LAB #3
DARCY'S LAW

Due week of Nov 18th/2012 in the 2B03 drop box by the start of your lab time

INTRODUCTION
Fundamentals of Water Flow

Understanding the movement of water through soils is very important in both agricultural and urbanized areas. The direction and flow rate of water can influence the amount of water that reaches plant roots, the water table, local streams, wells and drainage systems. There are three types of water movement within soil: saturated flow, unsaturated flow and vapor movement. In this lab we will focus on saturated water flow where the pores in the soil are completely filled with water.

Water movement depends on the **hydraulic conductivity** of a soil (See Section 5.5, pages 146-149 in your 2B03 Textbook). Hydraulic conductivity is defined as a measure of the "ease" of a soil to allow water movement. Hydraulic conductivity depends on the pore space geometry of a soil because the connection of pores and their size and shape determine water flow pathways. The larger the pore sizes, the more easily water will flow through the soil. Sandy soils usually have larger pores and thus they generally have a higher saturated hydraulic conductivity than finer-textured soils like clay and silt. Worm holes and pores created by dead root channels (biopores) as well as fractures associated with soil structure are all termed macro-pores and can account for a large proportion of the water movement in saturated soils. Soils with a stable sorted granular structure conduct water more rapidly than those with unstable, graded structural units, which can break down upon saturation and lead to clogged pores. Entrapped air can also impede the movement of water, resulting in an apparently lower saturated hydraulic conductivity.

By measuring the water flow through columns of saturated sands, Darcy (1856) determined that the volume of water flowing through soil in a given time is proportional to the **hydraulic gradient** (dh/dx) through the cross-sectional area of the column and the soil's hydraulic conductivity (K_s) (eq 1.1). Hydraulic gradient (dh/dx in eq 1.1) is defined as the rate of change in hydraulic head over distance and can be expressed as the difference in hydraulic head (h_2-h_1) divided by the distance between the measurement points (x) (eq 1.1). **Hydraulic head** (h) is equal to the sum of gravitational (z) and pressure (ψ) heads (eq 1.2). It is the driving force in Darcy's Law (eq. 1.1). For example, a larger hydraulic gradient causes a larger volume of water to flow through the soil in a given time.

$$|q| = \frac{V_w}{A \cdot t} \qquad q = -K_s \frac{dh}{dx} \qquad q = -K_s \frac{h_2 - h_1}{x} \qquad \text{eq 1.1 (Darcy's Law)}$$

where q = Darcy velocity (cm/sec)
K_s = saturated hydraulic conductivity (cm/sec)
dh/dx = hydraulic gradient (dimensionless)
V_w = volume of flow in specific time interval (cm^3)
A = cross sectional area of the soil (cm^2)
t = time interval (sec)
h_2-h_1 = hydraulic head difference (cm water)
x = distance over which the hydraulic head difference is measured (cm)

$$h = z + \psi \qquad \text{eq 1.2 (Hydraulic Head)}$$

where h = hydraulic head (cm)
z = gravitational head (cm)
Ψ = pressure head (cm of water)

<u>Measuring Saturated Hydraulic Conductivity</u>

In this lab you will measure the saturated hydraulic conductivity of two soils using the **Falling Head Method**; which involves adding water once to the inlet tube and allowing the water to percolate through the soil sample as the hydraulic gradient decreases exponentially over time. This method initially applies a relatively large hydraulic head to the top of the soil sample, then the applied hydraulic head decreases over time as the water flows through the soil sample. This generates an exponentially decreasing flow rate over time. The hydraulic conductivity of the soil can then be determined by measuring the length of time required for the falling water level to pass between two points on the inlet tube (H_2, H_1) *(Refer to Figure 1 for experimental set-up)*. By integrating Darcy's formula (eq. 1.1) for saturated water flow, the saturated hydraulic conductivity for the falling head method is:

$$K_s = \left[\frac{a \cdot L}{A \cdot t}\right] \times \ln\left(\frac{H_1}{H_2}\right)$$

where a = the cross-sectional area of the glass tube (cm)
A = the cross-sectional area of the soil sample (cm)
L = the length of soil sample in the cylinder (cm)
H_1 = the larger height of tube for time measurement (cm)
H_2 = the smaller height of tube for time measurement (cm)
t = time for water to pass from H_1 to H_2 (sec)

Note: Only simplified *Hydraulic Head* theory was covered in this lab, however in Earth Sc /Envir Sc 3W03, the concept of hydraulic head is thoroughly developed and discussed. In addition, an alternative method (*Constant Head Method*) is used for calculating saturated hydraulic conductivity in Earth Sc /Enviro Sc 3W03. This alternative method involves inducing water to flow through the soil sample at a constant rate under a constant hydraulic gradient.

