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Soil Permeability Testing

by

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Course 223
4 PDH (4 Hours)

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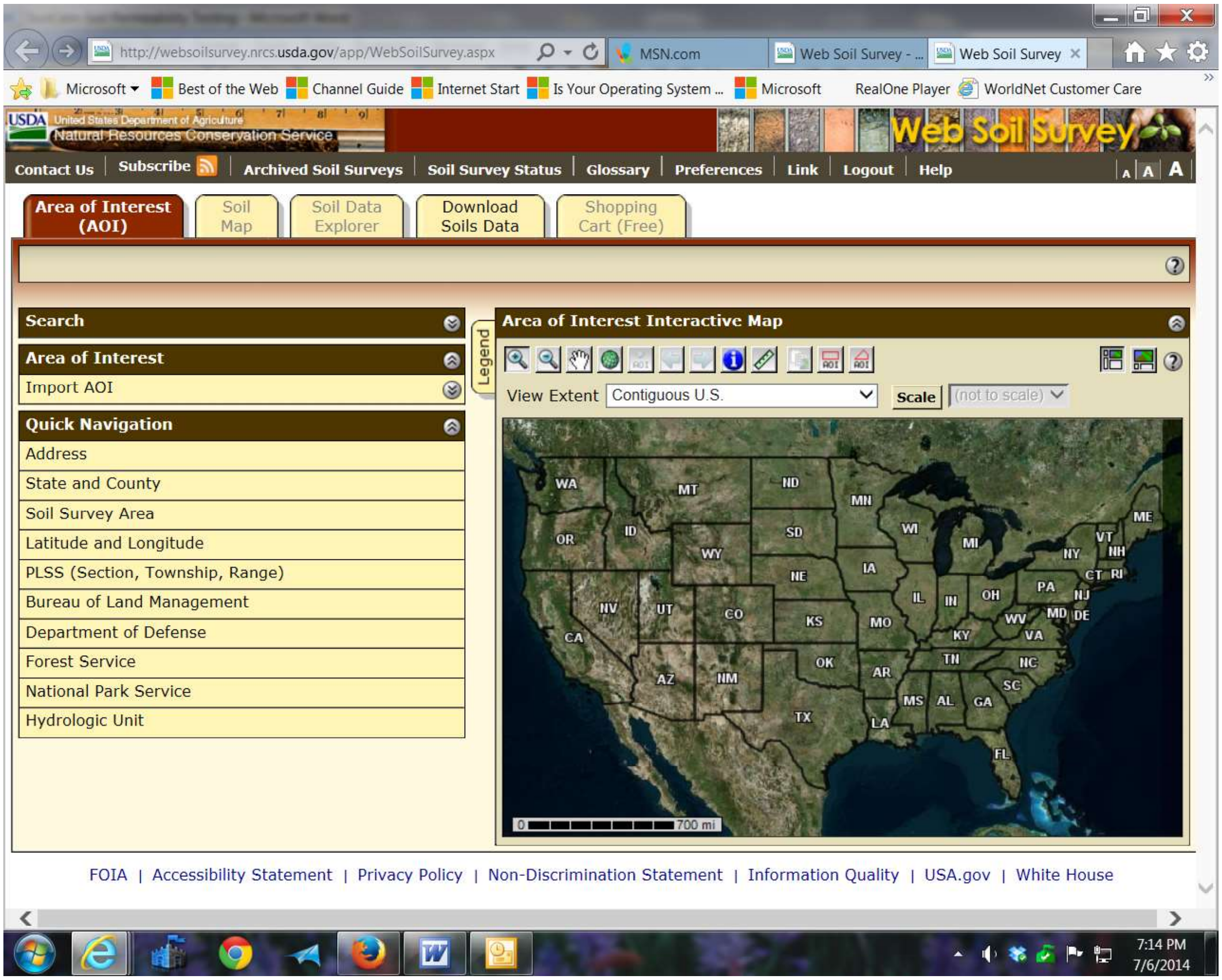
Introduction:
This course presents an overview of the ways to test soil permeability. It includes step by step procedures for several commonly employed permeability tests and includes a description of the equipment used in each.

The objectives of this course are to present an overview of soil permeability generally and to give practical, hands-on advice for conducting soil permeability testing. When you complete this course you should be familiar with the various types of soil permeability tests that are available and should have a working knowledge of the standard soils nomenclature. Most importantly, you should be able to conduct your own soils investigations on a site of interest. To accomplish this, a cookbook approach is presented which will allow you to conduct a variety of both in-situ and laboratory soil permeability tests.

Why Test the Soil Permeability:
The soil permeability testing described in this course is based on the regulations required by the New Jersey Department of Environmental Protection's requirements for designing septic disposal systems. However, there are many other design situations that require that the permeability of the soil underlying a particular site be determined. Of course, septic systems cannot function properly unless they are designed with a specific permeability in mind. In addition, however, certain drainage features (e.g. drywells and infiltration basins) also require adequate soil permeability to function properly.

Initial Investigations:
Prior to beginning on-site soil testing the engineer should review any published information regarding the area. The Natural Resource Conservation Service web soil survey is a good place to start. This resource can be accessed at:
http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx
When utilizing this soil survey the engineer can "zoom" into a particular site using the state and county of interest or can input an address directly. A screen shot of the survey is included below:



Once a site is located on the survey, the website allows the engineer to determine the underlying soil on the property. The picture below is taken from the web soil survey and delineates the various soil types found on a property Westchester County, NY. Note that this picture superimposes the soil types over an aerial photograph of the site.

The table below details the soils types delineated on the map above.

Map Unit Symbol	Soil Name
ChD	Charlton loam, 15 to 25% slopes
UpC	Urban land–Paxton complex, 8 to 15% slopes.
Uf	Urban land

The soil survey also gives a significant amount of supporting data on each of the soils identified including (among other things):

