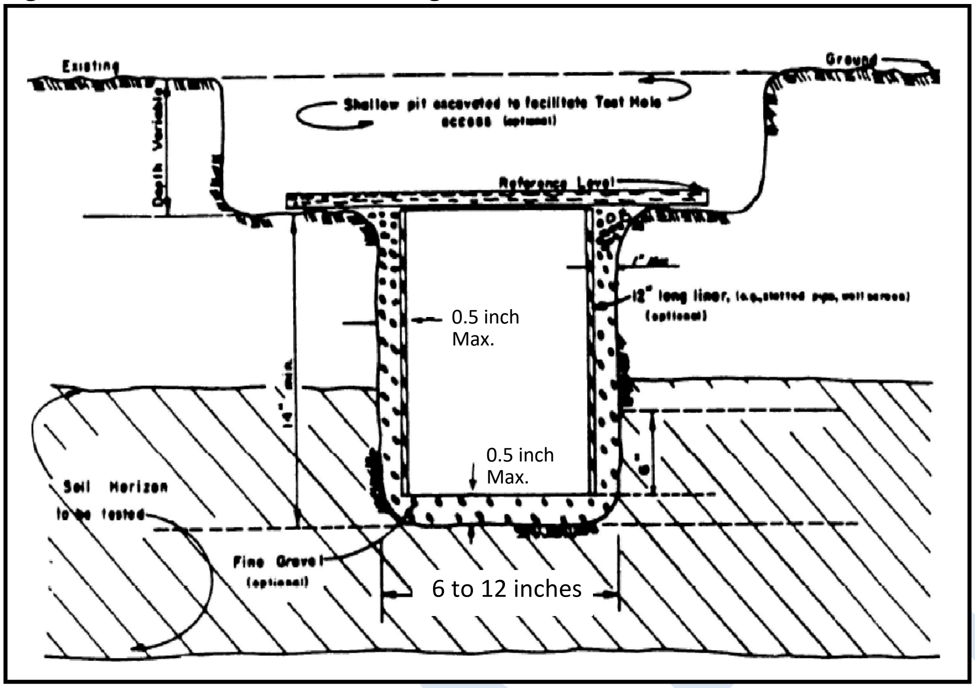
Table 12-8: Hydraulic Conductivity Test Procedures

Subsection A1: Percolation Test

A percolation test can be utilized to establish the hydraulic conductivity of soils provided that percolation test results are adjusted to hydraulic conductivity in accordance with item 5, which is located beginning on Page 31.

- Percolation tests must not be conducted in frozen ground or in holes which have been allowed to remain open to the atmosphere for periods greater than three days.
- The required configuration of the test hole is illustrated in Figure 12-9, on the following page.

Figure 12-9: Percolation Test Configuration



1. **Equipment Requirements**

The following equipment is required for the percolation test:

a. A soil auger, post-hole digger or other means of preparing a test hole as prescribed below,

b. A knife or trowel for removing smeared or compacted surfaces from the walls of the test hole,

c. Fine (from 2 to 10 millimeter in diameter) gravel (optional),

d. A water supply (50 gallons is generally adequate),

e. A straight board (to serve as fixed reference point for water level measurements),

f. A clock and a ruler (12 inches or longer, engineering scale),

g. An automatic siphon or float valve (optional) and

h. A hole liner consisting of a 14 inch section of slotted pipe or well screen, a 14 inch length of one-quarter inch hardware cloth or other similar material rolled into a tube (optional). The hole liner must be no smaller than 2 inches in diameter less than that of the test hole.

2. **Test Hole Preparation**

The test hole shall be prepared in accordance with the following list, in the order each step appears:

a. *Step One*: Excavate a test hole with horizontal dimensions of 6 to 12 inches at a depth such that the lower 6 inches of the test hole are contained entirely within the soil horizon or layer of fill material being tested. In order to facilitate access to the lower portion of the hole, the test hole may be excavated from the bottom of a shallow pit provided that the vertical axis of the test hole is a minimum of 14 inches measured from the bottom of the pit to the bottom of the test hole.

b. *Step Two*: In soil textures other than sands or loamy sands, remove smeared or compacted soil from the sides and bottom of the test hole by inserting the tip of a knife or trowel into the soil surface and gently prying upward and outward. Remove loose soil from the test hole.

c. *Step Three*: At this point, a 0.5 inch layer of fine gravel may be placed in the bottom of the hole to protect the soil surface from disturbance or siltation when water is added to the hole. If additional protection is desired, a hole liner as described in 1.h. above may be placed in the hole and the space between the liner and the sides of the hole may be filled with fine gravel.

d. *Step Four*: Place and secure a straight board horizontally across the top of the test hole, as shown in Figure 12-9, to serve as a fixed point for depth of water measurements to be made at appointed time intervals throughout the test.

3. **Pre-Soaking of Soils**

a. All soils, except for sandy textured soils which meet the requirements in 3.b. below, shall be pre-soaked using the following procedure. Any soil which exhibits cracks or fissures between soil aggregates must be pre-soaked in the following manner regardless of the texture.

   i. Fill the test hole with water and maintain a minimum depth of 12 inches for a period of 4 hours by refilling as necessary or by means of an automatic siphon or float valve.
   ii. At the end of 4 hours, cease adding water to the hole and allow the hole to drain for a period of duration ranging between 16 and 24 hours.

b. In sandy textured soils, including sands, loamy sands and sandy loams, where a rapid percolation rate is anticipated, fill the test hole with water to a depth of 12 inches and allow to drain completely.

   i. Refill the hole to a depth of 12 inches and record the time required for the hole to drain completely.
   ii. If this time is less than 60 minutes, the test procedure may begin as prescribed in 4. below without further pre-soaking.
   iii. If water remains in the test hole after 60 minutes, the hole must be pre-soaked as prescribed above before proceeding with the test.

4. **Percolation Rate Determination**

Immediately following the pre-soak procedure (no more than 28 hours after the start of the pre-soak procedure), the percolation rate shall be determined using the following procedure, in the order each step appears:

a. *Step One*: If water remains in the test hole after the completion of the pre-soak period, the test must be terminated and the percolation rate shall be reported as greater than 60 minutes per inch.

   i. If no water remains in the test hole, fill to a depth of 7 inches.

ii. After an interval lasting 5 to 30 minutes, depending upon the rate of fall, record the drop in water level to the nearest one tenth of an inch.

iii. Refill the hole at the end of each time interval and repeat this procedure using the same time interval until a constant rate of fall is attained, which occurs when the difference between the highest and lowest values for three consecutive measurements is no greater than two tenths of an inch.

b. *Step Two*: Immediately after the completion of "*Step One*," refill the test hole to a depth of 7 inches and record the time required for exactly 6 inches of water to seep away. This time divided by 6 will be the percolation rate in minutes per inch.