PURPOSE

To better understand water flow in soil by investigating Darcy's Law through the measurement of the saturated hydraulic conductivity of soil samples using the falling head method.

OBJECTIVES

- Use the falling head permeameter for measuring hydraulic conductivity of saturated soil and assess its limitations.
- Determine the hydraulic conductivity of a soil sample at different applied hydraulic heads.
- Determine the bulk density and textural class of two soil samples.
- Compare the characteristics of two soil samples.

FALLING HEAD PROCEDURE

Equipment

Large bowl	
300 mL (or larger) beaker	two soil samples
100mL beaker	rubber stopper with glass tube in centre
small funnel (if necessary)	elastic band
paper clip	stopwatch, hand watch or clock
ruler	metal retort stand
scale	erasable marker
clamp	plastic cylinder
a small square piece j-cloth	

Preparation

1. Weigh approximately 100-110g of both soil sample #1 and of sample #2 and record the exact mass of each soil used. Pick out the organics before you weigh the sample. *Note, soil samples were previously oven dried for at least 24 hours at 105°C.*

2. Secure a double-layer piece of j-cloth (approx. 3”x3”) to the bottom of the plastic cylinder using elastic bands. Make sure the J-cloth is pulled tightly and that the plastic cylinder and j-cloth are DRY. Use Duct tape to secure the DRY j-cloth to the outer wall of the DRY cylinder.

3. Place one of the soil samples into the plastic cylinder, spreading it to ensure even and level coverage across the entire cylinder area.

4. Measure the diameter of the plastic cylinder (d_s) and the length (L) of the soil sample within the cylinder. Calculate the cross-sectional area of the soil (A)

and the volume of the sample sample using d_s and L. Record these values in table 1.

5. Measure the diameter of the glass tube (d_g). Use this value to calculate the cross-sectional area of the glass inlet tube (a). Record these values in the results section.

6. Fill a large bowl with water – such that the water level is 1-2cm below the rim of the bowl.

7. VERY slowly so as not to disturb the soil sample, lower the plastic cylinder containing the soil into the bowl of water to the point where the bottom half of the cylinder is submerged in the water. Do not completely submerge the plastic cylinder; you only want the water to enter the bottom of the cylinder through the j-cloth to saturate the soil, NOT flow in from the top.

8. Hold the plastic cylinder in this position until the soil sample is visibly saturated (this may take a few minutes).

9. Once the sample is saturated, place the rubber-stopper-with-the-glass-tube-in–the-centre into the top of the plastic cylinder and push/twist it in tightly such that it can support the weight of the soil core. **DO NOT lift the soil sample from the water; ensure that the soil sample portion of the cylinder stays below the water level.**

10. Now that the soil is saturated, it is no longer as easy to disturb so the cylinder can be further lowered into the water. With the rubber-stopper-with-the-glass-tube-in–the-centre firmly in place, submerge the 300mL beaker in the bowl, and slide it under the cylinder (see Fig. 1). You may have to lift the cylinder slightly and briefly to do this.

11. The beaker should be upright, and filled with water, with the cylinder inside of it (**See Fig. 1)**. Next, simultaneously, remove the beaker & cylinder from the bowl. Position the plastic cylinder so that the top edge of the cylinder is just above the water level (~0.5cm) in the beaker. You may find it easier to pour water into the large beaker using the small 20ml beaker to achieve the desired reference height.

12. Clamp the glass tube to the retort stand to hold the cylinder in position.

13. To allow for easier flow of water from the large beaker to the small beaker, take a paper clip, bend it so that it forms an "L shape" and wrap it in a small piece of j-cloth. You won't want to put this in place until after your sample is saturated and you are about to begin your experiment. When you do, place it at the spout of the large beaker and the water will flow along into the small beaker.

14. Place the 100mL beaker below the “spout” of the large beaker to catch the water that will overflow.

15. You are now ready to begin the experiment. Be sure to wipe up any spilt water.

Method

1. Select points on the glass tube for several potential H_1 and H_2 values. You will need to measure four differences in height. Choose your points carefully so that you’ll get four different height differences (H_1-H_2). Include one long fall using most of the glass tube.

2. To measure H_1 and H_2, use the water level in the beaker as your reference elevation (i.e. position zero 0). Then measure with a ruler, the distance from the reference point to your lower mark. Record this value as H_2. Next measure the distance from the reference point to your higher mark and record this value as H_1. Mark the two points, H_2 and H_1 on the glass tube with an erasable marker or grease pencil.

