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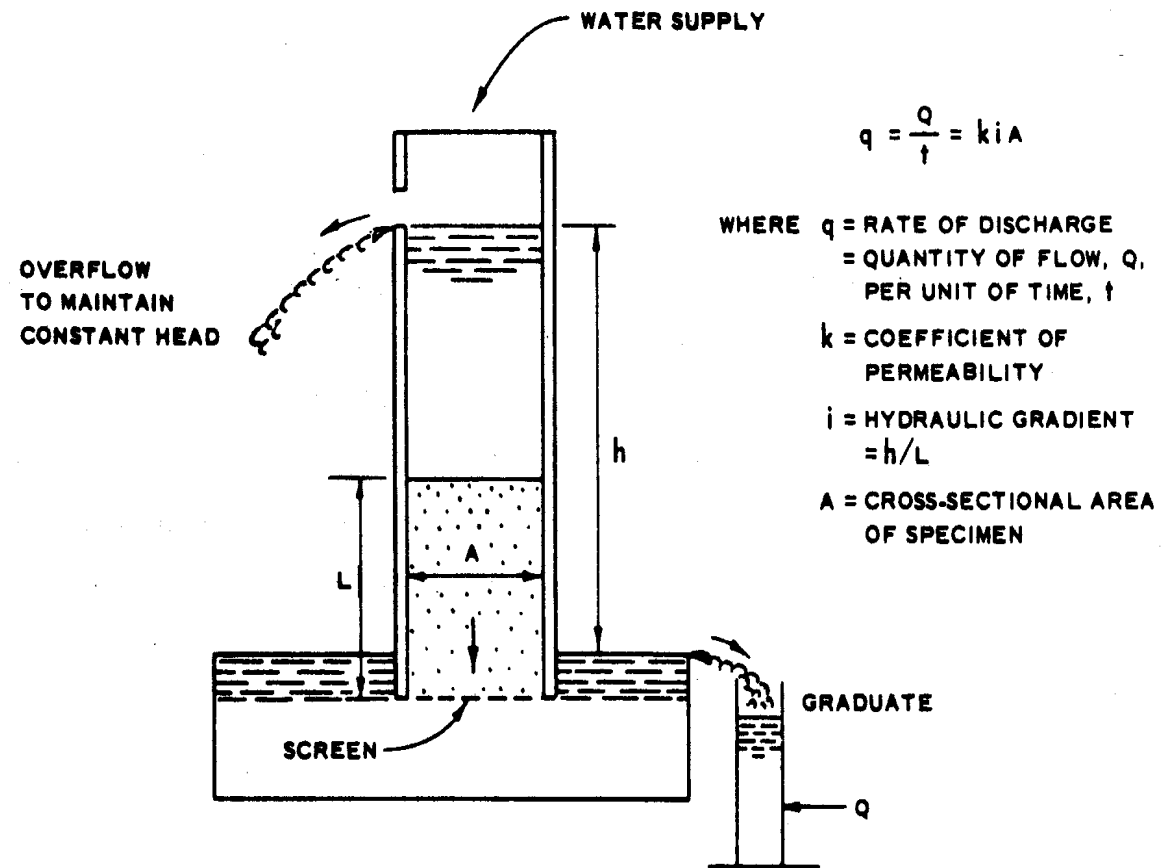
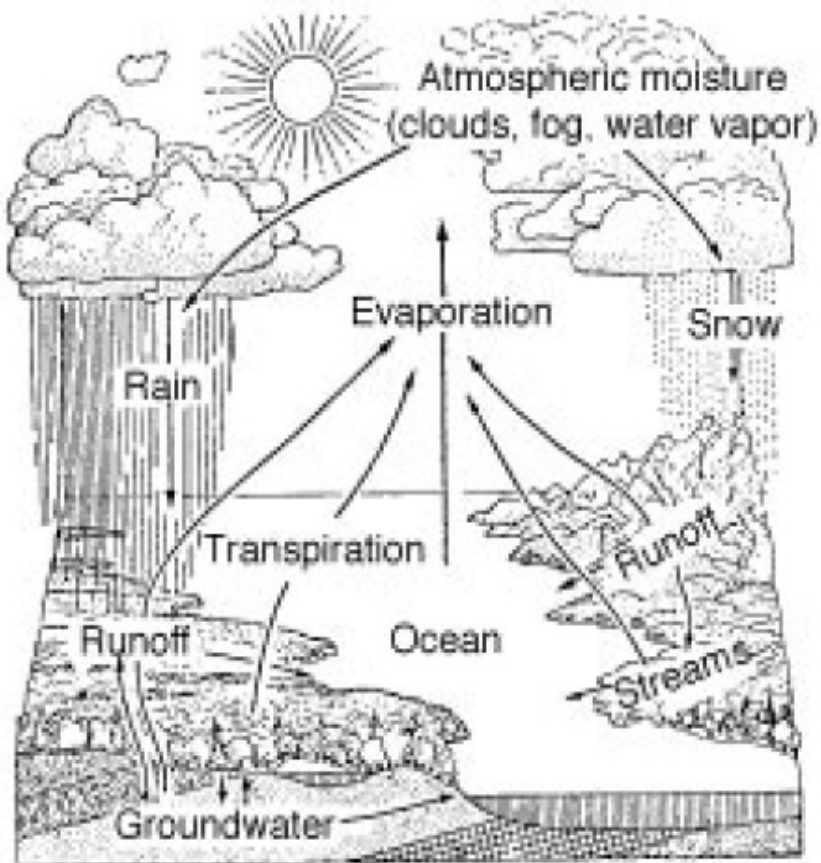


