



Understanding and interpreting soils and soil boring reports for infiltration BMPs



Caution: The MPCA *Highly recommends* field determination of soil infiltration rates. See Determining soil infiltration rates. If soil borings or soil pits are utilized, it is *Highly recommended* a certified soil scientist or geotechnical engineer

interpret the borings.

Knowing the soils in the area of a proposed infiltration best management practice (BMP) helps determine the suitability and design of the BMP. Soils determine how quickly stormwater will infiltrate, affect plant growth, and affect the fate and transport of pollutants. Section 16.10 of the Construction Stormwater general permit (https://stormwater.pca.state.mn.us/index.php?title=2018_Minnesota_Construction_Stormwater_Permit) states "Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates". The Minnesota Stormwater Manual recommends that soil borings or pits be dug to verify soil types and infiltration capacity characteristics and to determine the depth to groundwater and bedrock.



Example soil boring. Photo courtesy of Barr Engineering.

This article presents a discussion of soil sampling, soil borings, and interpreting soil information.

Caution: Objectives for collecting soil borings for stormwater infiltration practices differ from objectives for collecting borings for structural engineering purposes. Identification of low permeability or restrictive layers in soil is critical to proper design and construction of infiltration practices. In particular see the sections on *How to order a soil boring* and *Restrictive layers in soil profiles*.

Caution: It is Highly Recommended that soil borings be extended a minimum of 5 feet below the bottom of the proposed infiltration practice and that the most restrictive soil layer be considered in estimating infiltration rate.

Warning: The Construction Stormwater General Permit states "Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates"

This video (<https://www.youtube.com/watch?v=bNTIhjH-tvc>) provides an example of the impact of even thin layers of clay on infiltration.

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Number of borings to collect

The recommended number of borings is shown in the following table.

Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.

Link to this table

Surface area of stormwater control measure (BMP)(ft ²)	Borings	Pits	Permeameter tests
< 1000	1	1	5
1000 to 5000	2	2	10
5000 to 10000	3	3	15
>10000	4 ¹	4 ¹	20 ²

¹an additional soil boring or pit should be completed for each additional 2,500 ft² above 12,500 ft²

²an additional five permeameter tests should be completed for each additional 5,000 ft² above 15,000 ft²



Example of direct push technology used to collect a soil sample.

Historical site information

Prior to ordering a soil investigation, it is highly recommended that historical records are evaluated for the site. What other use(s) has the site had? Are historical soil borings available for the site? Could site soils be contaminated? A list of possible site soil constraints and additional information can be found here (http://stormwater.pca.state.mn.us/index.php/Stormwater_infiltration). This page (http://stormwater.pca.state.mn.us/index.php/Screening_assessment_for_contamination_at_potential_stormwater_infiltration_sites#Conducting_a_property_review) provides a summary of useful information sources for investigating the history of a site.

The more variable the site history, the greater variety of soil types you may expect to find. For example, a rural 1 acre site that has always been farmed will probably have more consistent soils from one location to the next compared to an urban 1 acre site which has had many different uses, including importation of fill materials. An urban site with many previous uses may require a larger amount of soil investigation to properly identify the soil profile.

Types of soil sample collection methods


There are several types of soil sample collection methods which can be used to determine soil characteristics. Sample collection methods are listed in the following table from simplest/quickest/cheapest to complex/slower/expensive. The table describes advantages and limitations and provides references and photographs for each of these methods.

1. Soil probe
2. Hand held or machine auger
3. Excavation test pit or trench
4. Direct push technology (DPT)
5. Rotasonic drilling
6. Soil boring (hollow stem auger or HSA method)



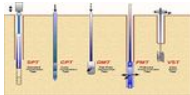
Of these six types of soil sample collection methods, soil borings are *highly recommended*. Soil borings provide the greatest amount of data. Knowing existing conditions as a result of proper soil investigation allows the design team to develop an accurate design and cost estimate prior to bidding or construction. Finding unexpected soil conditions during construction can result in time delays and costs associated with modifying the design.

Summary of drilling methods to collect soil samples for infiltration basins. Click on an image to enlarge.