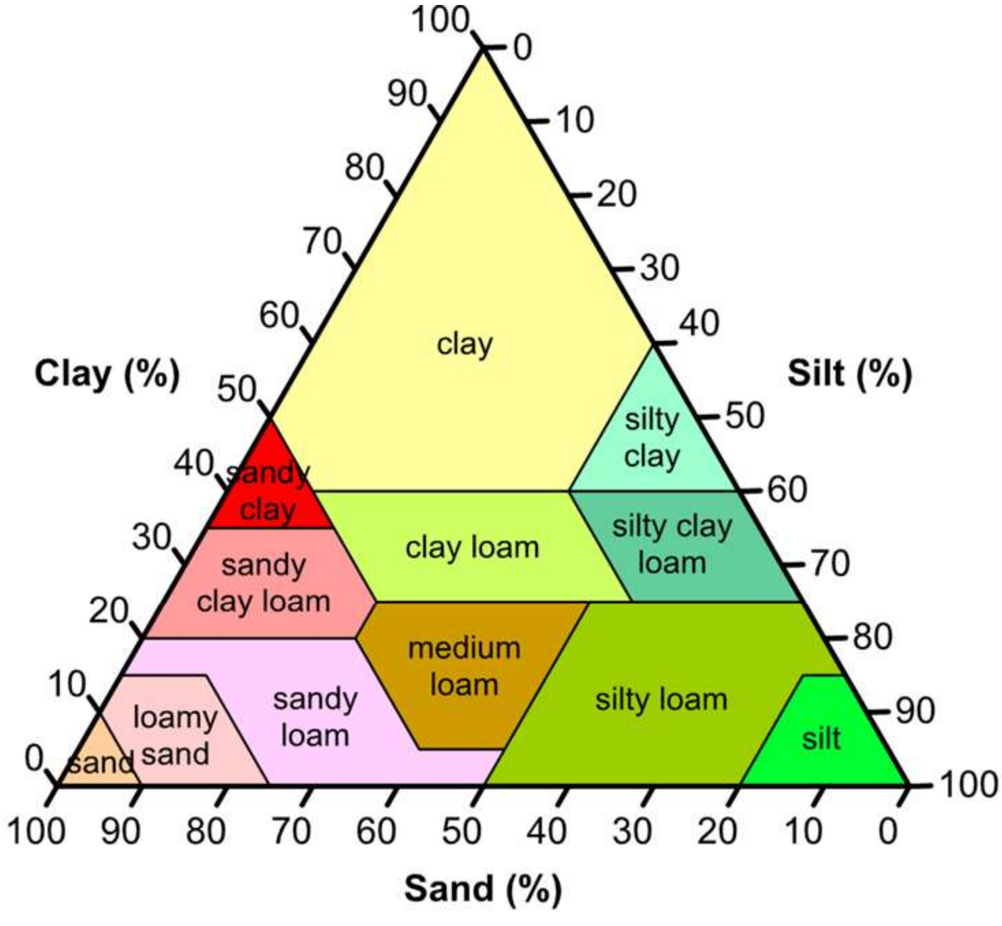
1. Depth to water table.
2. Depth to bedrock.
3. A typical profile of the soil.

As part of the preliminary soils investigations, the engineer should check with local or state regulations. For example, the New York Department of Health has specific standards for soils that will be used for septic systems in that state. These include the following:

1. Areas lower than the 10 year flood level are unacceptable for on-site systems. Slopes greater than 15% are also unacceptable.
2. There must be at least four feet of useable soil available above rock, unsuitable soil, and high seasonal groundwater for the installation of a conventional absorption field system.
3. Soils with very rapid percolation rates (faster than one minute per inch) are not suitable for subsurface absorption systems unless the site is modified by blending with a less permeable soil to reduce the infiltration rate throughout the area to be used.
4. The highest groundwater level shall be determined and shall include the depth to the seasonal high groundwater level and the type of water table - perched, apparent, or artesian.
5. If a subsurface treatment unit such as an absorption field is planned, at least four feet of useable soil shall be available over impermeable deposits (i.e., clay or bedrock). Highest groundwater level shall be at least two feet below the proposed trench bottom. Where systems are to be installed above drinking water aquifers, a greater separation distance to bedrock may be required by the local health department having jurisdiction. At least one test hole at least six feet deep shall be dug within or immediately adjacent to the proposed leaching area to insure that uniform soil and site conditions prevail. If observations reveal differing soil profiles, additional holes shall be dug and tested. These additional holes shall be spaced to indicate whether there is a sufficient area of useable soil to install the system. Treatment systems shall be designed to reflect the most severe conditions encountered. If the percolation tests results are inconsistent with field determined soil conditions, additional percolation tests must be conducted and the more restrictive tests must be the factor used for the system design.

6. Test holes for seepage pits shall extend to at least mid-depth and preferably full depth of the proposed pit bottom. At least three feet of useable soil shall exist between the pit bottom and rock or other impermeable soil layer and the highest groundwater level. This shall be confirmed by extending at least one deep test hole three feet below the deepest proposed pit.
7. A local health department may accept or require other soil tests in lieu of the percolation test when such tests are conducted or observed by local health department personnel.

When considering soil permeability it is helpful to refer to the textural chart below. This chart relates the soil particle size (sand, silt, & clay) to an overall soil texture.



A simple example will illustrate how to read the graph above.

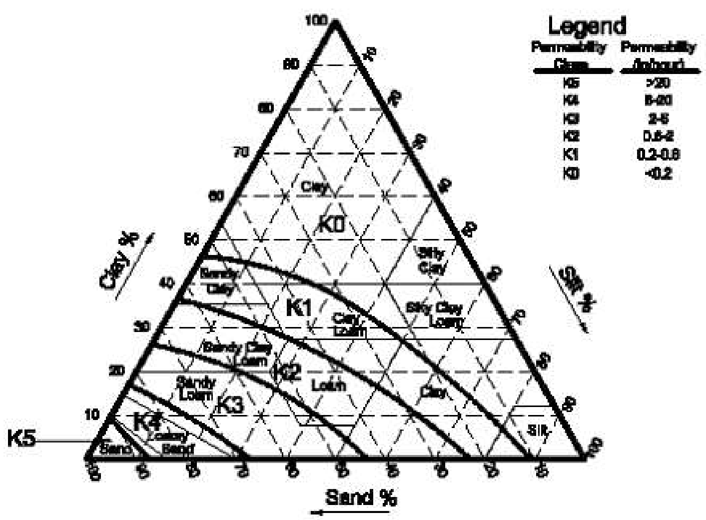
Suppose you have a soil sample with 70% sand, 20% silt, and 10% clay. In order to classify this material start at the bottom right of the graph and read to the left until you come to 70%. Then move upwards toward the left until you come to 10% clay. (You will see that this point also marks 20% silt). The resulting material is classified as "sandy loam".

In order to determine how this classification is related to the permeability of the soil, the related chart below superimposes permeabilities on top of the textural composition.

The soil permeability classes are defined in accordance with the table below:

Measured Permeability	Soil Permeability Class	Percolation Rate
>20 inches per hour	K5	< 3 minutes per inch
6-20 inches per hour	K4	3-10 minutes per inch
2-6 inches per hour	K3	10-30 minutes per inch
0.6-2 inches per hour	K2	30-100 minutes per inch
0.2-0.6 inches per hour	K1	100-300 minutes per inch
<0.2 inches per hour	K0	> 300 minutes per inch

Material that is classified as K0 is hydraulically restrictive and is not suitable for septic system installation.



Soil Permeability/Textural Triangle

Therefore, the soil sample described above (70% sand, 20% silt, 10% clay) has a permeability of K3, which translates to 2-6 inches per hour.

Initial Soil Investigations:

Soil Permeability Testing

However useful resources such as the NRCS web soil survey are they are no substitute for actual on-site investigations. In order to properly design a septic system, infiltration basin, or similar recharge-type system the engineer must conduct on-site surveys.
The most basic (and also one of the most comprehensive) soil investigations is a simple profile pit. A backhoe is used to dig an observation hole. This hole can be used for the following:

1. To record the different layers of the soil encountered according to texture, color, rock content, etc.
2. To determine the presence or absence of groundwater.
3. To determine the depth of bedrock.
4. To provide access to a soil level or levels, which can be used for in-situ permeability testing or from which samples can be taken for laboratory tests.