5. **Soil Hydraulic Conductivity Determination**

The soil hydraulic conductivity shall be established from the results of the percolation rate based on the following procedures. When the purpose of the test is to determine the soil hydraulic conductivity at the level of infiltration, the slowest percolation rate determined shall be used as a field measured percolation rate. If any of the measured percolation rates are slower than 60 minutes per inch, then this method shall not be utilized.

For circular holes, the field measured hydraulic conductivity value shall be calculated using Equations 1 and 2 below:

$$\mathrm{P}_m = \frac{\Delta t}{(\mathrm{H_o} - \mathrm{H_f})} \qquad (\textit{Equation 1})$$

$$\mathrm{K}_s = \frac{1}{\mathrm{P}_m}\, x \, \frac{60\ \mathrm{A}}{(A + 0.5\,\pi d\ (\mathrm{H_o} + \mathrm{H_f}))} \qquad (\textit{Equation 2})$$

where:

P_m is the percolation rate (min/in),
$\mathrm{H_o}$ is the initial height of the water (in),
$\mathrm{H_f}$ is the final height of the water (in),
A is the surface area of the bottom of the test hole (sq in),
Δt = the time water drops from $\mathrm{H_o}$ to $\mathrm{H_f}$ (min),
K_s is the saturated soil hydraulic conductivity (in/hr) and
d is the diameter of the test hole (in).

a. Since the test measures the time for 6 inches of water to empty from a circular hole, Equations 1 and 2 can then be simplified as shown below:

$$\mathrm{P}_m = \frac{\Delta t}{6}$$

$$\mathrm{K}_s = \frac{a}{\mathrm{P}_m}$$

where, a represents the right half of Equation 2. Thus, for various values of d, a is calculated as shown in Table 12-9 on the following page:

Table 12-9: a Values for Corresponding Test Hole Diameters

Parameter	Values					
d (in)	6	8	9	10	11	12
a	20.00	24.00	25.71	27.27	28.70	30.00

b. If the test is performed in a rectangular or square hole, Equation 2 is modified as follows:

$$P_m = \frac{\Delta t}{(H_o - H_f)} \qquad (\textit{Equation 1})$$

$$K_s = \frac{1}{P_m} x \frac{60\,A}{[A+(L+W)(H_o + H_f)]} \qquad (\textit{Equation 2 modified})$$

where:

L is the length of the test hole and
W is the width of the test hole.

On the following page is an example of an Excel spreadsheet that may be used for the conversion of the percolation rate to the soil hydraulic conductivity, in Figure 12-10. The workbook including this spreadsheet may be downloaded from the Department website at:

{updated link to be inserted here upon chapter finalization – file is currently located on the Draft BMP Manual Chapters Available for Comment page at: }
https://njstormwater.org/bmp_man_comments.htm.

Figure 12-10: Percolation Test Data Sheet

Percolation Test Data Sheet

Project:		Date:	
Municipality:			

Test Hole Dimensions

Test Pit #						
Test Hole Shape (select one)		Enter the Diameter (in) if Round was selected		Enter Dimensions (in) if Square or Rectangular was selected	Length	
					Width	

Test Results

Trial No.	Start Time	Stop Time	Time Interval (min)	Initial Water Depth (in)	Final Water Depth (in)	Change in Water Level (in)	Percolation Rate (min/in)	Converted Hydraulic Conductivity (in/hr)
1			0		0	0		
2			0			0		
3			0			0		
4			0			0		
5			0			0		
							Average	

Test Hole Dimensions

Test Pit #						
Test Hole Shape (select one)		Enter the Diameter (in) if Round was selected		Enter Dimensions (in) if Square or Rectangular was selected	Length	
					Width	

Test Results

Trial No.	Start Time	Stop Time	Time Interval (min)	Initial Water Depth (in)	Final Water Depth (in)	Change in Water Level (in)	Percolation Rate (min/in)	Converted Hydraulic Conductivity (in/hr)
1			0		0	0		
2			0			0		
3			0			0		
4			0			0		
5			0			0		
							Average	

Test Hole Dimensions

Test Pit #						
Test Hole Shape (select one)		Enter the Diameter (in) if Round was selected		Enter Dimensions (in) if Square or Rectangular was selected	Length	
					Width	