Link to this table

Drilling Method	Description	Sample Collection Possible	Depth	Advantages	Limitations	Photo reference/credit	Example Photo
Soil Probe	Soil probes are a basic form of soil sampling, used to collect shallow or surface samples by pushing a T-shaped probe into the ground. The probe cuts a core sample smaller than the diameter of the probe body. The sample can also be collected within a liner inside the probe.	Small diameter soil surface profile	≤ 3 feet	Inexpensive Quick Easy to use	May not be able to collect enough information to determine if infiltration is possible due to depth and limited soil information collected. Unable to perform blow counts. ¹	Iowa State University - University Extension (http://www.ipm.iastate.edu/ipm/icm/2005/10-10/scn.html)	

Drilling Method	Description	Sample Collection Possible	Depth	Advantages	Limitations	Photo reference/credit	Example Photo
Hand held or machine auger	The auger is held vertically and is driven into the ground and rotated by the handle while applying leverage. At every 30 cm of depth penetrated, the auger is taken out and the samples of the soils are collected separately for examination. This method works best in loose materials ranging from clay to sand to gravel.	Bag/jar samples of material	≤ 50 feet	Inexpensive, Easy to use. Large selection of auger types	Only suitable for unconsolidated deposits (loose materials) Slow compared to other methods Equipment can be heavy. Unable to perform blow counts ¹ .	University of New Hampshire - Institute for the Study of Earth, Oceans, and Space (http://www.eos.unh.edu/Spheres_0812/forest.shtml)	
Excavation Test Pit or Trench	A pit or trench is dug manually or with an excavator to depth desired in order to visually observe subsurface soil conditions.	Grab samples or bulk samples of material	≤ 20 feet	Quick, Easy to do, Shallow exploratory drilling method	Must be onsite during excavation to coordinate locations and depth as well as observe subsurface soils and behavior, taking photos and soil samples Shallow form of subsurface drilling Must be cautious of collapsible soils when digging Requires back fill and compaction. Unable to perform blow counts ¹ .	United States Department of Agriculture - Natural Resources Conservation Service New Hampshire (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nh/newsroom/photos/?cid=stelprd1254763)	

Drilling Method	Description	Sample Collection Possible	Depth	Advantages	Limitations	Photo reference/credit	Example Photo
Direct Push Technology (DPT)	<p>Geoprobe or Strataprobe is pneumatic hammer driven with continuous sampling into plastic tubes. Blow counts¹ are not provided through this method. Single tube and dual tube systems are available.</p>	Bag/jar samples of material	usually up to 60 feet but can go to over 100 feet	<p>Minimal to no cuttings Quick and efficient Small, relatively mobile rig Continuous sampling</p>	Unable to perform blow counts ¹	Minnesota Pollution Control Agency	
Rotosonic	<p>Rotosonic drilling is a method where continuous samples are taken. It is good for penetrating through most formations, but due to the ground disturbance, is not suitable for collecting undisturbed samples. Samples are brought out of the subsurface in clear plastic sleeves.</p>	Bag samples of material	>100 feet	<p>Continuous sampling Quick and efficient Produces little to no waste</p>	<p>Mobilization cost can be expensive. Unable to perform blow counts¹.</p>	<p>United States Geological Survey - Eastern Mineral and Environmental Resources Science Center (http://minerals.usgs.gov/east/baselines/rotodrill1.html)</p>	
Standard Penetration Test (SPT) using Hollow Stem Auger (HSA) drilling method	<p>Augers act as casing for borehole (prevent caving) Center of augers is hollow for sampling</p>	<p>Bag/jar sample Split-spoon (or other disturbed samples) Thin-wall samples (or other undisturbed samples)</p>	>100 feet	<p>Augers do not need to be removed to sample Can be used above and below water table. Can collect blow counts¹.</p>	<p>Heaving sands may clog the hollow stem auger. Can be slow when drilling in soils with cobbles and boulders.</p>	<p>U.S. Department of Transportation - Federal Highway Administration (http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/04_b.cfm)</p>	

¹ For information on blow counts, link here (https://stormwater.pca.state.mn.us/index.php?title=Understanding_and_interpreting_soils_and_soil_boring_reports_for_infiltration_BMPs#Disturbed_versus_undisturbed_soil_samples) or link here for table illustrating blow counts (<http://www.geotechdata.info/geotest/standard-penetration-test.html>).