A small backhoe, like the one in photograph below, is generally adequate for digging a soil log.

Soil Permeability Testing

When recoding a soil profile the depth and thickness (in inches) of each separate layer encountered should be described according to color, texture, volume of coarse fragments, presence of mottling, soil structure, and soil consistency. It is imperative to use standardized language. Local jargon to describe soil conditions should be avoided. The NJDEP recommends that the following terminology should be used:

1. Color: Color should be based on the descriptions contained within the Munsell Color Chart. When using this chart, a sample should be held between the pages (as shown in the photograph below) in order to obtain an accurate description of the color. The color of the chunk of soil in the photograph would be classified (reading the page number, the value, and the chroma) as 10YR 7/3. The color of the soil is sometimes a meaningful parameter because it tells something about the parent material of the soil. This, in part, can be used to determine why mottling is present, for example, or to determine the presence of high water table when testing is done during the dry season.

2. Texture: The texture should be described using the textural triangle shown above. The following descriptions are based on the particle size of the minerals making up the soil material.
   i. Sand consists of particle sizes generally between 0.05 and 2.0 millimeters.
   ii. Silt consists of particle sizes of between 0.02 and 0.05 millimeters.
   iii. Clay consists of particle sizes generally less than 0.002 millimeters.
   iv. Loam is a term that relates to a mixture of the above particle sizes.
3. Coarse Fragments: Coarse fragments should be quantified using the descriptions below:

i. “Gravel” refers to rounded fragments between 2 milimeters (0.1 inch) and 76 millimeters (3 inches) in diameter.
ii. “Cobbles” refer to fragments between approximately 3 inches and 10 inches in diameter.
iii. “Stones” refer to fragments in excess of 10 inches in diameter.

4. Mottling: A detailed description of mottling is included under the section headed “Determination of Groundwater Level”.
5. Soil Structure: Soil structure seems to be a somewhat arbitrary classification. However, with experience the engineer can usually determine the structure accurately. Structure is based on the shape of the soil aggregates.
    i. Structure is spheroidal when the aggregates are more or less equi-dimensional and lack sharp corners, edges, or well-defined faces. (This term includes ‘crumb” and “granular” structure as defined by the USDA.)
    ii. Structure is sub-angular blocky when the aggregates are more or less equi-dimensional and posses well defined flat or somewhat flat faces, but lack sharp corners or edges.
    iii. Structure is angular blocky when the aggregates are more or less equi-dimensional and possess well-defined flat or somewhat curved faces, sharp corners and sharp edges.
    iv. Structure is prismatic when the aggregates have one axis which is distinctly longer than the other two and are oriented with the long axis vertically.
    v. Structure is platy when the aggregates have one axis distinctly shorter than the other two and are oriented with the long axis vertically.
    vi. Structure is massive when the soil consists of a dense, compact mass showing no recognizable natural aggregates or structural faces.
    vii. Structure is single grain when the soil consists of loose individual sand grains which lack cohesion and are not bound together into recognizable soil aggregates.
6. Consistency: Soil consistency refers to the ease with which a soil clod can be crushed with the fingers in either dry or moist conditions. The following terminology is used:
    A. In dry soil, the consistency is regarded as:
    I. “Loose” when the soil is non-coherent.
    II. “Soft” when the soil mass breaks to a powder of individual grains with slight pressure.

III. "Slightly hard" when the soil mass is easily broken between thumb and forefinger.
IV. "Hard" when the soil mass can be broken with the hands without difficulty, but is barely breakable between thumb and forefinger.
V. "Very hard' when the soil mass can be broken with the hands with difficulty, but is not breakable between the thumb and forefinger.

B. In wet soil:

I. "Loose" when the soil is non-coherent.
II. "Friable" when the soil material crushes easily between the thumb and forefinger.
III. "Firm" when the soil material crushes under moderate pressure between thumb and forefinger.
IV. "Very firm" when the soil material is barely crushable under strong pressure between thumb and forefinger.
V. "Extremely firm" when the soil material cannot be crushed between thumb and forefinger, but can only be broken apart bit by bit.

The photograph below shows material that has been excavated out of a soil log hole. Note the preponderance of rocks at the top of the pile. This material came from the very bottom of the hole and it should be tested to determine if it fractured rock (which would be permeable) or massive rock (which would not be permeable).

When excavating in rock, a larger backhoe, such as the one pictured below is often necessary:

Determination of Groundwater Level:

One of the most important determinations in soil investigations is the discovery of the depth to seasonal high groundwater. This is easy to do in the wet season but can be more difficult in periods of dry weather. Groundwater can either be "perched" (meaning that it being held above a hydraulically restrictive horizon in the soil profile) or "regional" (meaning it is contiguous with the region's overall groundwater). Some common observations dealing with ground water are discussed below:

1. Seepage: This, of course, is the most obvious sign of the presence of groundwater. However, it is sometimes difficult to tell exactly where seepage is originating in a soil profile. Keeping a profile pit open for several hours is often a useful way to determine at what layer seepage is occurring. Seepage is not a fool-proof indication of the depth of groundwater however, due to the following:
    i. In the dry season, seepage may occur several feet below where the seasonal high table would occur during the wet season.
    ii. If the soil log is performed within a few days of heavy rain, seepage may actually be the result of surface water working its way into the profile pit. The engineer should look for tell-tale signs of saturation in the topsoil or upper reaches of the pit to identify this condition.
2. Mottling: Mottling is the term used to describe the colors left over by water in a soil layer. This coloration is generally a result of oxidation of the material. The presence of mottling is often the best way to determine the high water table elevation. The engineer should be aware that some parent materials (red shale, for one example) are resistant to mottling. The gray material shown in the photograph below is a clear indication of mottling and shows the limit of the high water table in this area.

3. Hydraulically restrictive horizons within the soil profile: The presence of a hydraulically restrictive horizon (generally a clayey material) within a soil profile often causes a perched water table. If this type of horizon is encountered in a profile pit, signs of water should be looked for immediately above it.
4. Roots: The presence of roots is sometimes a good indicator of the depth of the seasonal high table. If the roots in a profile pit extend down for several feet, this is generally a good indication that they have traveled that far to reach water and, therefore, the water table in this area is fairly deep. The photograph below shows another test hole with mottling. The bands of discoloration show that there is water seasonally close to the surface. In addition, the fact that the roots are all shallow indicates that water is present near the ground during the growing season.

Soil Permeability Testing

Groundwater monitoring can often be accomplished by a simple method as shown in the photograph below. The two pipes are set into different soil layers and the depth to water can be measured at different time of the year. This can tell a lot about the permeability of the two soil horizons being tested.