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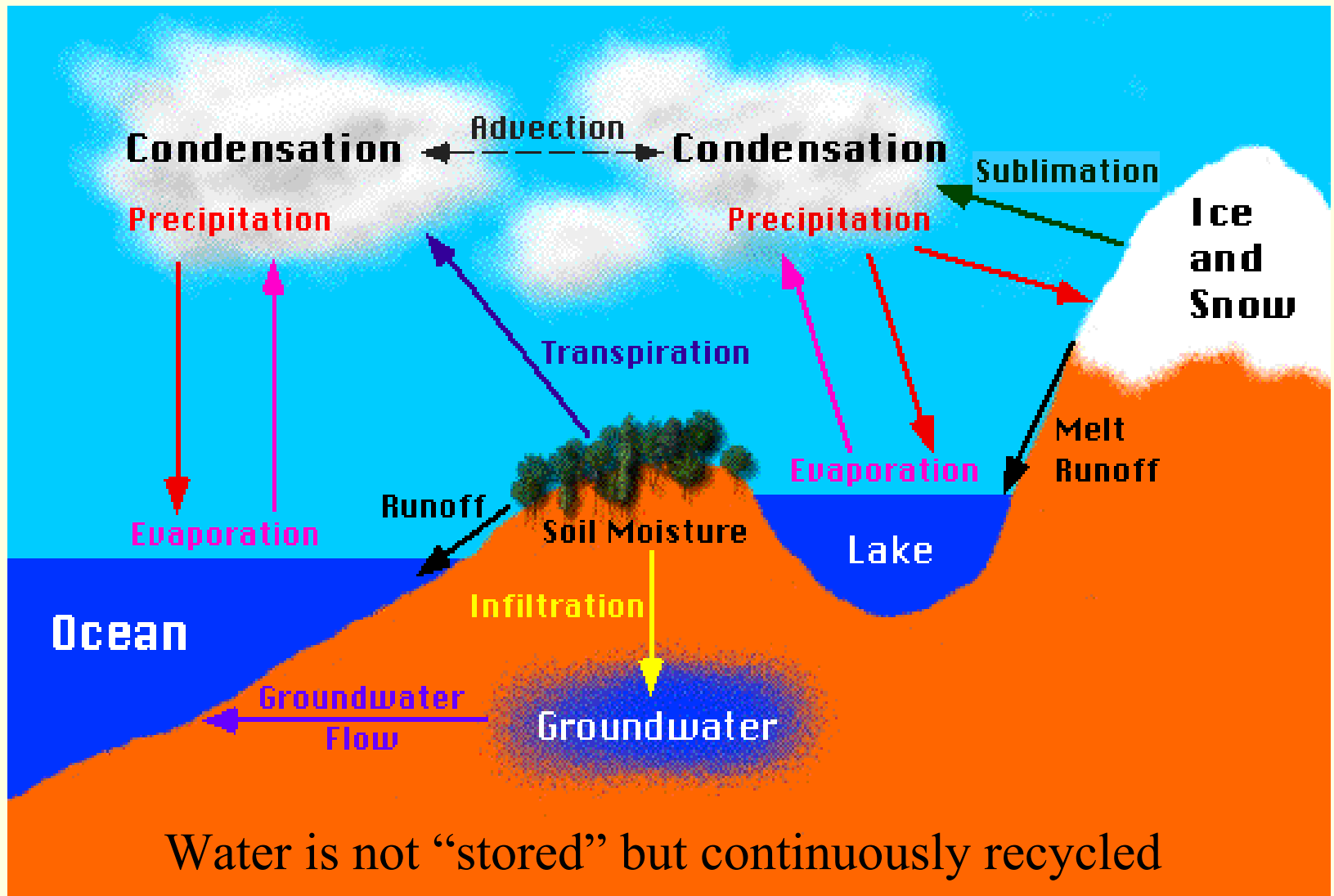
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ENCE 3610 Soil Mechanics