Disturbed versus undisturbed soil samples

There are two categories of soil samples, disturbed and undisturbed.

1. A disturbed sample does not retain the in-situ structure of the soil. These types of samples can be used for classification tests such as the grain size analysis which is described in greater detail below. There are generally three types of disturbed samples that can be collected during an investigation.
 1. Bulk samples. These can be a small grab sample that fits into a zip-lock bag. Larger samples can be collected in 5-gallon buckets. These samples are usually auger cuttings from the top 5 feet, or taken from an excavation test pit or trench.
 2. Split-spoons samples are 1-3/8 inch diameter cylindrical columns of soil obtained using a split-spoon sampler. The sampler is pounded into the soil in three or four 6-inch drives using a driving weight assembly. The number of hammer blows needed to pound the spoon 6 inches in depth is called the blow count (<http://www.geotechdata.info/geotest/standard-penetration-test.html>) and is recorded on the boring logs. The 6 to 12 inch and 12 to 18 inch blow counts are added and recorded as the n-value for that split-spoon. Gravel and cemented soils have high blow counts while clay and soft soils will have low blow counts. Split-spoon samples are taken during a soil boring. This type of sample will give the most relevant information in determining soil suitability for an infiltration BMP.
 3. Continuous sampling methods provide a complete record of the soil beneath a drilling site. Samples are usually collected in plastic 5-foot liners. Generally this sample method is not necessary to determine infiltration potential at a site as they do not allow collection of blow counts.
2. Undisturbed samples are recovered completely intact and the in-situ structure and stresses are not modified in any way during collection. Samplers used to collect relatively undisturbed samples include Thin-wall, Modified California, Piston, and Pitcher. Undisturbed samples are generally not collected when trying to determine infiltration potential at a site as they do not allow collection of blow counts.

How to order a soil boring

Having a geotechnical engineer/technician (engineer) present during drilling investigations is highly recommended as they specialize in field reconnaissance, coordinating and directing the drillers, logging boreholes, and collecting soil samples. Having an engineer onsite during drilling investigations will cost more initially, but if subsurface information is inaccurate or inadequate, a greater number of assumptions need to be incorporated into the design, which increases the potential for negative impacts later in the design life and/or costly surprises during construction.

If an engineer cannot be onsite during drilling investigations, good communication with the drillers prior to performing soil borings will help ensure the most valuable information is obtained. It is important the drillers understand the purpose of the investigation. Explain that drilling is being done to find soils indicative of restrictive layers (http://stormwater.pca.state.mn.us/index.php?title=Understanding_and_interpreting_soils_and_soil_boring_reports_for_infiltration_BMPs&action=edit&action=8); i.e. soils that inhibit the flow of water. Listed by most restrictive to least restrictive, these soils are: clay, silt, sand, and gravel. Provide drillers with the following guidance:

- If recovery in a split-spoon sample is less than six inches, drill two feet deeper and perform another split-spoon sample.
- If a confining layer is found, or there is low recovery in a split-spoon, reduce sampling intervals to every two feet. Record the presence of the most restrictive layer, even if that material is not the most abundant in the split-spoon sample.
- If low recovery is encountered, explain in the field notes why the driller thinks this is happening (i.e. gravel in the shoe of the split-spoon)
- Blow counts or “N” values found during a Standard Penetration Test (SPT) are critical to determining the presence of restrictive layers. For information on standard penetration tests, see here (<http://www.geotechdata.info/geotest/standard-penetration-test.html>)
- If soil boring auger refusal is encountered prior to depth desired, offset approximately five feet from initial borehole, blind-drill (continuous drilling without soil sampling) to refusal depth, and continue drilling/sampling from that point. Note there will be an additional cost associated with the offset and blind drill. If the second attempt results in the same refusal as the first, the driller should call the engineer to inquire about next steps immediately, prior to

leaving the site. During that call, ask drillers to describe why they think refusal has been met and, if necessary to drill deeper, discuss alternative drilling methods or an additional offset.