Types of Soil Tests:
There are several types of specific soil permeability tests that can be performed. However, the design engineer should choose the type of test based on the soil conditions encountered on the site and the purpose of the test itself. The table below indicates which types of tests are suitable for a variety of situations:

Soil Permeability Testing

Purpose of Test & Soil Conditions Encountered at Test Depth	**Acceptable Type of Permeability Tests**
Determination of design permeability, identification of hydraulically restrictive or excessively coarse strata above the water table:	---
For sandy & loamy soils with single grain structure:	Tube permeameter test, soil class rating analysis or percolation test
For all other soil textures:	---
If an undisturbed sample can be taken:	Tube permeameter test, soil class rating analysis or percolation test
If an undisturbed sample cannot be taken:	Soil class rating analysis or percolation test
Identification of Massive Rock strata above the water table	Basin Flood Test
Identification of a hydraulically restrictive horizon or massive rock horizon below the water table	Pit-bailing test or Piezometer test

In-Situ Soil Testing:
There are several types of in-situ soil tests that can be conducted on-site. Many engineers favor these types of tests because they feel that they are more reliable than laboratory tests of the soil samples. Because these tests are done in-place, they believe that they better represent the way the soil will react under actual field conditions. The following four types of in-situ tests are commonly employed and the first three of these will be discussed in some detail:

1. Percolation tests.
2. Basin flood tests.
3. Pit-bail tests.
4. Piezometer tests.

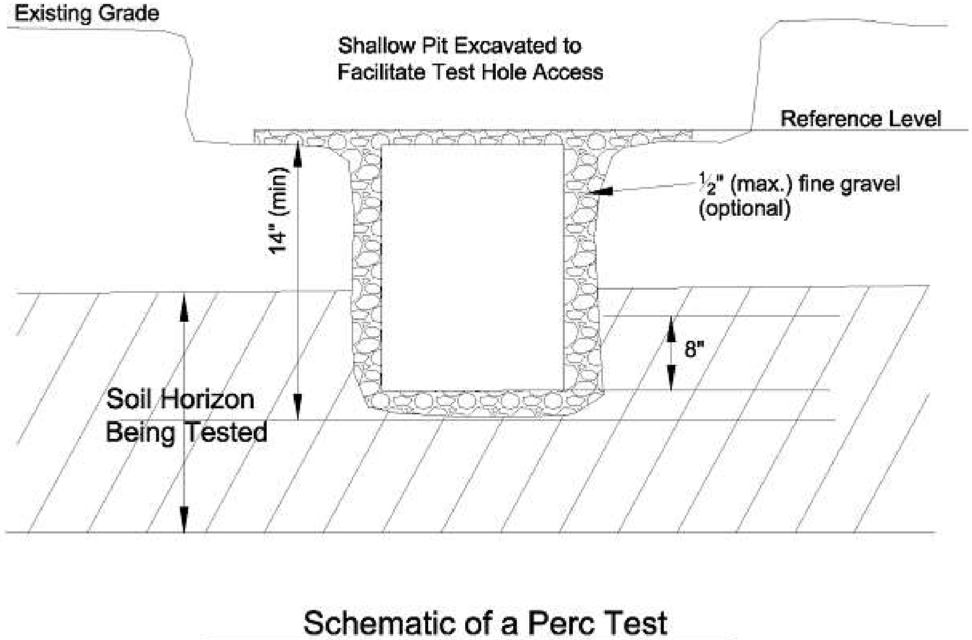
Percolation Tests: These are the old-fashioned "perc tests" that have been conducted for many years. These tests are relatively easy to run and the resuts are self-explanatory. In order to conduct a perc test, one needs the following equipment:

1. A soil auger, post-hole digger or other instrument for preparing the hole.
2. A knife or trowel for removing smeared or compacted surfaces from the walls of the test hole.
3. Fine (2 mm to 10 mm) gravel (optional).
4. A water supply (generally 50 gallons is adequate).
5. A straight board to serve as a fixed point for measuring the level of water drop.

6. A clock or watch.
7. A ruler, 12" or longer.
8. An automatic siphon or float valve (otional).
9. A hole liner consisting of a 14 inch section of 2" diameter slotted pipe or equivalent (optional). A 14 inch length of ¼" hardware cloth or similar material can be used. If a hole liner is used, it should be no more than 2 inches smaller than the diameter of the test hole.

In order to perform a perc test, the following procedure should be followed:

A. Excavate a test hole have horizontal dimensions of 8 to 12" and a depth of at least 12 inches. The bottom 6" of the test hole must be within the layer of soil which is being tested. The test should not be conducted in frozen ground nor in a test hole that has been left open for more than three days.
B. If the soil is not sand or loamy sand, remove smeared or compacted soil from the sides of the test hole with a knife or trowel. Remove any loose soil from the test hole.
C. Optional: A one half inch layer of fine gravel can be placed in the bottom of the test hole to protect the bottom surface from siltation or disturbance when the water is added to the hole. A hole liner (slotted pipe) can also be added at this point if it is felt that the sides of the hole may become silted and more protection is needed.
D. Place and secure a straight board horizontally across the top of the test hole to serve as a fixed reference for depth measurements to be made. A schematic of a perc test hole is shown below.



E. Pre-soak the soil as described below. (Note that for sandy–textured soils (including sands, loamy sands, and sandy loams) the NJDEP requires the pre-soaking procedure described in "F", below).
   i. Fill the test hole with water and maintain a minimum depth of 12" for a period of 4 hours by re-filling as necessary or by means of an automatic siphon or float valve.
   ii. At the end of four hours, cease adding water to the hole and allow the hole to drain for a period of between 16 and 24 hours.

F. In sandy-textured soils where a rapid percolation rate is anticipated, fill the test hole to a depth of 12 inches and allow it to drain completely. Refill the hole to a depth of 12 inches and record the time required for the hole to drain completely. If the hole has drained completely within 60 minutes, then the pre-soaking is complete and the perc test may begin. If the hole is not completely drained within 60 minutes, the hole should be pre-soaked as described in E, above.

G. Immediately following the pre-soak procedure (within 28 hours at the most), the percolation rate shall be determined using the following procedure:
   i. Step one: If water remains within the test hole after the 60 minute period, the test should be abandoned and the perc rate should be recorded as greater than 60 minutes per inch. If no water remains in

the test hole, re-fill the hole to a depth of 7 inches. At specified intervals of between 5 and 30 minutes (depending on the expected perc rate) record the drop in the water level to the nearest tenth of an inch. Refill the hole at the end of each time interval and repeat the procedure using the same time interval until a constant rate of fall is observed. For purposes of this test a constant rate of fall is considered to have been reached when the drop in water level between three consecutive tests is no greater than 2 tenths of an inch.

ii. 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 the water level to drop exactly 6 inches. The time required for this fall divided by 6 will be the resulting percolation rate.

H. According to the NJDEP, the results of the percolation test should be interpreted as follows, if it is being conducted to design a septic system:

i. When the purpose of the test is to determine the design permeability at the level of infiltration, the slowest percolation rate determined within the proposed septic system shall be used for design purposes. In this case, if the slowest percolation rate is greater than 60 minutes per inch, the area is not considered suitable for an on-site septic disposal system.

ii. If the result of the test or tests is a perc rate of greater than 60 minutes per inch the soil horizon being tested must be considered hydraulically restrictive.

iii. If the result of the test or tests is a perc rate of less than 3 minutes per inch the soil horizon being tested must be considered excessively coarse.