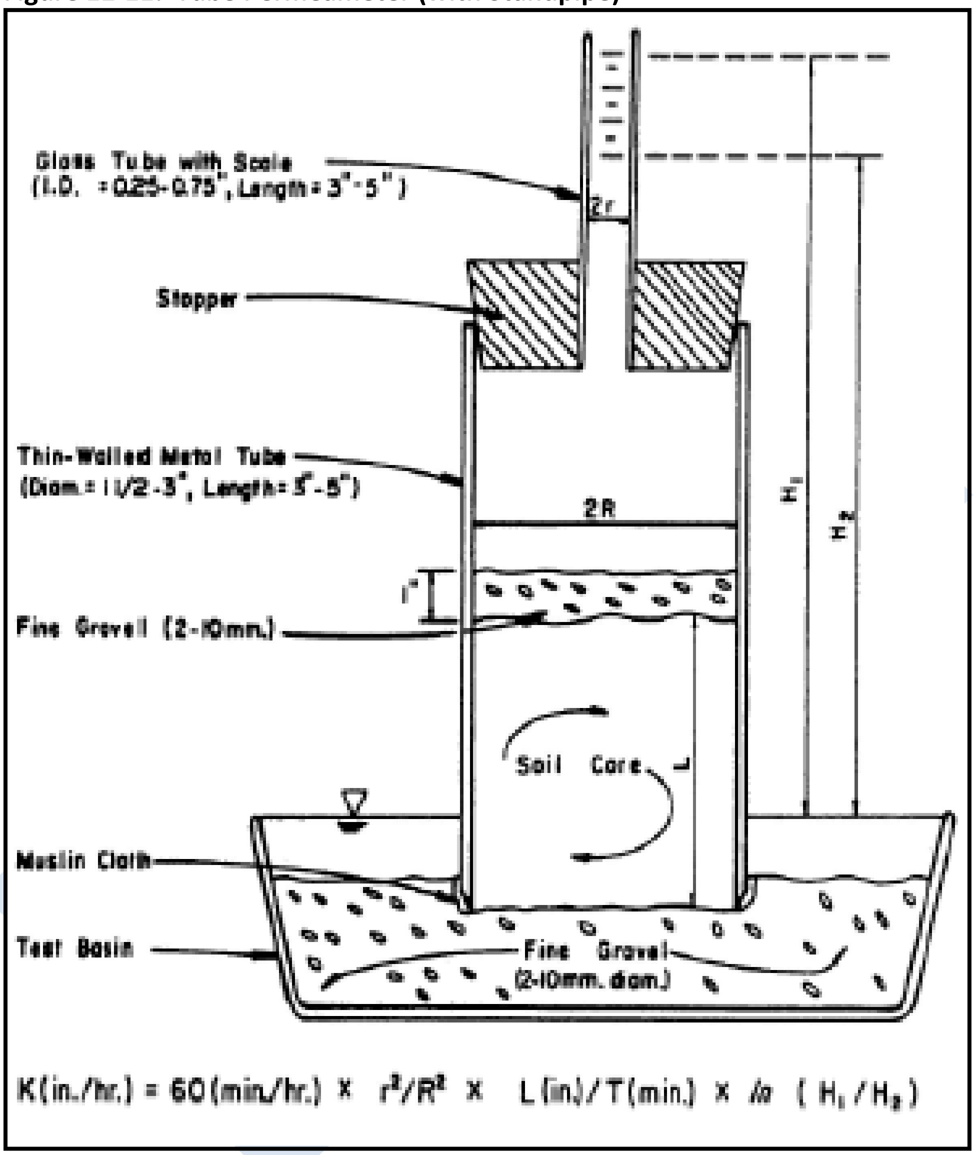
Test Results

Trial No.	Start Time	Stop Time	Time Interval (min)	Initial Water Depth (in)	Final Water Depth (in)	Change in Water Level (in)	Percolation Rate (min/in)	Converted Hydraulic Conductivity (in/hr)
1			0		0	0		
2			0			0		
3			0			0		
4			0			0		
5			0			0		
							Average	

Subsection A2: Tube Permeameter Test

A Tube Permeameter test (depicted in Figure 12-11 below) can be utilized to establish the soil hydraulic conductivity of soils in accordance to the procedures below.

Figure 12-11: Tube Permeameter (with Standpipe)



1. **Equipment Requirements**

   The following equipment is required for performing a tube permeameter test:

   a. A thin-walled (1 millimeter or less in thickness) metal tube, from 1.5 to 3 inches in diameter, 6 inches in length and beveled on the lower outside edge,

   b. A wooden block with dimensions broader than the diameter of the tube in the previous item above, plus a hammer to drive the tube into the soil,

c. A small trowel,

d. A knife to trim the core,

e. Muslin or similar open-textured cloth and a rubber band,

f. A soaking basin of adequate size and depth to soak the cores as prescribed in 2.d. below,

g. Fine gravel (from 2 to 10 millimeters in diameter),

h. A test basin of adequate length (generally 10 inches or greater) and width (generally 4 inches or greater) to accommodate one or more replicate samples at a time. The depth of the basin should be adequate to allow placement of the sample on a layer of gravel while keeping the bottom of the core several inches below the rim of the basin, as prescribed in 2.d. below (See Figure 12-11),

i. A stopper which fits water-tight into the top of the sample tube and which is fitted with a glass standpipe from 3 to 5 inches long and from 0.25 to 0.75 inches in diameter (See Figure 12-11). The standpipe should have a scale for measuring changes in water level over time as required in 3.b. below,

j. A small laboratory wash bottle for refilling standpipe,

k. A clock or watch with second hand,

l. A ruler (with preferably 1:10 engineering scale demarcations,

m. One gallon of water per test. The water should be allowed to stand in an open container until clear of dissolved air. Boiling may be used to remove air provided that the water is allowed to cool down to room temperature before use and

n. A two-millimeter sieve.

2. **Sample collection and preparation**

The samples shall be collected in accordance with the following:

a. Undisturbed samples shall be collected as prescribed in 2.c. below.

   i. When the texture of the soil to be tested is sand or loamy sand, if there is a lack of soil cohesion or the presence of large amounts of coarse fragments, roots or worm channels prevent the taking of undisturbed samples, the tube permeameter test must not be used.
   ii. When the texture of the soil is other than sand or loamy sand and undisturbed samples cannot be taken, the tube permeameter test shall not be used.

b. When the tube permeameter test is used, a minimum of 2 replicate samples must be taken and the procedures outlined in this section shall be followed for each replicate sample to be tested.

   i. It is recommended that more than 2 replicate samples be taken to avoid the necessity of re-sampling in the event that samples are damaged in transport or the results of one or more replicate tests must be rejected due to extreme variability of results, as required in 4.b. below.
   ii. Replicate samples shall be taken from within the same soil horizon at the same location within

the area of interest.

c. The following procedure shall be used to collect each replicate sample:

i. *Step One*: Expose an undisturbed horizontal surface within and a minimum of 3 inches above the bottom of the soil horizon or layer to be tested.

ii. *Step Two*: Position the sampling tube on the soil surface at the point chosen for sampling.

- Care should be taken to avoid large gravel or stones, large roots, worm holes or any discontinuity which might influence results.
- If the soil is excessively dry it may be moistened, but not saturated, provided that the force of falling water is not allowed to act directly upon the soil surface.

iii. *Step Three:* Hold the wooden block on the top of the sampling tube and drive the tube into the soil a distance of 2 to 4 inches (but not entirely through the horizon) using light even blows with the hammer.

- Care should be taken to hit the block squarely in the center and to drive the tube straight down into the soil.
- Do not attempt to straighten the tube by pushing or by hitting the tube on the side with the hammer.

iv. *Step Four:* When the tube has been driven to the desired depth, carefully remove the soil around the outside of the tube, insert a trowel into the soil below the tube and, exerting pressure from below, lift the sampling tube out of the soil.

v. *Step Five:* Trim the bottom of the soil core flush with the sampling tube using a knife and taking care not to smear the soil surface.

- Carefully invert the sampling tube and tap the side lightly with the handle of the knife or similar implement to remove any loose soil which may be resting on the top of the soil core and to verify that an undisturbed sample has been obtained.
- Omit this step in the case of sandy-textured non-cohesive soils with single grain structure.
- Check the top and bottom surfaces of the core sample and discard any sample which has worm holes or large cracks caused by handling.

vi. *Step Six:* After the core has been checked for worm holes or signs of disturbance, stretch a piece of muslin cloth over the bottom of the tube and secure with a strong rubber band.

d. The following procedure shall be used for pre-soaking undisturbed core samples for the tube permeameter test:

i. *Step One*: Place the soil core in the pre-soak basin and fill the basin with water to a point just below the top of the soil core.

- Never fill the basin to a level which is higher than the top of the soil core.

- Never use water directly from the tap to soak cores.
- Use only de-aired water as prescribed in 'm' in the equipment requirements section above.
- Allow the sample to soak until the top surface of the core is saturated with water. This may require only a few minutes of soaking for sandy textured soils or several days for clay textured soils.
- Failure to soak the sample for sufficient time may result in greatly reduced soil hydraulic conductivity measurements due to entrapped air.

ii. *Step Two:* When the sample has soaked for sufficient time, place a 1 inch layer of fine gravel (from 2 to 10 millimeters in diameter) on top of the soil core in the sampling tube.