- Ask the driller to include soil type, recovery, blow counts, and presence of water in their field logs, and request a copy of their field logs.
- It is highly recommended that the drillers use a standard form (attached). If they do not use a standard form, request to see their form prior to drilling and suggest modifications as necessary.
- To the extent possible, the final boring logs should contain information listed in the table *Summary of Information to Include on a Boring Log* (see below).

Information gathered from soil samples




Soil samples help provide a general subsurface profile and can be used to measure engineering properties, including those properties indicating the presence of a restrictive soil layer. When a soil boring is performed to determine if a site is suitable for infiltration, the following information should be requested from a soil boring company or geotechnical engineer (see attached Table 2 for greater detail):

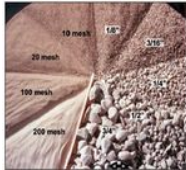
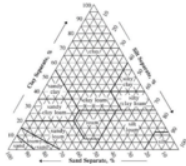


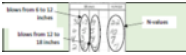
1. Boring name
2. Project name/project number/client/nearest city or county
3. Boring coordinates (location) and ground surface elevation (local reference to a fixed point on the site is acceptable)
4. Start / End date and time
5. Site conditions at time of sampling, including weather
6. Type and depth of boring
7. Type of drilling method
8. Sampling method and sample type
9. Sample recovery
10. Soil Density or Consistency
11. Soil Color (includes mottling or redoximorphic feature color, abundance, size and contrast)
12. Grain size determined by Particle Size Distribution (PSD) lab test
13. Particle shape (<http://www.ltu.se/research/subjects/Geotechnical-engineering/Forskningsprojekt/Soil-behavior-considering-particle-s-shape-1.78260?l=en>)
14. Classification (ASTM D2487-11): USDA (<http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/training/soilsOther/soil-USA-textural-class.pdf>), AASHTO, and USCS (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053562) (with USCS being the most commonly used)
15. Sedimentary structure
16. Layer boundaries and thickness (transition in color or between two different types of soil)
17. Blow Counts
18. Depth to bedrock, and/or refusal
19. Depth to groundwater (indicated during drilling by wet or saturated soil moisture content and after drilling by recording the water level in an open borehole typically measured after 24 hours)
20. Plasticity (plasticity of a soil is its ability to undergo deformation without cracking and is greatly influenced by the particle size, water content, and aging)
21. Moisture
22. Inclusion is used to describe the secondary mineral component in a soil sample
23. Topsoil (A Horizon) thickness
24. Photos

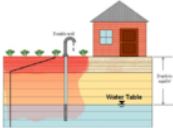


Summary of information to include on a boring log. To enlarge an image, click on the image.

Link to this table

Include on log	Description	Example / Photo
Boring name or number	Important to identify and distinguish each boring with a unique name	Most borings start with B or BH and end with a number Example: B-01 or BH01