Lecture 6 Groundwater I

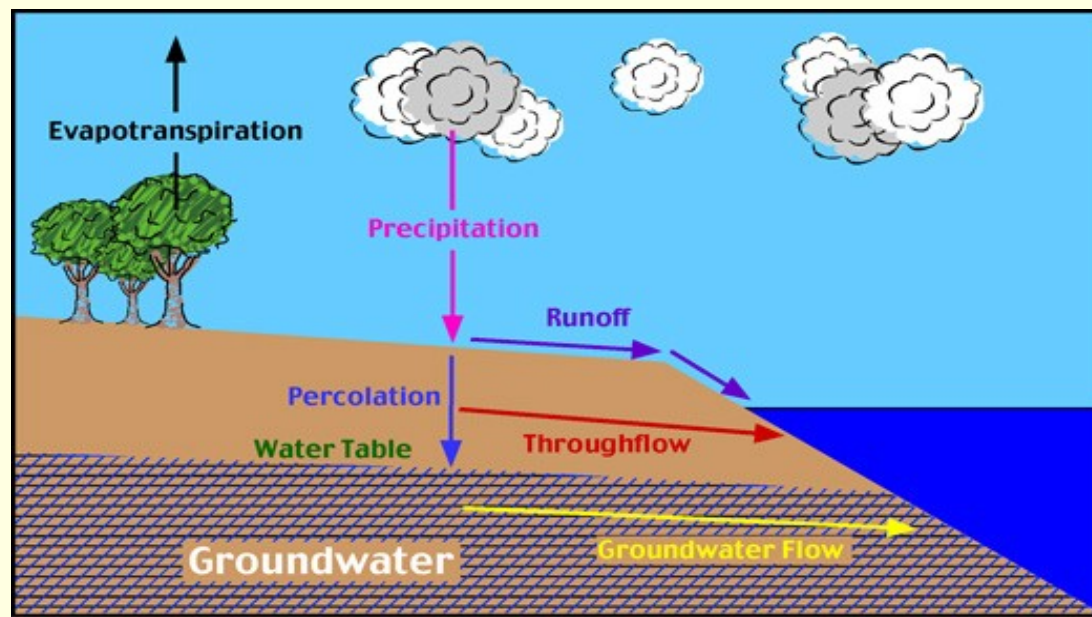


Hydrologic Cycle



Aspects of Hydrology

- A relatively small amount of the earth's water (<1%) is contained in the groundwater, but the effects of this water are out of proportion to their amount
- The permeability of soil affects the distribution of water both between the surface and the ground mass and within the ground mass itself



Theory

- Bernoulli's Law

$$h = \frac{v^2}{2g} + \frac{p}{\gamma} + z$$

- Kinetic Component
- Pressure Component
- Gravitational (Potential) Component

- In reality, an energy balance of the soil as it flows through the ground
- Kinetic Component can usually be ignored