- Slowly fill the tube with de-aired water taking care not to disturb the surface of the core.
- A small spatula or similar implement may be used to break the fall of the water as it is poured into the tube.

iii. *Step Three*: Immediately transfer the soil core to the test basin in which a layer of gravel has been placed and gently press the soil core into the gravel so that it stands vertically with its base positioned at the desired depth below the rim of the test basin.

3. **Tube Permeameter Testing Procedure**

The following procedure shall be used to conduct the tube permeameter test:

a. *Step One:* When the soil core has been positioned at the desired height within the test basin (see Figure 12-11), fill the test basin to overflowing with de-aired water.

i. Note: The hydraulic head used in the test depends upon the height of the top of the sample tube or standpipe above the rim of the test basin as shown in Figure 12-11.
ii. In general, a higher hydraulic head should be used for heavy textured soils to expedite the test and a lower head should be used for sandy textured soils to prevent an excessively fast flow rate.

b. *Step Two*: Fill the tube to overflowing with de-aired water and record the time, in minutes, required for the water level in the tube to drop a standard distance, e.g., 0.5, 1 or 2 inches.

i. Repeat this step until the rate of fall becomes constant or the difference between the highest and lowest of three successive readings is less than five percent.
ii. When the readings are less than 20 minutes in length the time should be reported to the nearest second.

Alternate Step Two: When the rate of fall observed in "*Step Two*" is slow, the flow rate may be increased by use of a standpipe as shown in Figure 12-11.

i. Carefully insert the standpipe into the top of the sample tube and fill with de-aired water.

ii. The apparatus should be checked for leaks where the standpipe fits into the sample tube. Silicon jelly, petroleum jelly or a similar material may be used to prevent leakage.
iii. Measure the rate of fall of the water level in the standpipe as in *Step Two*.

4. **Determination**

The soil hydraulic conductivity shall be established from the results of the Tube permeameter test based on the following procedures.

a. *Step One*: The soil hydraulic conductivity of each replicate sample tested shall be calculated using the following formula:

$$\mathrm{K} = 60 \text{ min/hr } x \frac{L}{T} \, x \, \frac{r^2}{R^2} \, x \left[\ln\left(\frac{\mathrm{H}_1}{\mathrm{H}_2}\right)\right]$$

where:

K is the soil hydraulic conductivity of the soil sample (in/hr),
L is the length of the soil core (in),
H_1 is the height of the water level above the rim of the test basin at the beginning of each test interval (in),
H_2 is the height of the water level above the rim of the test basin at the end of each test interval (in),
T is the time required for the water level to drop from H1 to H2 during the final test interval (min),
r is the radius of the standpipe (either cm or in) and
R is the radius of the soil core (also either in cm or in and matching the units used for r). Note that when the standpipe is not used, $\frac{r^2}{R^2}$ = 1.
Lastly, "ln" is abbreviation for the natural logarithm.

b. *Step Two*: The variability of test results shall be evaluated as follows:

i. The variability of soil hydraulic conductivity test results shall be considered acceptable only where the results of all replicate tests fall within 1 soil hydraulic conductivity class or 2 adjacent permeability classes. Soil hydraulic conductivity classes are defined by their respective range of hydraulic conductivities, as depicted on the following page in Table 12-10.

Table 12-10: Soil Hydraulic Conductivity Classes

Measured Hydraulic Conductivity (in/hr)	Soil Hydraulic Conductivity Class
20	K5
6 – 20	K4
2 – 6	K3
0.6 – 2	K2
0.2 – 0.6	K1
Less than 0.2	K0

ii. Where the results of replicate tests differ by more than one soil hydraulic conductivity class, the samples must be examined for the defects listed below. If any of these defects are found, the defective core(s) must be discarded and the test repeated using a new replicate sample for each defective replicate sample.

- Cracks, worm channels, large root channels or poor soil tube contact within the sample yielding the highest soil hydraulic conductivity value(s),
- Large pieces of gravel, roots or unsaturated soil within the interior of the sample yielding the slowest soil hydraulic conductivity value(s) and
- Smearing or compaction of the upper or lower surface of the sample yielding the lowest soil hydraulic conductivity value(s).

c. *Step Three*: When test results have been obtained with an acceptable range of variability as defined in "*Step Two*" above, the results shall be interpreted as follows:

i. When the purpose of the test is to determine the design soil hydraulic conductivity at the level of infiltration, the slowest of the test replicate results shall be used for design purposes.

ii. When the purpose of the test is to identify a hydraulically restrictive horizon or substratum above the water table, the horizon or substratum in question shall be considered hydraulically restrictive if the average soil hydraulic conductivity of the replicate samples tested falls within soil hydraulic conductivity class K0 as defined in i of "*Step Two*" above.

iii. When the purpose of the test is to identify an excessively coarse horizon or substratum above the water table, the horizon or substratum in question shall be considered excessively coarse if the average hydraulic conductivity of the replicate samples tested falls within soil hydraulic conductivity class K5 as defined in i of "*Step Two*" above.

d. *Step Four*: Where results of replicate tests exceed the limits of variability allowed in i of "*Step Two*" above, the results shall be interpreted as follows:

i. When the purpose of the test is to determine the design soil hydraulic conductivity at the depth of infiltration, the slowest of the test replicate results must be used for design purposes.

ii. When the purpose of the test is to identify a hydraulically restrictive horizon or substratum above the water table, the horizon or substratum in question shall be considered hydraulically restrictive if the slowest soil hydraulic conductivity of the replicate samples tested falls within soil hydraulic conductivity class K0 as defined in i of "*Step Two*" above.

iii. When the purpose of the test is to identify an excessively coarse horizon or substratum above the water table, the horizon or substratum in question shall be considered excessively coarse if the fastest soil hydraulic conductivity of the replicate samples tested falls within soil hydraulic conductivity class K5 as defined in i of "*Step Two*" above.

Subsection A3: Basin Flooding Test

A Basin Flooding test can be utilized to establish the hydraulic conductivity of fractured bedrock in accordance to the procedures below.

- The basin flooding test must not be conducted in rock strata which have been blasted with explosives.
- Due to the potential safety hazards which are posed by the excavation of a large test basin such as that required for this test, adequate safety measures must be taken including the use of stepped and sloped sidewalls as shown in Figure 2 of Appendix A in N.J.A.C. 7:9A.
  - Access to the test basin during the test procedure is permitted when conditions are safe.
  - Care must be taken and include the use of warning signs or a fence to limit access to the basin by the public during periods when the basin is left unattended, or both, as a minimum precaution.

1. **Equipment Requirements**

   The following equipment is required for performing a basin flooding test:

   a. Excavating equipment capable of producing a test basin as prescribed in 2 below,

   b. Water supply (minimum of 375 gallons per basin filling) and

   c. A means for accurately measuring the water level within the basin as required in 3 below.