Include on log	Description	Example / Photo																																				
Project name, number, client, and city or county	Information is used identification purposes and for sample storage																																					
Boring coordinates and ground surface elevation	Each hole should be located and verified with coordinates in case of discrepancies If possible, record ground surface elevation with GPS Locations should be shown on a figure or map	Include Datum (NAD29 vs NAD83, NAVD 1929 or NAVD 1988) Understand coordinate systems. For example. UTM is in meters while Lat/long is in degrees or deg/min/sec																																				
Start and end date and time	Helpful for tracking how long drilling is taking per borehole A known date can help identify the project for future reference Will be used to determine the hammer efficiency if performing blow counts. Examples include:	Date Boring Started: 3/1/16 10:00 am Date Boring Completed: 3/2/16 11:30 am																																				
Type of drill rig and boring depth	<ul style="list-style-type: none"> ▪ rubber tire ATV/buggy rig ▪ truck rig ▪ track rig (CME750) 																																					
Drilling method	Record method used or depth where there is any change in the method being used. Different drilling methods may require different sampling techniques or procedures. Drilling methods include: Hollow Stem Auger, Direct Push Technology, Mud Rotary, Rotasonic, Air Rotary, ODEX.	Rotasonic drill on truck rig. Source: United States Geological Survey - Eastern Mineral and Environmental Resources Science Center (http://minerals.usgs.gov/east/baselines/rotodri111.html)																																				
Sampling method and sample type	<ul style="list-style-type: none"> ▪ Split-spoon samples (disturbed sample) ▪ Grab samples (disturbed sample) ▪ Bulk samples such as auger cuttings <p>Make sure to record the date, project number, borehole location, depth of sample, N value (for SPT sample), and sample number on each sample collected</p>	 <p>Source: Photo courtesy of Barr Engineering</p>																																				
Sample recovery	Record recovery of samples for comparison to length of drilled sample Note assumed reasoning for poor recovery (i.e. bedrock, gravel stuck in splitspoon)	For example, the split-spoon was pounded 18" but only 10" of soil was recovered in the sampler																																				
Soil Density or Consistency	Different characterization of coarse and fine grained samples Based on N-value of sample	<table border="1" data-bbox="1071 1438 1453 1564"> <thead> <tr> <th colspan="2">Granular Soils</th> <th colspan="2">Fine-Grained Soils</th> </tr> <tr> <th>N-value</th> <th>Qualitative Density</th> <th>N-value</th> <th>Qualitative Consistency</th> </tr> </thead> <tbody> <tr> <td>blows per foot</td> <td>Description</td> <td>blows per foot</td> <td>Description</td> </tr> <tr> <td><4</td> <td>Very Loose</td> <td><2</td> <td>Very soft</td> </tr> <tr> <td>4 to 10</td> <td>Loose</td> <td>2 to 4</td> <td>Soft</td> </tr> <tr> <td>10 to 30</td> <td>Medium dense</td> <td>4 to 8</td> <td>Medium stiff</td> </tr> <tr> <td>30 to 50</td> <td>Dense</td> <td>8 to 15</td> <td>Stiff</td> </tr> <tr> <td>> 50</td> <td>Very dense</td> <td>15 to 30</td> <td>Very stiff</td> </tr> <tr> <td></td> <td></td> <td>> 30</td> <td>Hard</td> </tr> </tbody> </table>	Granular Soils		Fine-Grained Soils		N-value	Qualitative Density	N-value	Qualitative Consistency	blows per foot	Description	blows per foot	Description	<4	Very Loose	<2	Very soft	4 to 10	Loose	2 to 4	Soft	10 to 30	Medium dense	4 to 8	Medium stiff	30 to 50	Dense	8 to 15	Stiff	> 50	Very dense	15 to 30	Very stiff			> 30	Hard
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		> 30	Hard																																			
Color	Most colors should be earth tones with descriptors. Include all mottling or redoximorphic feature colors. Note iron staining or oxidized areas for indication of previously wet soil that has been dried out	 <p>Source:North Carolina State Cooperative Extension Resources (http://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients)</p>																																				

Include on log	Description	Example / Photo
Grain size	For granular samples only (not for silts and clays). Can be called: very fine-, fine-, medium-, coarse-, or very coarse-grained	
Particle shape	Can be angular, subangular, subrounded, or rounded. Important for understanding deposition environment and weathering of soil.	Source: Virginia Cooperative Extension - Virginia tech/Virginia State University (http://pubs.ext.vt.edu/452/452-510/452-510.html)
Soil classification	<ul style="list-style-type: none"> ■ USCS (most commonly used): behavioral classification: particle size, color, moisture, inclusions, granular vs. cohesive ■ USDA: tri-plot (shown in the caption to the right), more of a textural classification based on grain size distribution ■ ASHTO: more of an engineering classification, based on grain size and Atterberg limits 	
Sedimentary structure	Refers to bedding and laminations in the soil. Provides insight to origin of soils or potential weathering or chemical reactions experienced. Provides insight to geologic hazards (i.e. weak soil layers, collapsibility)	
Layer boundaries and thickness	Note stratigraphy breaks on logs. Unless transition is obvious while drilling, assume it is halfway between sampling intervals.	Source: Ontario Ministry of Agriculture Food and Rural Affairs (http://www.omafra.gov.on.ca/IPM/english/soil-diagnostics/soil-structure.html)
Blow Counts	The number of hammer blows to pound the split-spoon 6, 12, 18, and 24 inches into the soil. The 6 to 12 and 12 to 18 inch blow counts are added and recorded as the n-value for that split-spoon. "Refusal" or termination of borehole occurs if the hammer does not advance for >50 blows/6 inches. Note the advancement (e.g. 50/2").	
Depth to bedrock and/or refusal	"Refusal" or termination of borehole occurs if the hammer does not advance for >50 blows/6 inches. Note the advancement (e.g. 50/2"). Note refusal on logs. Note sample recovery if refusal is reached in a split spoon interval.	