3. To allow for easier flow of water from the large beaker to the small beaker, take a paper clip, bend it so that it forms an “L shape” and wrap it in a small piece of j-cloth. Place it at the spout of the large beaker and the water will flow along into the small beaker.

4. Using a funnel if necessary, pour water into the glass tube until it is almost full and get your stop watch ready or use the second hand on a watch.

5. Measure the amount of time it takes for the water to pass from H_1 to H_2. Record this time as t in Table 1.

6. Repeat steps 1 to 4 using four different height differences (H_1-H_2), i.e. different values and different interval lengths.

7. Repeat this procedure for the other soil sample (soil #2) **using the same H values** you used for the first soil.

RESULTS

(I) Falling Head Results for Soil # 1

Inner Diameter of the glass tube (d_g) = _______cm
Cross-sectional area of the glass tube ($a = \pi r_g^2$) = _______cm^2
Length of soil sample (L) = _______cm
Inner Diameter of the cylinder (d_s) = _______cm
Cross-sectional area of the cylinder ($A = \pi r_s^2$) = _______cm^2
Volume of soil sample in cylinder (V= LA) = _______cm^3
Mass of soil (M) = _______g
Bulk density (M/V) = _______g/cm^3

Table 1: Falling Head Data for Soil #1

Trial #	H_1 (cm)	H_2 (cm)	Time, t (s)	aL /At (cm/s)	$\ln(H_1/H_2)$ (unitless)	$K_s = (aL/At)*\ln(H_1/H_2)$ (cm/s)

(II) Falling Head Results for Soil # 2

Inner diameter of the glass tube (d_g) = _______cm
Cross-sectional area of the glass tube ($a = \pi r_g^2$) = _______cm^2
Length of soil sample (L) = _______cm
Inner diameter of the cylinder (d_s) = _______cm
Cross-sectional area of the cylinder ($A = \pi r_s^2$) = _______cm^2
Volume of soil sample in cylinder (V= LA) = _______cm^3
Mass of soil, M = _______g
Bulk density (M/V) = _______g/cm^3

Table 2: Falling Head Data for Soil #2

Trial #	H_1 (cm)	H_2 (cm)	Time, t (s)	aL /At (cm/s)	$\ln(H_1/H_2)$ (unitless)	$K_s = (aL/At)\ln(H_1/H_2)$ (cm/s)