2. **Test Basin Preparation**

   The test basin must be prepared in accordance with the following:

   a. A test basin meeting all of the following requirements shall be excavated within or immediately adjacent to the area of concern.

      i. The bottom area of the basin must be a minimum of 50 square feet,
      ii. The bottom of the basin must be made as level as possible so that high areas of rock do not project above the water level when the basin is flooded as prescribed in 3 below and
      iii. If groundwater is observed within the test basin, the basin flooding test must not be used.

3. **Basin Flooding Test Procedure**

   The following procedure must be used to conduct the Basin Flooding test:

   a. *Step One*: Fill the test basin with exactly 12 inches of water and record the time.

      i. Allow the basin to drain completely.
      ii. If the time required for the basin to drain completely is greater than 24 hours, the test shall be terminated and the limiting zone in question shall be considered to be a massive rock substratum.

   b. *Step Two*: If the basin drains completely within 24 hours after the first flooding, immediately refill the basin to a depth of 12 inches and record the time.

i. If the basin drains completely within 24 hours of the second filling, the limiting zone in question shall be considered to be fractured rock substratum.
ii. If water remains in the basin after 24 hours the limiting zone in question shall be considered to be a massive rock substratum.

4. **Hydraulic Conductivity Determination**

A design soil hydraulic conductivity shall only be used if the basin drains completely within 12 hours while performing "*Step Two*" described in 3 above. The design soil hydraulic conductivity used shall be 0.5 in/hr.

Subsection A4: Modified Basin Flooding Test

This test is intended for testing the soil hydraulic conductivity of green infrastructure BMPs, under post-construction conditions.

- Due to the potential safety hazards which are posed by the test basin and ponding water required for this test, adequate safety measures must be taken in accordance with N.J.A.C. 7:9A.
  - Access to the test basin during the test procedure is permitted when conditions are safe.
  - Care must be taken and include the use of warning signs or a fence to limit access to the basin by the public during periods when the basin is left unattended, or both, as a minimum precaution.

1. **Equipment Requirements**

The following equipment is required for performing a Modified Basin Flooding test:

a. A supply of water,

b. A means for accurately measuring the water level within the BMP as required in 3 below and

c. A timepiece or timer to record the lapse of time.

2. **Test BMP Preparation**

The post-construction hydraulic conductivity test must the conducted at the bottom of the excavation of the BMP before the sand layer or soil bed is placed into the BMP.

- If ponding water is observed in the BMP when no precipitation occurs within 72 hours prior to the observation of the ponding water in the BMP, the modified basin flooding test shall not be used and the BMP shall be determined to fail the test.

3. **Modified Basin Flooding Test Procedure**

a. *Step One*: Fill the test BMP with 1/3 of the maximum designed water depth above the lowest excavated elevation and record the time. Allow the BMP to drain to the lowest excavated elevation completely. If the time required for the BMP to drain completely is greater than 24 hours, the test shall be terminated and the green infrastructure BMP shall be determined to have failed to drain.

b. *Step Two*: If the BMP drains completely within 24 hours after the first flooding, immediately refill the BMP to 1/3 of the_maximum designed water depth and record the time.

4. **Soil Hydraulic Conductivity Determination**

The soil hydraulic conductivity is calculated using the following equation:

$$K_s = \frac{12\,v}{T\;x\,(A_b + 0.5A_s\,)}$$

where:

K_s is the saturated soil hydraulic conductivity (inch/hour),

v is the volume occupied by the 1/3 of the maximum designed water depth in the BMP (cubic feet),

T is the time to drain the BMP (hours),

A_b is the surface area of the bottom of the BMP (square feet) and

A_s is the surface area of the sides of the BMP for the 1/3 of the maximum designed water depth (square feet)

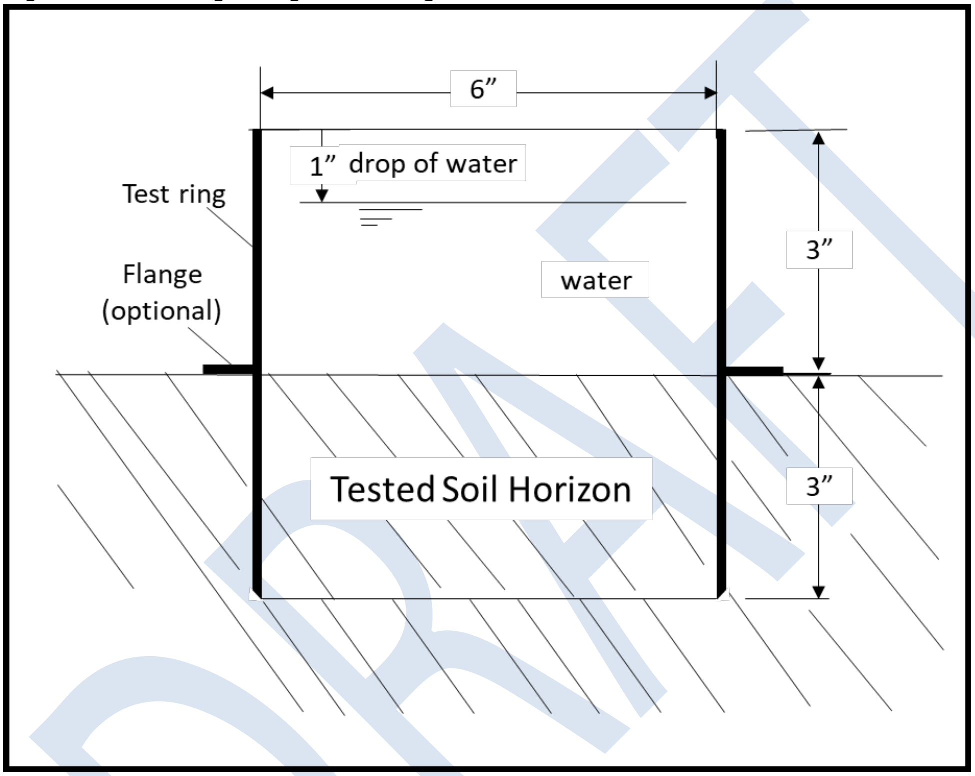
For a BMP with a bottom area measuring 10 feet by 5 feet and a 2 feet of maximum design, A_b = 50 square feet. The value for A_s is equal to the sum of 2 sides measuring 10 feet in length plus 2 sides measuring 5 feet in length, which is then multiplied by the 2/3 foot depth, i.e., A_s = 2 x (10 ft +5 ft) x 2/3 ft = 20 square feet.

Subsection A5: Single Ring Infiltration Test

A Single Ring Infiltration test may be used to establish the soil hydraulic conductivity of soils in accordance to the procedures below.