Include on log	Description	Example / Photo
Depth of groundwater	Record during and after drilling Note perched layers of water in sand or lignite. Record cave-in depth in unstable boreholes. Note if water isn't encountered. Saturated silts will have high dilatancy.	 <p>Source: U.S. EPA (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/prz-m-gw-version-107-model-and-scenario-development)</p>
Plasticity	Plasticity helps determine if a clay is lean (low plasticity) or fat (high plasticity). Is very dependent on moisture content (i.e. dry fat clay can seem like it has low plasticity)	
Moisture	Provides indication of water table. For each sample identify if it is moist, wet, or saturated. Used to describe the secondary components in a soil sample.	
Inclusions	<ul style="list-style-type: none"> ▪ "With" - more than 30% of an inclusion should be included as a main descriptor ▪ "Some" - 15 to 30% ▪ "Little" - 5 to 15% 	 <p>Source: United States Geological Survey (http://geomaps.wr.usgs.gov/parks/rxmin/rock2.html)</p>
Topsoil thickness	Helpful to know how much topsoil stripping may be necessary. Note organic material if present or not.	 <p>Photo: Pat Dumas (https://www.flickr.com/photos/jerseyred/5390999270/). Creative Commons BY-NC-SA (cropped).</p>
Photographs	Pictures should be taken of each borehole location. Take photo of stake and all four directions. Record and photograph any crop damage. Photograph any interesting soil samples that may be of concern	

Interpreting soil boring logs

Boring logs can be presented vertically or horizontally. Examples of logs for four of the drilling methods previously presented are attached.

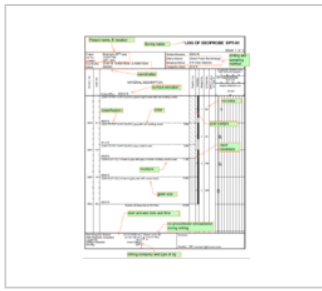
1. Excavation Test Pit or Trench log
2. Direct Push Technology (DPT) log
3. Rotasonic log
4. HSA soil boring log (horizontal and vertical)

Note that layer boundaries are well defined on each of these logs making it easy to identify the transition between different soil types. All the information discussed in Table 2 is presented on the logs as well as laboratory testing results.

Examples of soil boring logs. Click on an image to enlarge.



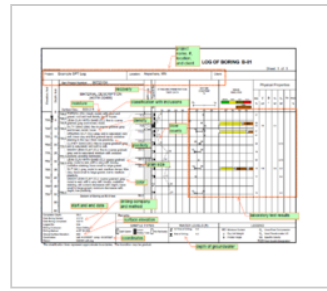
Log of test pit TP-01



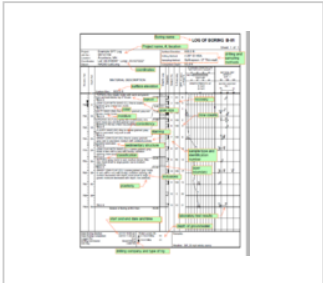
Log of geoprobe DPT-01



Log of boring R-01



Log of boring B-01



Log of boring B-01

Note that each of the example logs above utilize the United Soil Classification System (USCS). While this is the most commonly used classification system on boring logs, other systems, such as the United States Department of Agriculture (USDA) classification system, may be used. An example blank form that allows for both the USCS and USDA classifications is shown in the figure to the right (Source: USDA-NRCS) (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024037.pdf). Comparisons between the USCS and USDA classifications are shown in the following table.