- Head Differential

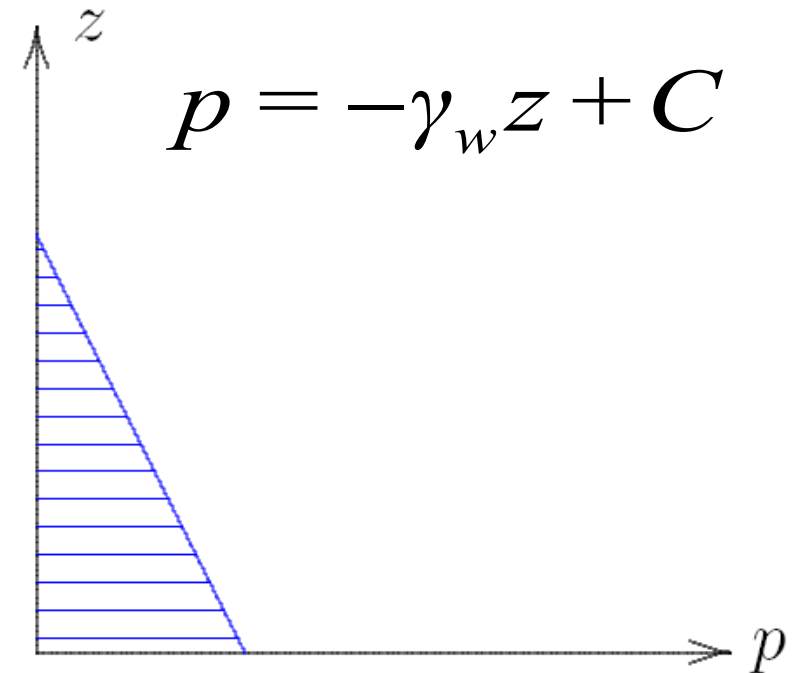
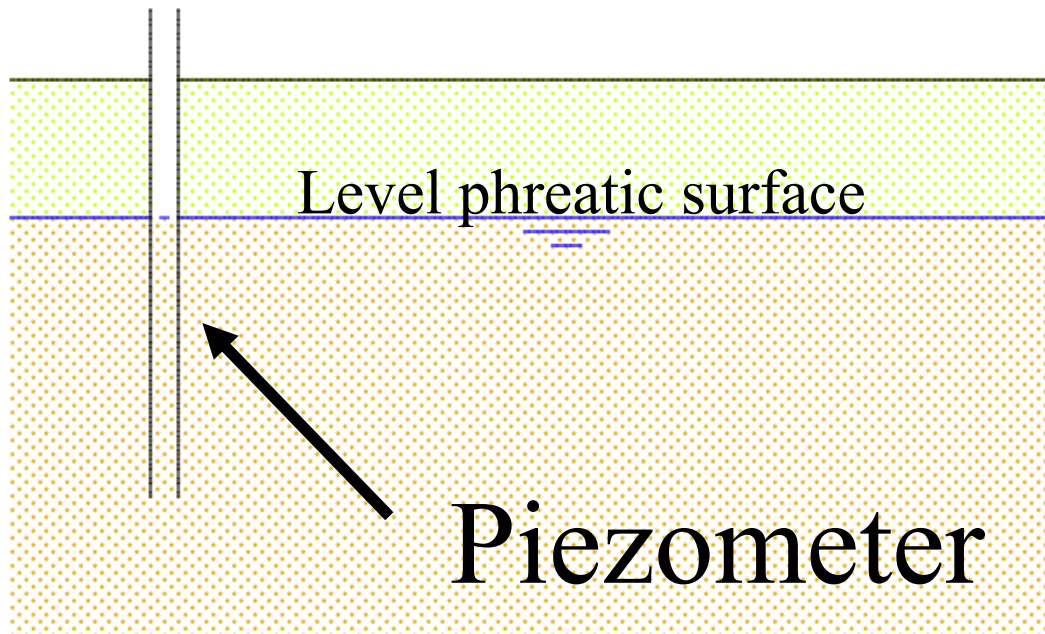
$$h_1 - h_2 = \left(\frac{p_1}{\gamma} + z_1 \right) - \left(\frac{p_2}{\gamma} + z_2 \right)$$