Example: A septic system needs to be installed for a new home in Erie County, NY. The design engineer has conducted a perc test at a depth of 5 feet below ground level. After performing the required pre-soaking procedure and filling the test hole so that a constant rate of fall is achieved, the test hole is re-filled to a depth of 7 inches. At this filling the water level in the hole falls exactly 6” in 50 minutes. What is the design perc rate for the new septic system?

Solution: In order to determine the design perc rate, the enginer has to calculate the rate of fall of the water. This is shown below:

$Rate = 50\,minutes / 6inches = 8.33\,minutes / inch$

This can rounded up to 9 minutes per inch for design purposes.

The New York State Department of Health has the following additional requirements regarding perc tests:

1. At least two percolation tests shall be made at the site of each proposed sewage treatment system.
2. For seepage pits, one test shall be conducted at the bottom depth, and the other at half the pit depth. If different soil layers are encountered when digging the test pit, a percolation test shall be performed in each layer with the overall percolation rate being the weighted average of each test based upon the depth of each layer. The local health department having jurisdiction may adopt an alternative procedure for determining the permeability of soil for the installation of seepage pits.
3. A percolation test is only an indicator of soil permeability and must be consistent with the soil classification of the site as determined from the test holes.

Basin-flood Test: A basin flood test can be thought of as a perc test done on a grand scale. The NJDEP limits its usefulness to measuring the permeability of fractured rock but it can be used in any type of dry soil or rock. The following equipment is needed to conduct a basin-flood test:

1. Excavating equipment capable of producing test hole of 50 SF.
2. A water supply (a minimum of 375 gallons is needed per filling).
3. A means for accurately measuring the water level within the test holes.

In order to perform a basin-flood test, the following procedure should be used:

A. Step 1: Dig a 50 SF hole with as level a bottom as possible. Because this hole may be kept open for 24 hours or longer, adequate safety measures must be taken. Depending on the area, it may be necessary to install a security fence around the perimeter of the test area. The bottom of the test hole should be made as flat as possible. If groundwater is encountered within the test hole, the test must be abandoned as a basin flood test cannot be conducted below the level of the groundwater.

B. Step 2: Fill the test basin with exactly 12” of water and record the time. Allow the basin to drain completely. (If the basin does not drain within 24 hours, the NJDEP considers the test a failure for septic systems).

C. Step 3: If the test hole drains completely within 24 hours, refill the basin with another 12” of water and record the time again. Allow the basin to drain completely and record the time.

D. Step 4: The permeability of the material can be calculated using similar reasoning as was done with the percolation test. The amount of water entered into the basin is divided by the bottom basin area to obtain a final permeability rate.

Example: A basin flood test is conducted on a property in Somerset County, New Jersey. This test is being conducted to design an underground infiltration system for stormwater management. The bottom of the test hole has an area of 50 SF. At the second filling 375 gallons of water are poured into the hole and the hole requires 6 hours to empty completely. What is the calculated permeability of the material?

Solution: 375 gallons of water evacuates the hole in 6 hours. Using 3600 seconds per hour and 7.48 gallons per CF, this can be expressed as follows:
$Volume = 375/7.48 = 50.1CF$
$Time = 6X3600 = 21{,}600\sec onds$
$Rate = 50.1CF/21{,}600\sec onds = 0.0.0023CFS$
This can be divided by 50 SF to determine the discharge rate per SF of bottom area.

A pit-bailing test: This test is useful when groundwater is present within the test hole. Like the basin flood test, the NJDEP considers this type only applicable in fractured rock, but it can be used to determine the permeability of any soil or rock substratum that has sufficient water. To conduct a pit-bailing test the following materials are needed:

1. A back-hoe.
2. Wooden or metal stakes, a string, and a hanging level.
3. A measuring tape.
4. A pump (optional).
5. A stop watch.
6. A perforated of at least 3” in diameter.

The following procedure is to be used for the preparation of the test pit, performance of the test, and calculation of the test results;

A. Excavate a test pit into (but not below) the soil layer to be tested. The bottom of the pit should be at least 18” below the observed water level in the pit. The bottom of the test pit should be made as level as possible. The pit itself can be any shape, but the long dimension (at the bottom) should not be more than twice the short dimension.
B. Allow the water level to rise in the test pit for a minimum of two hours and until the sides have stabilized. If large volumes of soil have slumped into the pit, this soil must be removed prior to continuing with the test. If the sides continue to slump and cannot be stabilized, the test must be

abandoned. If water is observed seeping into the pit from soil horizons above the zone of saturation, adequate means shall be taken to divert this water away from the test pit. If this cannot be accomplished, the test results will not be accurate and the test must be abandoned. The test must also be abandoned if, during the excavation of the pit, the water level rises suddenly after a hydraulically restrictive horizon is penetrated.

C. Step 3: Establish a fixed reference point for depth to water level measurement which will not be disturbed during removal of water from the pit or which can be temporarily removed and repositioned in the exact same place. One way to establish a removable reference level mark is as follows:
   i. Drive stakes firmly into the ground on opposite sides of the test pit, several feet beyond the edge, where they will not be disturbed.
   ii. Next, stretch a string with a hanging level from stake to stake, over the pit, and adjust the string to make it level.
   iii. Finally, secure the string to the stakes and mark or notch the positions on the stakes where the string is attached so that the string may be removed temporarily and later repositioned in exactly the same place.

D. Step 4: Measure the distance from the reference level to the bottom of the test pit and to the observed water level.

E. Step 5: Lower the water in the pit by at least 12 inches by pumping or bailing. If the back-hoe bucket is used to bail water from the pit, it may be necessary to remove the reference level marker prior to bailing and reposition prior to Step 6.

F. Step 6: Choose a time interval based on the observed rate of water level rise. At the end of each time interval measure and record the information listed in (i) through (iii) below. Repeat these measurements until the water level has risen a total of at least 12 inches.
   i. Time (in minutes). The time interval between measurement should be chosen to allow the water level to rise several inches during each interval.
   ii. Depth of water level below the reference string at the end of each time interval, to the nearest eight of an inch or hundredth of a foot.

iii. The area of the water surface, in square feet. Measure appropriate dimensions of the water surface, depending on the shape of the pit, to permit calculation of the water surface at the time of each water level depth measurement. **Caution: Entering a soil pit excavated below the level of the water table can be extremely dangerous and should be avoided.** The distance between two opposing edges of the water surface can be measured accurately, without entering the pit, as follows. Place a board on the ground, perpendicular to the side of the pit and extending out over the edge. Using a plumb-bob, position this board so that its end is directly over the edge of the water surface in the pit, below. Position a second board, in the same manner, on the opposite side of the pit. Measure the distance between the ends of the boards to determine the length of the water surface below.