- Single Ring Infiltration tests must not be conducted in frozen ground nor in holes which have been allowed to remain open to the atmosphere for periods greater than three days.
- The required configuration of the test is illustrated in Figure 12-12 below.

Figure 12-12: Single ring test configuration



1. **Equipment Requirements**

   The following equipment is required for the Single Ring Infiltration test:

   a. A 6 inch long beveled edge test ring with an inside diameter of 6 inches,

      i. It is better if the test ring has an outer flange located 3 inches from the lower end of the test ring in order to stop the test ring from penetrating more than 3 inches into the soil layer.
      ii. Better observations are made using a test ring that has a mark on the inner wall, located 1 inch below the top end. With this mark, there may not be a need for the ruler.

   b. A leveler (a carpenter's level is best),

   c. A piece of filter fabric (at least 1.5 inches by 1.5 inches, but less than 3 inches by 3 inches),

   d. A block of wood,

e. A hand sledgehammer,

f. A small hand shovel (trowel),

g. A supply of water (50 gallons is generally adequate),

h. A stopwatch with an accuracy to at least one tenth of a second,

i. A ruler (12 inches or longer, engineering scale) and

j. Recording papers.

2. **Test Location Preparation**

The test location shall be prepared in accordance with the following steps:

a. Excavate the test pit to the soil layer to be tested. The tested soil layer must be the most restrictive layer of the soil layers within the soil profile pit.

b. The surface of the soil shall be nearly level. However, do not compact the soil when leveling the surface.

c. Remove any rock fragments that will prevent the test ring from being driven into the soil.

3. Test Procedure

a. *Step One*: Drive the test ring into soil

i. Place the block of wood on top of the test ring. Using the hand sledge and block of wood, drive the test ring a depth of 3 inches into the test soil layer. Move the wood block around the edge of the test ring top every one or two blows so that the test ring will penetrate the soil uniformly. Do not shake or shift the test ring sideways so as to cause annular space between the test ring and the soil surface surrounding the test ring, which may lead to a leak of water from the annular space.

ii. Use a leveler to check whether the test ring is leveled.

iii. If the surface of the soil surrounding the wall of the test ring is only slightly disturbed, tamp the disturbed soil adjacent to the inside and outside wall of the test ring until the soil is as firm as it was prior to disturbance. If the surface of the soil surrounding the wall of the test ring is excessively disturbed (signs of extensive cracking, excessive heave, and the like), reset the test ring to other locations.

b. *Step Two*: Pre-soaking the soil

i. Place the piece of filter fabric on top of the soil in the center of the test ring.

ii. *For sandy textured soils*, including sands, loamy sands and sandy loams, where a rapid infiltration rate is anticipated,

- Place the ruler into the test ring if the test ring is not marked with a 1 inch mark.

- Gently and slowly add water from a position close to the piece of filter fabric resting on the soil and slowly lift the water container as the water level rises. Fill the test ring to the top with water.
- Let the water drain completely.

iii. *For other than sandy textured soils*,

- Place the ruler into the test ring if the test ring is not marked with a 1 inch mark.
- Gently and slowly add water from a position close to the piece of filter fabric resting on the soil and slowly lift the water container as the water level rises. Fill the test ring to the top with water.
- Let the water drained completely. If the elapsed time for the water level to drop to a height of 1 inch is more than 60 minutes, stop timing.

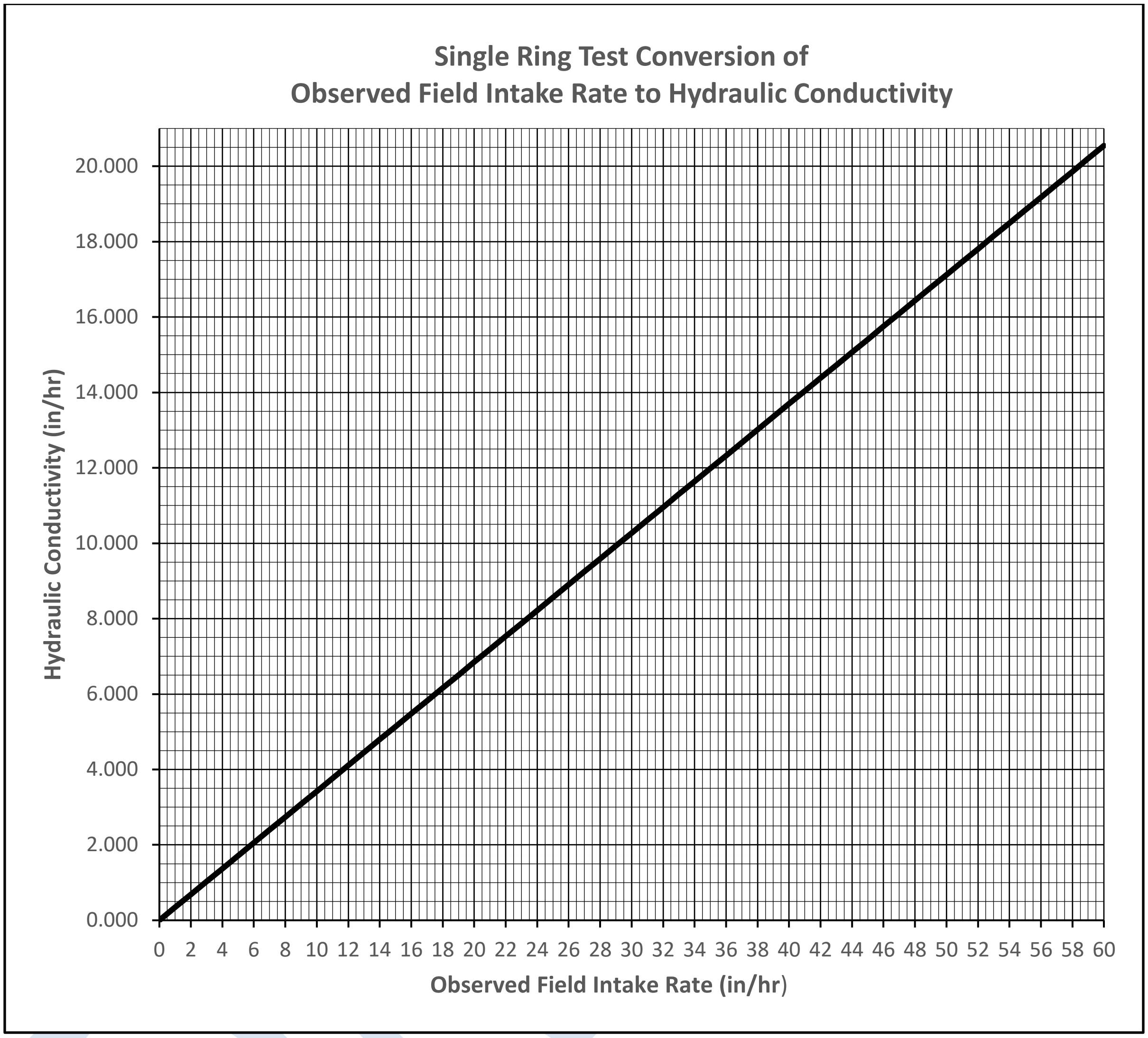
c. *Step Three*: Observed Field Intake Rate Determination