- Pressure difference causing water to flow under the ground

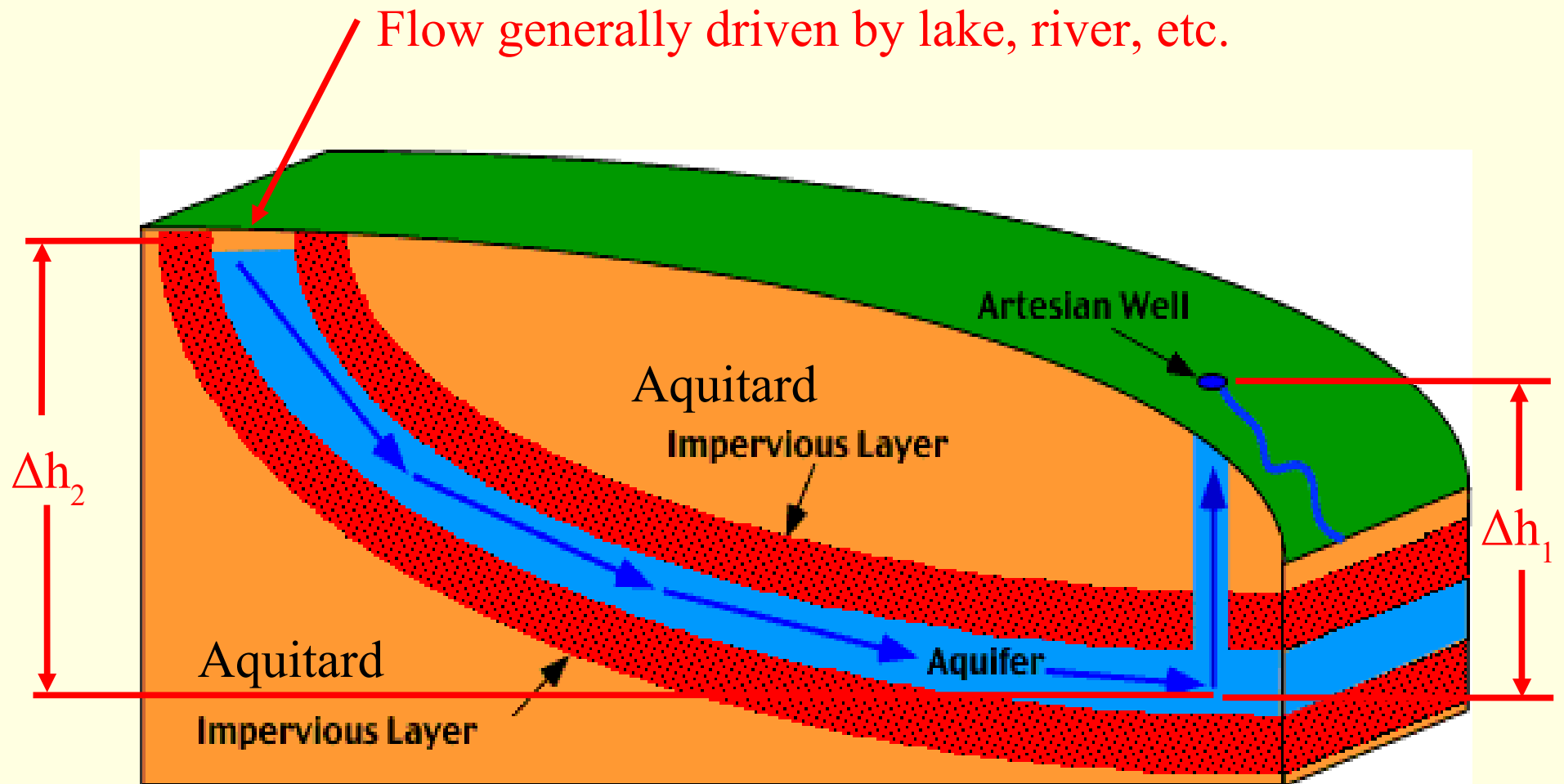
$$\Delta p = \gamma(h_1 - h_2)$$

Hydrostatic Condition

- Condition of water under the soil when water is not moving
- Useful for many soil mechanics problems



Underground Flow



$\Delta h_2 > \Delta h_1$ makes ground water flow at well possible

Changes in Groundwater Level

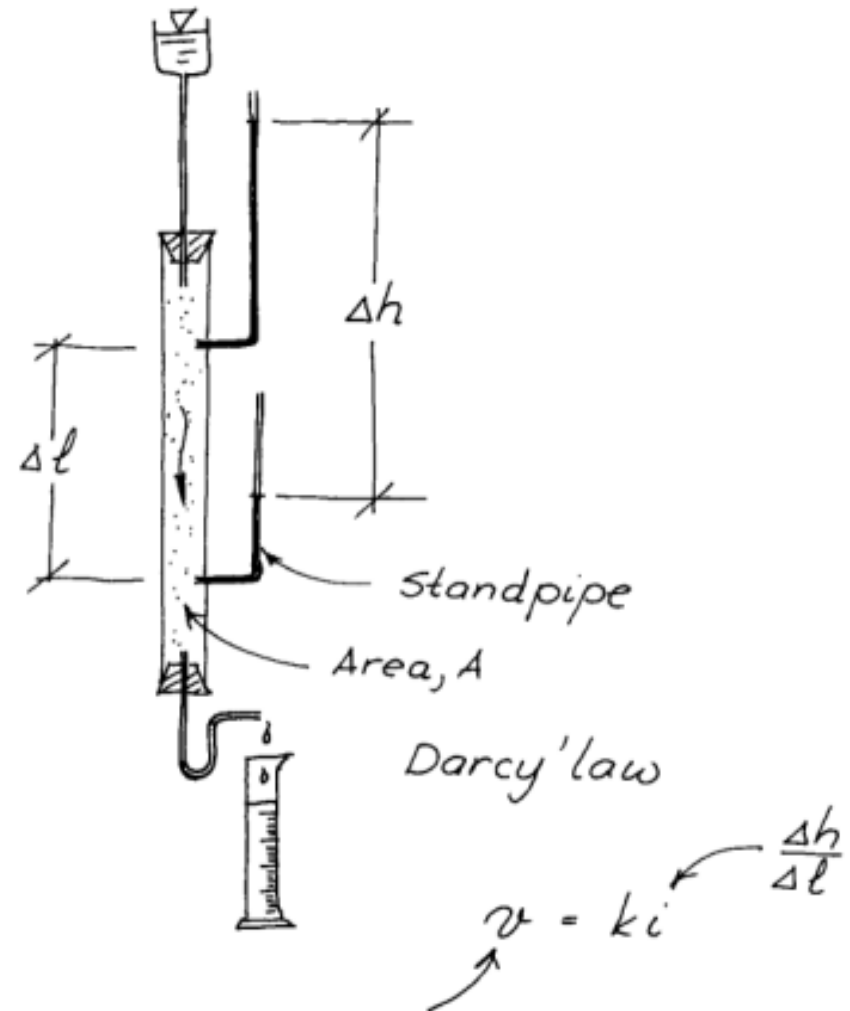
- Seasonal variations; variations due to drought, heavy rains, etc.
- Addition of artificial structures and elements to landscape
 - Reservoirs, dams, and artificial river channels
 - Construction site excavations
- Drawdown due to well water, drains, etc.