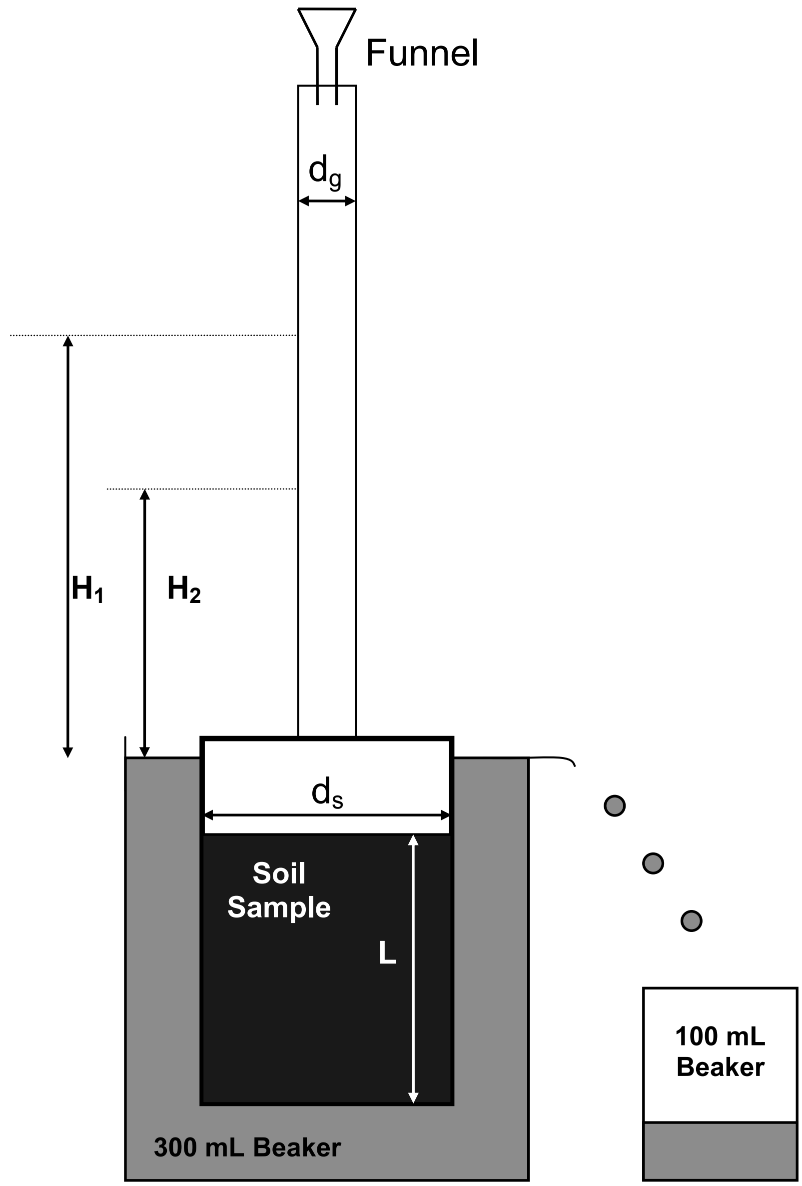

Figure 1: Falling Head Apparatus

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FINAL LAB REPORT

Part I: Lab Component

1. Using the falling head data, plot a graph of the ln(H_1/H_2) vs At/aL for both soil samples. What is the average saturated hydraulic conductivity (slope of the line with a zero intercept) of each soil? Again comment on the line and data of each soil. Should it be a straight line? Why or why not?
2. Explain any variation observed in values of K_s obtained using the falling head method. What factors could make the value change?
3. Based on the K_s of each soil sample, determine the textural classification of soil#1 and soil#2? Refer to Figure 3 below. Is it consistent with the observed texture?
4. What is the bulk density of each soil? Are the hydraulic conductivity values of each soil what you would expect considering the bulk density and texture of each soil? Why or why not?

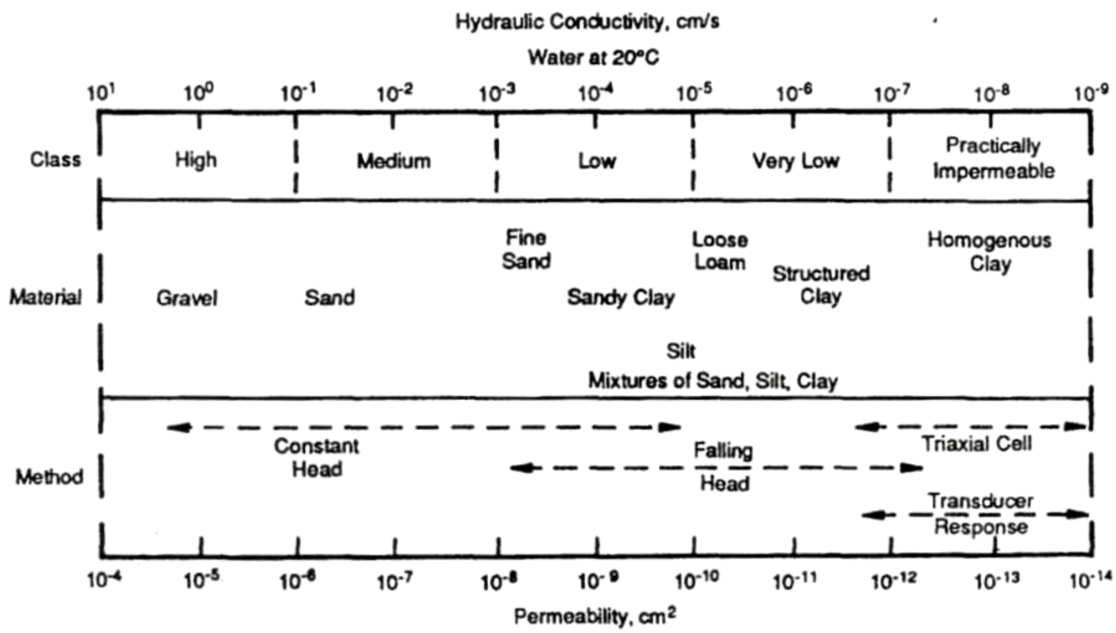

Figure 3: Hydraulic conductivity of various materials at saturation. (From Klute and Dirksen, 1986).

Part II: Comprehensive Questions

1. What causes water to flow through soils?
2. What factors or properties of soils would most influence its saturated hydraulic conductivity?
3. What are macropores and how do they affect the hydraulic conductivity of a soil?