G. Step 7: Determine if an adequately consistent set of data has been obtained in accordance with the following:

i. Calculate the permeability for each time interval using the equation:
$Ka = (hrise / t) X (Aav / 2.27(H2 - h2)) X 60 \text{ min/} hr$, where:

ii. Ka = permeability, in inches per hour, Hrise = difference in depth to the water level at the beginning and end of the time interval, in inches, t = length of time interval, in minutes, Aav = average of water surface at the beginning and the end of the time interval, in square feet, h = the difference between depth to assumed static water level and actual or assumed depth to impermeable stratum, in feet (depth to impermeable stratum, if unknown, is assumed to be one and one half times the depth of the pit, and h = difference in average depth of water levels at the beginning and the end of the time interval and actual or assumed depth to impermeable stratum, in feet.

iii. If the calculated values of Ka for successive time intervals show either an increasing or a decreasing trend, repeat steps five and six until consecutive values of Ka are approximately equal.

H. Step 8: Remove as much water as possible from the pit. Continue excavating the pit until an impermeable stratum is encountered or as deep as possible considering the limitations of excavating equipment used and the nature of the soil conditions encountered. Where no impermeable stratum is encountered, the impermeable stratum shall be assumed to be at the bottom of the excavation. Due to the potential safety hazard posed by the excavation of a large test pit such as the pit required for this test, adequate safety measures shall be taken, including the posting of warning signs and the installation of a fence to prohibit access to the pit by the public during periods when the pit is left unattended.

I. Step 9: Re-calculate the permeability using the following formula: $K = (hrise / t) X (Aav / 2.27(H2 - h2)) X 60\,\mathrm{min}/hr$, where:

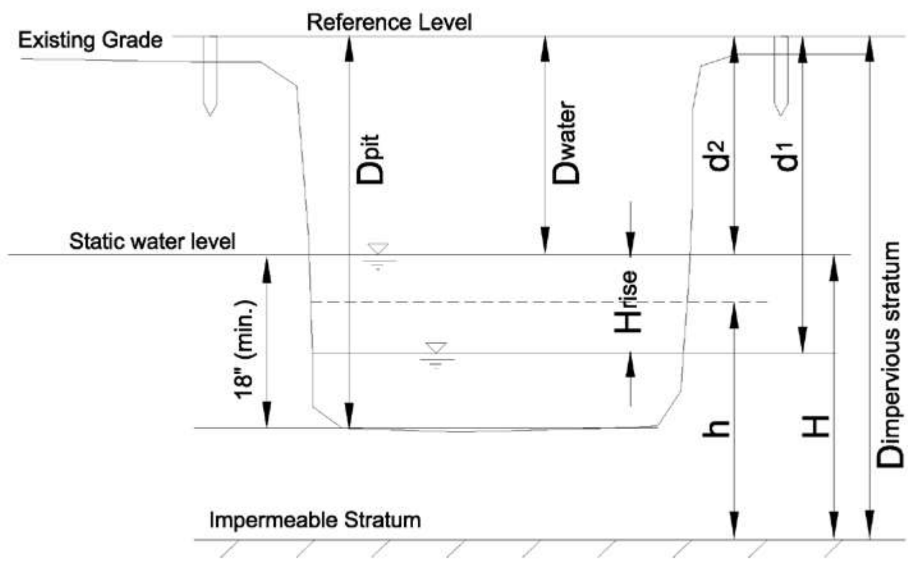
   *K is the permeability in inches per hour

   *The values of hrise, t, and Aav are the values recorded for these parameters in the last time interval of Step 6, above.

   *H is the difference between the actual corrected static water level and the actual or assumed depth to an impermeable stratum (as recorded in Step 8), in feet.

   *h is the difference between the average depth of water levels at the beginning and end of the last time interval recorded in step 6 and the actual or assumed depth to an impermeable stratum recorded in step 8, above.

   These parameters are shown in the schematic pit bail diagram below.



Schematic of a Pit-Bail Test

Example:
The results of a pit-bailing test are shown in the table below. The depth from static water level to an impermeable stratum is assumed to be 9 feet. Determine the permeability of the tested soil horizon.

Time Interval	Time from start)	Depth below reference level	Water surface length	Water surface width	Area of water surface
T0	0	74.5"	4.5 feet	9.7 feet	43.65 SF
T1	30 min	70.1"	4.8 feet	9.8 feet	47.04 SF
T2	60 min	66.1"	5.0 feet	9.9 feet	49.5 SF
T3	90 min	62.3"	5.2 feet	10.1 feet	52.52 SF
T4	120 min	59.6"	5.2 feet	10.2 feet	53.04 SF

Solution: The table below summarizes the calculations. Note that the calculated permeability values in the various time intervals agree quite well and that there is not a clear rising or dropping trend. Therefore, the reported permeability is the final Ka value calculated below (i.e. 4.10 inches per hour).

Time (minutes)	dn (in)	h_{rise} (in)	A_{av} (ft^2)	h(ft)	Ka (Inches per hour)
0	74.5	----------	----------	-----	----
30	70.1	4.45	45.345	6.16	4.13
60	66.1	4.0	48.27	6.49	4.38
90	62.3	3.8	51.01	6.81	4.93
120	59.6	2.7	52.52	7.11	4.10

Note that pit bailing tests and basin-flooding tests are very similar in that they measure the time it takes for a large amount of water to move through a test pit. Both pits are generally, but not exclusively, conducted within a layer of fractured rock. The difference is that a basin-flooding test is performed above the level of the water table whereas the pit-bailing test is done below this level. In some cases, however, the investigator will find that he is below the level of the water table but there is insufficient water in the soil horizon to conduct a pit-bailing test. In this case, neither of these tests will yield accurate results. The basin-flooding test will fail because the test hole will not drain completely and the pit-bailing test cannot be run because the test will never be flooded to a depth of at least 12 inches. The NJDEP is silent about what to do in this situation. However, the engineer should attempt to run one or more of the other permeability tests described in this course to determine the appropriate value to use.

Piezometer test:
A full discussion of the peizometer test is beyond the scope of this course. However, as the name implies, it employs the use of a piezometer to measure the rate at which water passes through a soil layer. This rate is then translated to a underlying soil permeability class based on an equation using the rate of fall of water within the soil horizon..

Laboratory Soil Testing:
For a variety of reasons, engineers often opt for a laboratory test rather than in-situ testing. These tests, if they are done properly, can also give very good indications of a soil's permeability. In many cases, they are easier and less time consuming than some of the in-situ soil tests. The following types of laboratory testing are commonly done:

1. Soil class rating analysis.

2. Tube permeameter test.

Soil Class Rating Analysis: This is a very simple, inexpensive, and accurate way to determine the consistency of the soil. In order to perform a soil class rating analysis the following equipment is needed:

1. A two millimeter sieve with an eight inch diameter (or larger) frame.
2. A set of sieves with five inch or larger frames, with covers and a pan. The sieves must meet the following specifications:
    a. The first sieve shall be 0.25mm, 60 mesh, Bureau of Standards, phosphor bronze wire cloth; and
    b. The second sieve shall be 0.045 mm, 325 mesh, Bureau of Standards, phosphor bronze wire cloth (0.0015 wire).
3. A wooden rolling pan or mortar with rubber-tipped pestle.
4. An oven.
5. A scale with an accuracy to 0.1 gram.
6. Distilled water.
7. A sodium hexametaphosphate solution of 50 grams of the salt dissolved in one liter of distilled water.
8. An electric mixer or mechanical shaker.
9. A 1000 ml graduated cylinder with rubber stopper.
10. A soil hydrometer calibrated to read in grams per liter at 68 degrees Fahrenheit (ASTM #152H).
11. A thermometer.
12. A clock or watch with a second hand.
13. A sieve shaker.