Permeability

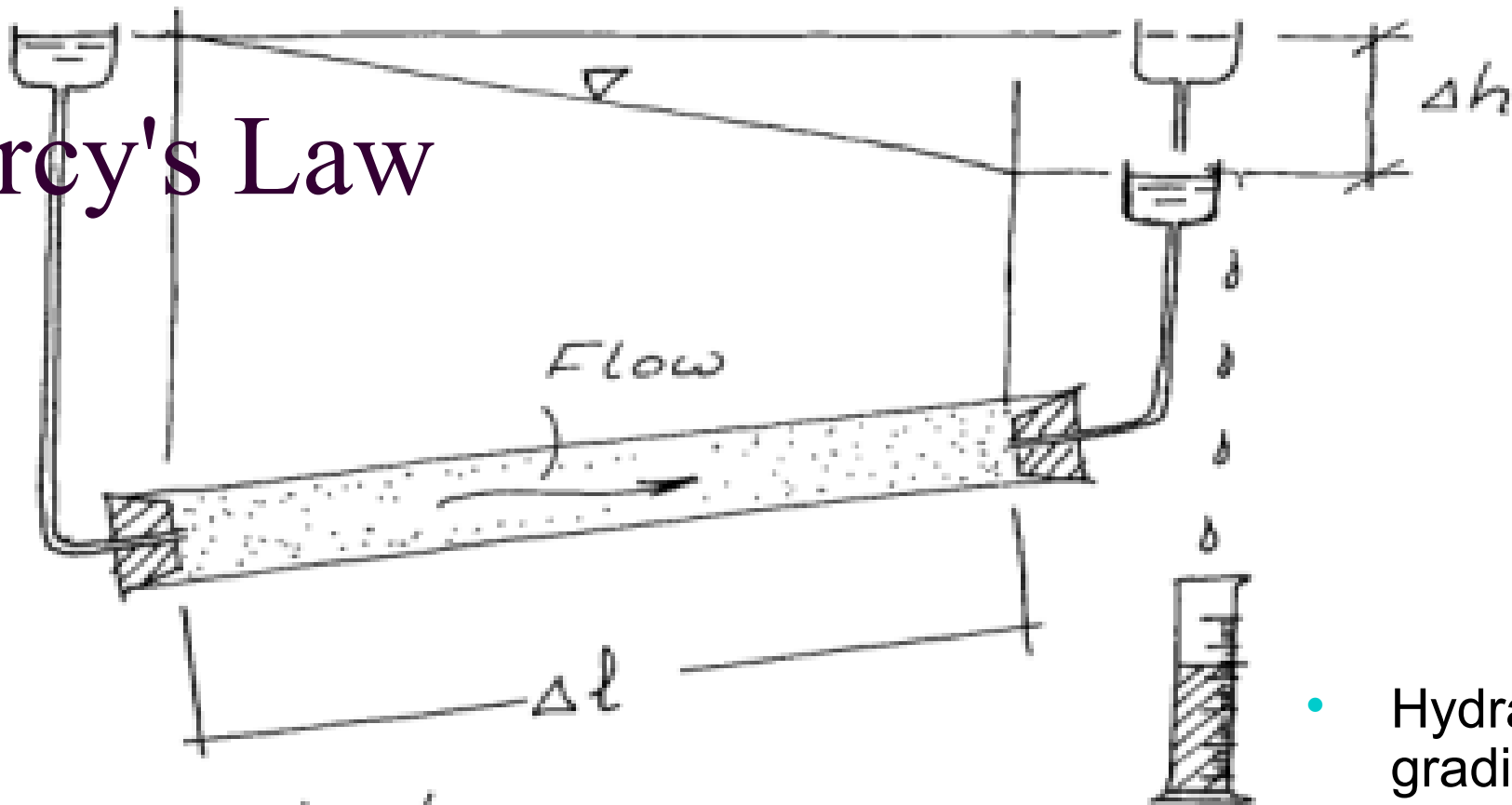
- Definition
 - The property of soils that allows water to pass through them at some rate
 - This property is a product of the granular nature of the soil, although it can be affected by other factors (such as water bonding in clays)
 - Different soils have different permeabilities, understanding of which is critical to the use of the soil as a foundation or structural element