Immediately following the pre-soak procedure, the Observed Field Intake Rate shall be determined using the following procedure:

i. Gently and slowly add water from a position close to the piece of filter fabric resting on the soil and slowly lift the water container as the water level rises. Fill the test ring to the top with water.
ii. Start the stopwatch as soon as the water fills to the top of the test ring.
iii. Measure the elapsed time for the water to drop 1 inch. Record the elapsed time in each test.
iv. Repeat steps *i* to *iii* until the elapsed time to drop 1 inch of water becomes stabilized. If the difference between two measurements of the time is within five tenths of a second, it is deemed stabilized.
v. The observed field intake rate (in/hr) is 1 inch divided by the stabilized elapsed time to drop 1 inch of water.
vi. At least three observed field intake rates shall be observed before the test is ended.
vii. If the elapsed time to drop 1 inch of water is more than 1 hour for two consecutive tests, the soil is deemed to have an observed field intake rate less than 1 in/hr, and the test can be ended.

4. Hydraulic Conductivity Determination

The observed field intake rate **must be converted** to the hydraulic conductivity by using the curve found on the following page:



When the observed field intake rate is greater than 60 in/hr, the hydraulic conductivity shall be reported as "greater than 20 in/hr." When the observed field intake rate is less than 1 in/hr, the hydraulic conductivity shall be reported as "less than 1 in/hr."

5. Reporting the test results

The information in the test report shall include, at a minimum, the following items:

a. Date and time,

b. Project name and location,

c. Test pit identification number,

d. The descriptions of the tested soil layer, such as classification of soil and the thickness of the soil layer,

e. The elapsed time for each round of the test, including those tests conducted before reaching the stabilized rate,

f. The observed field intake rates,

g. The conversion of the Observed Field Intake Rates to the values of the hydraulic conductivity,

h. The averaged hydraulic conductivity for the tested soil layer and

i. The averaged soil hydraulic conductivity for the tested soil layer reported as the "tested soil hydraulic conductivity."

Subsection A6: Cased Borehole Infiltration Test

A Cased Borehole Infiltration test is only recommended when the site characteristics do not allow for an infiltration test to be performed in a test pit, a single-ring infiltration test or the standard Borehole Infiltration test found in ASTM D6391 (Standard Test Method for Field Measurement of Hydraulic Conductivity Using Borehole Infiltration). Note that all ASTM standards referenced herein are interpreted to mean the active standard published by ASTM International.

1. **Equipment Requirements**

The following equipment is required for the percolation test:

a. Hollow-Stem Auger as described in ASTM D6151,

b. A casing pipe having sufficient length to reach the tested soil layer,

c. A leveler (a carpenter's level is best),

d. Fine gravel,

e. A supply of water,

f. A stopwatch with an accuracy of to at least one tenth of a second,

g. A ruler (12 inches or longer, engineering scale),

h. A thermometer that can be placed inside the casing pipe and

i. Recording papers.

2. **Test location Preparation**

The test location shall be prepared in accordance with the following steps:

a. The casing installation must be completed using ASTM D6151, Hollow-Stem Auger Method, with the inner diameter of the pipe being no less than 4 inches.

b. Infiltration tests must not be completed within the same borehole as the hollow-stem augered borehole conducted for studying soil characterization, but must be completed no more than 25 feet away from the soil characterization borehole location(s).

c. Dry excavation is preferred to the use of drilling fluids.

d. Advance a borehole to the depth of the proposed infiltration interface depth using the Hollow-Stem Auger Method (ASTM D6151). The augered hole diameter must be at least 2 inches larger than the outer diameter of the inner casing. The inner casing will consist of the casing pipe with a minimum inner diameter of four inches and a smooth, square bottom.

e. Push the inner casing within the auger hollow stem to the infiltration interface and firmly set into the bottom of the borehole.

f. The casing shall extend to a depth as follows:

   i. If the tested soil layer is relatively pervious, a least 2.5 times the inner diameter of the casing pipe below the top of the tested soil layer and at least 1.5 times the inner diameter of the casing pipe above the bottom of the tested soil layer.
   ii. If the tested soil layer is relatively impervious, a least 5 times the inner diameter of the casing pipe below the top of the tested soil layer and at least 3.5 times the inner diameter of the casing pipe above the bottom of the tested soil layer.

g. Use a borehole plane to scarify the soil surface at the bottom of the casing and remove any remaining loose soil. Measure the depth from the top of casing to the bottom of the hole to the nearest 0.01 feet.

h. The top of the casing pipe shall be leveled.

i. Remove the augers.

3. Pre-soaking the soil

a. Fill the casing pipe with water at a very low rate so as to not disturb the bottom sediments.

b. Place water to a depth of at least 6 inches above the bottom of the casing and readjust every 30 minutes for 1 hour.

4. Observation and Recording

Immediately following the pre-soaking procedure, the incremental change in the water depth shall be determined using the following procedure:

a. Place the thermometer to the bottom of the casing pipe. Record the temperature of the water at the bottom of the casing. Pull out the thermometer.

b. Fill the casing pipe with water until it reaches the top of the casing pipe.

c. The incremental change in the water level during the last 30 minutes of the presoaking period must be applied to the following standard to determine the time interval between readings:

   i. If the incremental change in the water level is 2 inches or more, use 10 minute measurement intervals.

ii. If the incremental change in the water level is less than 2 inches, use 30 minute measurement intervals.

d. Measure the incremental change in the water level for each time interval. Measurement of the water level must continue at the interval determined until a minimum of 8 readings are completed or until a stabilized rate of incremental change is obtained, whichever occurs first. A stabilized rate of incremental change means a difference of 0.25 inches or less in the increments observed, between the highest and lowest readings, for four consecutive readings.

e. The water level must remain at least 12 inches above the bottom of the hole. All water added must be recorded as a volume along with the time of addition.