The photograph below shows many of the materials required for a soil class rating analysis.

The soil class rating analysis, as its name implies, will allow the investigator to determine the consistency of a soil sample. Note that the hydrometer analysis described below cannot be performed in a room where the temperature varies by more than 2 degrees Farenheit during the duration of the test. In order to perform this analysis the following procedure should be used:

1. Step 1: Collect a sample of soil weighing at least 200 grams from the soil horizon to be tested.
2. Step 2: Allow the sample to air dry. Then pass the sample through a 2 millimeter sieve to remove the coarse fragments. Use moderate pressure with a wooden rolling pin or a mortar and rubber-tipped pestle to break soil aggregates (but not rock fragments) which are larger then 2 millimeters.
3. Step 3: Weight both the material that is retained on the 2 millimeter sieve and the material that passes through the sieve. If the amount of coarse fragments (i.e. the

material that remains on the sieve) is greater than 75% of the total sample weight, the test should be abandoned and a different type of test should be employed to measure the permeability of the soil horizon. If not, then proceed to Step 4.

4. Step 4: Discard the coarse fragments.
5. Step 5: The following procedure should be followed for each replicate sample tested. Place 40 grams of air-dry soil which has been passed through the 2 millimeter sieve into a mixing cup or 1 liter shaker bottle together with 100 milliliters of sodium hexametaphosphate solution and 400 milliliters of distilled water. Weigh out an additional 40 gram sample for determination of oven dry weight. Place the latter sample in an oven for 24 hours at a temperature of 105 degrees centigrade. Not that only one sample of oven dry weight needs to be collected regardless of the number of replicates used for the hydrometer analysis.
6. Step 6: If a motor mixer is used, allow the soil to soak in the cup for 10 minutes, place the cup on the mixer and mix the sample for 5 minutes. Then transfer the suspension completely to the cylinder. Rinse the mixing cup with distilled water and pour the rinse water into the cylinder so that none of the suspension remains in the mixing cup. Bring the volume of the suspension in the cylinder up to the 1000 milliliter mark with distilled water. Allow the suspension to reach room temperature before proceeding with Step 7.
7. Alternate Step 6: If a reciprocating shaker is used (instead of a motor mixer), shake the sample for 12 hours at a rate of approximately 120 strokes per minute and transfer the suspension to the cylinder rinsing the shaking bottles with distilled water. Bring the volume of the suspension in the cylinder up to the 1000 milliliter mark with distilled water. Allow the suspension to reach room temperature before proceeding with Step 7.
8. Step 7: Calibrate the hydrometer as follows: Add 100 milliliters of sodium hexametaphosphate solution to a 1000 Milliliter cylinder and fill the cylinder to the 1000 milliliter mark with distilled water. Place the stopper in the cylinder and shake vigorously using a back and forth motion. Place the cylinder on a table and lower the hydrometer into the solution. Determine the scale reading at the upper edge of the meniscus surrounding the hydrometer stem. This is the hydrometer calibration (Rc). Record the temperature in degrees Farenheit.
9. Step 8: Place a stopper in the cylinder containing the dispersed soil sample, shake the cylinder using a back and forth motion and place the cylinder on the table. (Note that it is important to avoid causing circular currents in the cylinder when shaking the suspension as this can lead to invalid results). Record the time

immediately. After 20 seconds carefully lower the hydrometer into the cylinder and, after exactly 40 seconds, read the hydrometer. Repeat this step until two successive readings are obtained which agree within 0.5 grams per liter.

10. Step 9: Determine the temperature of the suspension and correct the hydrometer reading as follows:
    i. Subtract the reading obtained in Step7 (Rc) from the hydrometer reading.
    ii. For each degree Farenheit above 68 add 0.2 grams to the reading or for each degree Farenheit below 68 subtract 0.2 grams.
11. Step 10: Remove the hydrometer, place the stopper in the cylinder, and shake the hydrometer as in Step 8. Remove the stopper and immediately place the cylinder on a table where it will not be disturbed. Take a hydrometer reading after exactly two hours and correct the hydrometer reading as described in Step 9. The photograph below shows soil samples in hydrometera.

12. Step 11: Record the following data:
    i. Oven dry weight of the soil (Wt).
    ii. Hydrometer calibration (Rc) and temperature.
    iii. Hydrometer reading at 40 seconds (R1).
    iv. Temperature of suspension.

v. Corrected hydrometer reading (R1'), as described in Step 9.
vi. Hydrometer reading at two hours (R2).
vii. Corrected hydrometer reading (R2'), as described in Step 10.

13. Step 12: Calculate the percent of sand and percent of clay in the sample using the following equations.
    i. $\%sand = ((Wt - R1')/Wt)x100$
    ii. $\%clay = (R2'/Wt)X100$
14. Step 13: The following four steps describe a sieve analysis which is to be conducted on each of the replicate samples, unless the sand content (as calculated above) is found to be less than 25%, in which case the sieve analysis can be omitted. After the completion of Step 10 pour the suspension from the cylinder into a 0.045 millimeter sieve and wash the fine material through the sieve using running water.
15. Step 14: Dry the sieve and its contents in an oven. Cool the sieve and transfer the sand to a pre-weighed evaporating dish (or similar heat-resistant vessel) carefully, using a soft brush.
16. Step 15: Place the dish and its contents in an oven at 105 degrees centigrade for two hours to dry. Cool the dish and its contents and weigh to the nearest 0.01 gram. Determine the weight of the sand by subtracting the weight of the dish.
17. Step 16: Assemble a stack of sieves consisting of the 0.25 millimeter sieve, the 0.045 millimeter sieve, and the pan, from top to bottom, respectively. Inspect the sieves carefully before using them to ensure that they are clean and not damaged. Transfer the sand from the evaporating dish to the top sieve using a soft brush.
18. Step 17: Put the cover on the top sieve, firmly fasten the sieves to the sieve shaker and shake for three minutes. Disassemble the stack of sieves and transfer the contents of each sieve separately to a weighing dish.
19. Step 18: Weigh the contents of each sieve to the nearest 0.1 gram and record the following data:
    i. Total weight of the sand fraction.
    ii. Weight of sand passing the 0.25 millimeter sieve (retained in the 0.045 millimeter sieve).
    iii. The percent of fine plus very fine sand. This is calculated by dividing the weight of the sand passing the 0.25 millimeter sieve by the total sand fraction weight and multiplying this value by 100. A set of type of sieves used in this analysis is shown in the photograph below. It is

important to keep these sieves clean (to prevent partial clogging) and free from any damage. Dirty or damaged sieves will yield erroneous results.