Darcy's Sand Filtration Experiment

- Assumptions
- Laminar Flow
 - Generally applicable in soils due to low fluid flow velocities
 - Laminar flow generally exists when $i < 5$
- Soil is saturated



Darcy's Law



Darcy's law.

$$v = k \cdot i$$

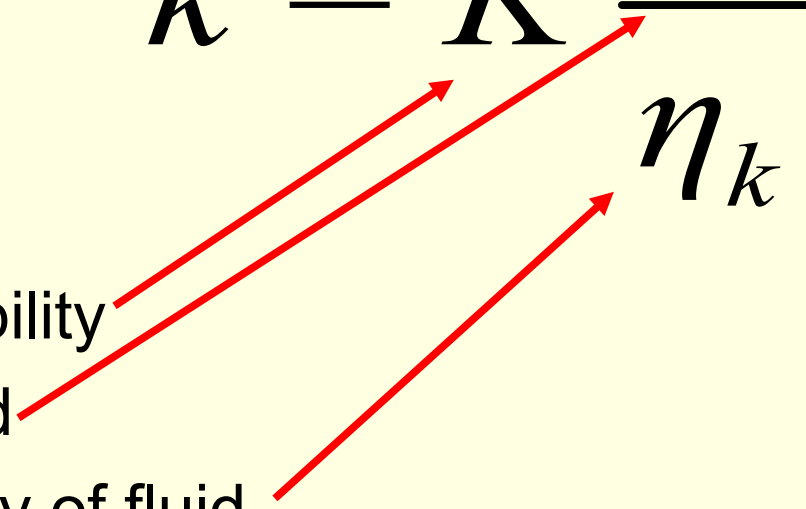
$\frac{Q}{tA} = \frac{q}{A}$

Coefficient of permeability
 Hydraulic gradient
 Gross area!

- Hydraulic gradient $i = \Delta h / \Delta l$
- Velocity = $Q / (tA)$
- $q = Q / t$
- $q = \text{flow} = \text{volume} / \text{time}$
- $A = \text{cross-sectional area}$
- k has velocity units

Coefficient of Permeability or Hydraulic Conductivity

- Definition

$$k = K \frac{\gamma}{\eta_k}$$


- Absolute permeability
- Unit weight of fluid
- Kinematic viscosity of fluid
- Absolute Permeability is only significant with soils when different fluids are considered

Typical Values of k

Table 5-4. Characteristics pertinent to embankment and foundation construction.

Major Divisions (1)	Letter (2)	Symbol		Name (6)	Value for Embankments (7)	Permeability Centimeters Per Second (8)	Compaction Characteristics (9)	Standard AASHTO Maximum Unit Dry Weight Pounds Per Cubic Foot (10)	Value for Foundations (11)	Requirements for Seepage Control (12)	
		Hatching (4)	Color (5)								
Coarse-grained soils	Gravel and gravelly soils	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired roller, steel-wheeled roller	125 - 135	Good bearing value	Positive cutoff
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired roller, steel-wheeled roller	115 - 125	Good bearing value	Positive cutoff
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Reasonably stable, not particularly suited to shells but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired roller, sheepfoot roller	120 - 135	Good bearing value	Toe trench to none
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious cores	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired roller, sheepfoot roller	115 - 130	Good bearing value	None
	Sand and sandy soils	SW		Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{-3}$	Good, tractor	110 - 130	Good bearing value	Upstream blanket and toe drainage or wells
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100 - 120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM		Yellow	Silty sands, sand-silt mixtures	Fairly stable, not particularly suited to shells but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired roller, sheepfoot roller	110 - 125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC		Yellow	Clayey sands, sand-silt mixtures	Fairly stable, may be used for impervious core for flood-control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepfoot roller, rubber-tired roller	105 - 125	Good to poor bearing value	None
Fine-grained soils	Sils and clays LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepfoot roller	95 - 120	Very poor, susceptible to liquefaction	Toe trench to none
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores, and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepfoot roller, rubber-tired roller	95 - 120	Good to poor bearing value	None
		OL		Green	Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepfoot roller	80 - 100	Fair to poor bearing value, may have excessive settlements	None
	Sils and clays LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepfoot roller	70 - 95	Poor bearing value	None
		CH		Blue	Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets, and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepfoot roller	75 - 105	Fair to poor bearing value	None
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepfoot roller	65 - 100	Very poor bearing value	None
Highly organic soils	Pt		Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations		

- Notes:
1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.
 2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions and the thickness of lift are properly controlled.
 3. In column 10, unit dry weights are for compacted soil at optimum moisture content for standard AASHTO (standard Proctor) compactive effort CE 55.