5. Hydraulic Conductivity Determination

The observed field intake rate must be converted to the hydraulic conductivity by using the following procedure:

a. Use Method B (9.4) in the ASTM D6391 standard,

where:

$$K_1 = R_T\, G_1 \frac{ln\left(\frac{Z_1}{Z_2}\right)}{(t_2 - t_1)} \qquad (1)$$

$$G_1 = \left(\frac{\pi d^2}{11 D_1}\right)\left[1 + a\left(\frac{D_1}{4 b_1}\right)\right] \qquad (2)$$

b. The values for Equations (1) and (2), shown above, are determined as follows:

i. R_T = [2.2902(0.9842 ^{T})]/[$T^{0.1702}$] and T is the temperature of the water at the bottom of the casing, converted to degrees Celsius (°C),

ii. D_1 is the inner diameter of the casing,

iii. d = the inner diameter of the standpipe = D_1 for this test,

iv. b_1 is the thickness of the tested layer between top of soil layer and the bottom of the casing,

v. a = +1 for an impermeable base at b_1 ,
= 0 for an infinite depth (greater than or equal to 20* D_1) of tested material and
= -1 for a permeable base at b_1,

vi. c is the decrease in the water depth between t_1 and t_2,

vii. Z_1 is the water depth at time t_1,

viii. $Z_2 = Z_1 - c$, meaning it is the water depth at time t_2,

ix. t_1 is the time at the beginning of the observation,

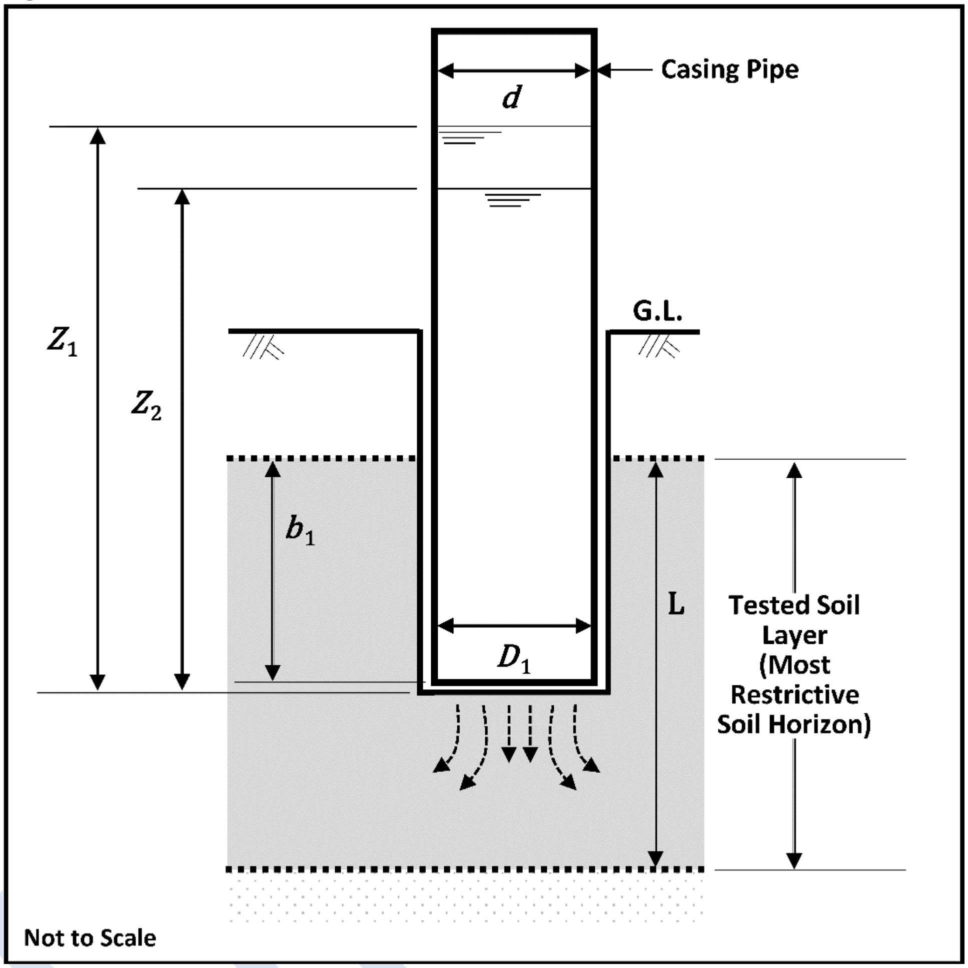
x. t_2 is the time at the end of the period yielding the decrease in the water depth, c and

xi. K_1 is the isotropic hydraulic conductivity at time t

c. Use the arithmetic average of the conductivities obtained from the stabilized rate.

Figure 12-13 depicted below illustrates the parameters described above, where L is thickness of the most restrictive soil horizon and $D_1 << b_1$:

Figure 12-13: Cased Borehole Test Parameters



6. Reporting the test results

The information in the test report shall include, at a minimum, the following items:

a. Date and time,

b. Project name and location,

c. Borehole identification number,

d. Surface elevation,

e. The description of the tested soil layer, such as classification of soil and the thickness, the elevation of the top and the bottom of the soil layer,

f. The augur size and the depth of drilling,

g. The water temperature,

h. The inner diameter of the casing pipe,

i. The length of the casing pipe from the top to the bottom,

j. The beginning and end time for each round of the test, including those tests conducted before reaching the stabilized rate,

k. The incremental changes in the water depth,

l. The averaged hydraulic conductivity for the tested soil layer and

m. The averaged hydraulic conductivity for the tested soil layer, which is reported as the "tested hydraulic conductivity (in/hr)."

A sample of a worksheet for the conversion of the percolation rate to the hydraulic conductivity is provided on the following page, in Figure 12-14. A workbook with all of the test worksheets is available for download at

{*updated link to be inserted here upon chapter finalization – file is currently located on the Draft BMP Manual Chapters Available for Comment page at:* }
https://njstormwater.org/bmp_man_comments.htm.

Figure 12-14: Cased Borehole Test Data Sheet

Cased Borehole Hydraulic Conductivity Test Data Sheet

Project: ______________

Municipality: ______________ Date: ____________

Test Hole Dimensions

Borehole # ______________ Surface Elev. ____________

Trial No. ______________

Borehole Inner Diameter (D1)	4	inch
Thickness of tested layer between bottom of casing and top of underlying stratum (b1)	10	inch
Testing Pipe Length	140	inch
Tested Soil Layer Depth (L)	30	inch
Tested soil textual classification (select from drop down menu)	**Loam**	
Temperature (Fahrenheit)	68	°F
a value	-1	
Rt	1.00024254	
G1	1.02815760	

Test Time (minutes)	Z (in)	K1* (in/hr)	
0	120.000		
10	100.000	1.125	
20	80.000	1.377	
30	60.250	1.749	
40	40.000	2.528	
50	39.500	0.078	0.07761664
60	39.000	0.079	0.07860542

"-" indicates negative or zero value, which is ignored from the calculation.

Tested Permeability Rate, K1 = **1.251** (Mean Value of K1* between 1Q and 3Q)

Q1 = 0.340

Q3 = 1.656

References

ASTM International. 2011. ASTM D6391 Standard Test Method for Field Measurement of Hydraulic Conductivity Using Borehole Infiltration. West Conshohocken, PA.

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