20. Step 19: Using the soil permeability/textural triangle which is repeated below, determine the permeability class of the soil horizon being tested, based on the average percentage of sand and clay calculated in the replicate samples.
21. If the average percentage of fine plus very fine sand in the samples is 50% or greater, adjust the permeability class determined in Step 19 down one class. For example if the percent of sand and clay indicates that the material is in the permeability class K3 and the percent of fine plus very fine sand is greater than 50 percent, then the material is assigned to permeability class K2.
22. If the soil horizon being tested is found to have a massive or platy structure or a hard, very hard, firm, or very firm consistency, adjust the permeability class determined in Step 19 down one class.

Soil Permeability Testing

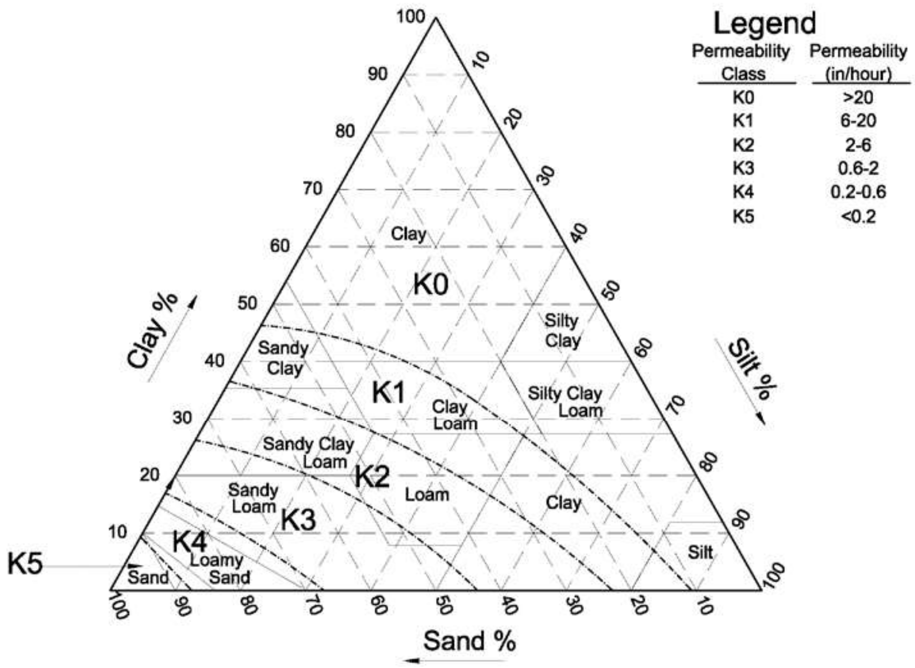
To illustrate the permeability calculations from a soil class rating analysis, consider the following example:

Example: A septic system must be designed for a residential lot in Somerset County, NJ. A soil log was dug and a sample was taken at a depth of 60". A soil class rating analysis was conducted on the material and the results obtained are shown in the table below. What is the permeability of this soil horizon?

Parameter	Result Obtained
Total weight of sample	205.2 grams
Weight of material retained on 2 mm sieve	42.9 grams
Oven dry weight of soil	39.9 grams
Hydrometer calibration	6.0
Temperature of suspension	66 degrees
Hydrometer Reading R1	22.0
Corrected Hydrometer Reading (R1')	15.6*
Hydrometer Reading R2	7.5
Corrected Hydrometer Reading (R2')	5.1**
Sieve Analysis: Oven dry weight of remaining sand	22.6
Weight of fine + very fine sand	6.8

* The corrected hydrometer reading is calculated by subtracting 0.4 grams from the reading of 22.0 (because the temperature is 2 degrees below 68) and then subtracting the hydrometer calibration (6.0) this value (21.6) to obtain 15.6.
** The corrected hydrometer reading is calculated by subtracting 0.4 grams from the reading of 10.5 (because the temperature is 2 degrees below 68) and then subtracting the hydrometer calibration (6.0) this value (7.1) to obtain 1.1.

Solution:
Percentage of coarse fragments:
$Coarse\% = 42.9 / 205.2 = 20.9\%$
Remaining material:
$\%sand = ((Wt - R1') / Wt)x100 = ((39.9 - 15.6) / 39.9X100 = 60.9\%$
$\%clay = (R2' / Wt)X100 = (1.1 / 39.9)X100 = 2.8\%$
$\%silt = 100 - 60.9\% - 2.8\% = 36.3\%$
Based on the soil textural triangle (repeated below), this material would be classified as "sandy loam" and would be assigned a permeability value of K3.



Soil Permeability/Textural Triangle

However, the NJDEP also requires that the percentage of fine to very fine sand be determine in order to assign a final permeability value to the material. Remember, that if the percentage of fine plus very fine sand is greater than 50% the permeability value must be reduced by one class. (i.e. In this case the K3 would be reduced to K2). This percentage is calculated below:

$Fine\% = 6.8/22.6 + 30.1\%$

In this case, the percentage of fine to very fine sand is less than 50%. Therefore, the final result remains K3.

Tube Permeameter Test: A complete description of the tube permeameter test is beyond the scope of this course. However, in many respects it is a more difficult test than the soil class rating analysis. For one thing, it is important to collect undisturbed soil samples (or disturbed soil samples with certain conditions met). This makes the field collection of the material more difficult. The soil must be pre-soaked in a tube permeameter test and, depending on the type of soil, this pre-soaking period can last anywhere from only a few minutes to several days. Finally, the results obtained from a series of replicate samples sometimes differ by one or more permeability classes. When this occurs, the soil investigator must re-analyze the samples and ensure that they are free of cracks, worm holes, and other inconsistencies. All of these factors make this procedure a somewhat complicated process. For all of these reasons, the soil class rating test described above is the preferred laboratory test for most soil conditions.

Final Considerations:
Although many different types of tests were described in this course, it is always up to the engineer's judgment as to how to approach a specific situation. Real-life problems not discussed in this course include an artesian situation, "quick sand" and other problem soil conditions. Each of these conditions should be evaluated individually to determine the exact soil characteristics. In more typical soils, the engineer can choose from one of the methods discussed in this course. The final determination of the final testing to be done should be based on a variety of factors, including especially the actual soil conditions encountered. Finally, it is always advisable to run replicate tests to ensure that the results obtained accurately reflect the actual soil conditions. The engineer should also bear in mind that more is sometimes better when it comes to soil testing. For instance if there are several soil layers, it might be useful to take a test in each of the layers. Sometimes the results can be surprising. Often a material will look clayey, but upon formal testing, will be seen to have a higher content of coarse particles (sand) than was expected. Also, in many areas soils can change significantly over a very short distance. It is important that sufficient soil logs are performed to adequately evaluate the entirety of the area required for a septic system of other infiltration feature. The soil testing procedures described in this course will allow the engineer to determine the exact consistency of the soil.