Design infiltration rate as a function of soil texture for bioretention in Minnesota

The values shown in this table are for uncompacted soils. This table (https://stormwater.pca.state.mn.us/index.php?title=General_relationship_of_soil_bulk_density_to_root_growth_based_on_soil_texture) can be used as a guide to determine if a soil is compacted. For information on alleviating compacted soils, link here (https://stormwater.pca.state.mn.us/index.php/Alleviating_compaction_from_construction_activities). If a soil is compacted, reduce the soil infiltration rate by one level (e.g. for a compacted B(SM) use the infiltration rate for a B(MH) soil). Link to this table

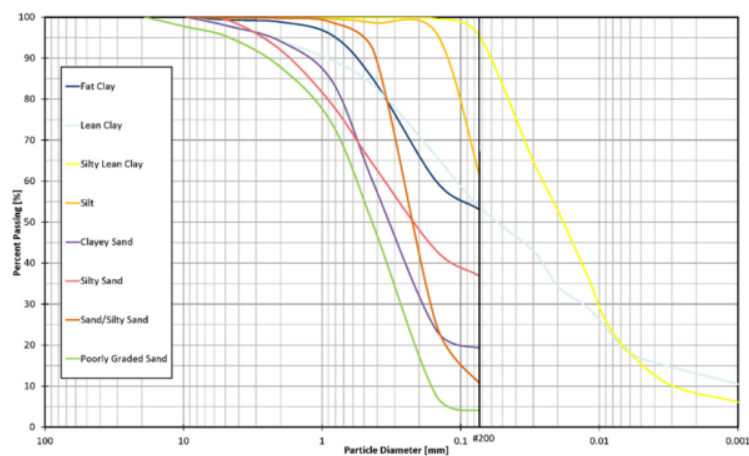
Soil texture (USDA classification)	Corresponding Unified Soil Classification	Corresponding hydrologic soil Group (HSG)	Design Infiltration Rate (in/hr)
Gravel, sandy gravel, and silty gravels	GW – Well-graded gravel or well-graded gravel with sand	A	1.63
	GP – Poorly graded gravel or poorly graded gravel with sand		
	GM – Silty gravel or silty gravel with sand		
Sand, loamy sand, and sandy loam	SW – Well-graded sand or well-graded sand with gravel	A	0.8
	SP – Poorly graded sand or poorly graded sand with gravel		

Example boring log with columns for USCS and USDA classifications. Source: [https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_024037.pdf]

Soil texture (USDA classification)	Corresponding Unified Soil Classification	Corresponding hydrologic soil Group (HSG)	Design Infiltration Rate (in/hr)
Silty sand	SM – Silty sand or silty sand with gravel ML – Silt	B	0.45
Silt loam, loam	OL – Organic silt or organic silt with sand or gravel or gravelly organic silt GC – Clayey gravel or clayey gravel with sand	B	0.3
Sandy clay loam	SC – Clayey sand or clayey sand with gravel CL – Lean clay or lean clay with sand or gravel or gravelly lean clay	C	0.2
Clay, clay loam, silty clay loam, sandy clay, and silty clay	CH – Fat clay or fat clay with sand or gravel or gravelly fat clay OH – Organic clay or organic clay with sand or gravel or gravelly organic clay MH – Elastic silt or elastic silt with sand or gravel	D	0.06

Samples for laboratory testing

Samples collected from the soil exploration can be tested in the laboratory for Particle Size Distribution (h [ttp://www.engr.uconn.edu/enviro/phys/pdf/vadose_pdf/Lecture03_Spring2004.pdf](http://www.engr.uconn.edu/enviro/phys/pdf/vadose_pdf/Lecture03_Spring2004.pdf)) (PSD). This test is critical to determining the most limiting soil layer with respect to infiltration. A disturbed or bulk sample is appropriate for this test. The PSD test was developed to classify a soil particle based on its size according to the particle's ability to pass through a series of standard sieves. A sieve is a carefully manufactured mesh of wires with a specified opening size. The ASTM D2487 (<https://www.astm.org/>) standard is the most commonly used for particles retained on the #200 sieve or greater than 0.003 inches (0.075 millimeters) in diameter. A hydrometer analysis (<https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GTM-13b.pdf>) can be performed on particles smaller than the #200 sieve following ASTM D422 standard, but is generally not necessary for infiltration analysis. If a large percentage of soil sample particles are passing the #200 sieve, infiltration is not recommended. PSD curves are created from the sieve and/or hydrometer results which provide the information needed to classify a soil and determine if the soil is poorly-graded (does not have a good representation of soil particle sizes) or well-graded (has a good representation of soil particle sizes). An example of a PSD curve is shown to the right.



Example of a particle size distribution (PSD) curve, which shows the percentage of soil from a sample passing through a sieve of known diameter. For example, in a sand, only about 5 percent of the sample passes through a 0.1 millimeter diameter sieve, while for a silt, 80 percent pass through.

Restrictive layers in soil profiles

A restrictive soil layer is one continuous layer of soil that impedes the movement of water through it. A restrictive layer will also impede air movement and root growth. Bedrock, frozen soils, dense soils, cemented soils, saturated soils, and a clay layer are examples of restrictive layers. A restrictive soil layer is capable of perching groundwater above the layer. This video (<https://www.youtube.com/watch?v=bNTIhjH-tvc>) provides an example of the impact of even thin layers of clay in soil.

Infiltration is limited by the least permeable or most restrictive layer in the soil profile. The Minnesota Construction Stormwater general permit prohibits infiltration in areas with less than three feet of separation distance from the bottom of the infiltration system to the elevation of the seasonally saturated soils or the top of bedrock. Other published guidance found on the California Environmental Protection Agency State Water Resources Control Board website (http://www.swrcb.ca.gov/rwqcb3/water_issues/programs/stormwater/docs/lid/salinas_tm2.pdf) recommends that any restrictive soil layer found within ten feet of the bottom of an infiltration BMP should be evaluated by a Professional Engineer (PE) and approved by the City Engineer.

If a restrictive layer is found within ten feet of the bottom of an infiltration BMP, the Project Engineer should evaluate whether the site is a good location for an infiltration BMP, or if another type of BMP would be more successful. Items to consider include depth to restrictive layer, restrictive layer thickness, classification of soils above and below the restrictive layer, density of soils above and below restrictive layer, depth of wet and/or saturated soils (groundwater), depth of seasonally high groundwater, area hydrology, and size of watershed draining to infiltration BMP. Additional considerations when considering a site for infiltration can be found here (http://stormwater.pca.state.mn.us/index.php/File:Final_MIDS_Flow_chart.pdf) in the Minnesota Stormwater Manual:

Soil exploration reports

At the end of a soil exploration program, and when the soils collected from the field have been subjected to visual observation and laboratory testing, a soil exploration report is prepared for use in planning and design, clearly summarizing results and providing soil data (including boring logs). A larger exploration program will require a larger report while a smaller program might only be summarized in a short technical memo. The items listed below should be present in both types of reports, but the level of information or detail summarized will vary.

1. Scope and purpose of investigation
2. Description of proposed development
3. Geologic conditions of the site
4. Summary of field exploration
5. Groundwater conditions
6. Laboratory testing
7. Analysis of subsurface conditions
8. Design recommendations/anticipated construction problems
9. Closure/limitations of the investigation
10. Maps/figures
 1. Site location
 2. Location of borings with respect to the proposed structure
11. Appendix A – Boring Logs
12. Appendix B – Laboratory Test Results

Additional resources

Additional information about evaluating site soils can be found in Site Evaluation for Stormwater Infiltration (<http://dnr.wi.gov/topic/stormwater/documents/dnr1002-Infiltration.pdf>) by the Wisconsin Department of Natural Resources Conservation Practice Standards (2004).

Information on soil investigations for petroleum contaminated sites include the following.

- Soil and Ground Water Assessments Performed During Site Investigations (<https://www.pca.state.mn.us/sites/default/files/c-prp4-01.pdf>). Guidance document 4-01.

- Soil Sample Collection and Analysis Procedures (<https://www.pca.state.mn.us/sites/default/files/c-prp4-04.pdf>). Guidance Document 4-04.

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This page was last edited on 15 June 2021, at 15:45.

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