One Dimensional Example Illustration

- Given
 - River and Canal, parallel to each other
 - $\Delta h = 5\text{m}$
 - $L = 200\text{ m}$
 - $t_{\text{stratum}} = 2\text{ m}$
 - $k = 2\text{ m/day}$
 - Find
 - Seepage loss per km of river-canal length
- Solution
 - $q = kiA$
 - $i = \Delta h/L = 5/200$
 - $q = (2)(5/200)(2) \times 1000$
 - $q = 100\text{ m}^3/\text{day}/\text{km}$ length

Methods of Determining Permeability Coefficient

- Laboratory Methods
 - Constant Head Test (Cohesionless Soils)
 - Falling Head Test (Cohesive Soils)
- Empirical Correlations and “Typical” Values
- In-Situ Methods
 - Pumping Tests
- Consolidation Tests
- Permeability is the most difficult soil property to determine accurately, especially in the laboratory

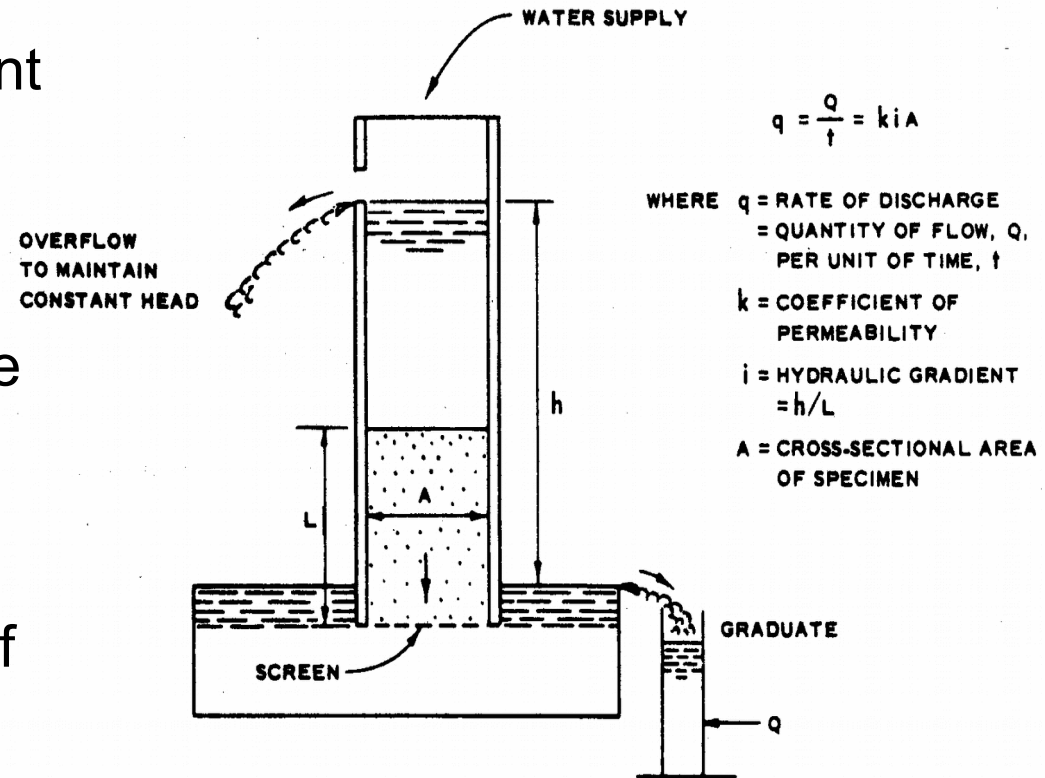
Type of soil	k (m/s)
gravel	$10^{-3} - 10^{-1}$
sand	$10^{-6} - 10^{-3}$
silt	$10^{-8} - 10^{-6}$
clay	$10^{-10} - 10^{-8}$

Laboratory Tests

- Constant Head Test
 - Direct measure of permeability using Darcy's Law
 - Suitable for cohesionless soils with permeabilities $> 10 \times 10^{-4}$ cm/sec
- Falling Head Test
 - Indirect measurement of permeability using time of flow
 - Suitable for cohesive soils with permeabilities $< 10 \times 10^{-4}$ cm/sec

Constant Head Test

- The simplest of all methods for determining the coefficient of permeability
- This test is performed by measuring the quantity of water, Q , flowing through the soil specimen, the length of the soil specimen, L , the head of water, h , and the elapsed time, t . The head of water is kept constant throughout the test.



Computation

- Compute the coefficient of permeability, k for laboratory test:
 - k_{20} = coefficient of permeability, cm/sec at 20° C
 - Q = quantity of flow, cm³
 - L = length of specimen over which head loss is measured, cm.
 - R_T = temperature correction factor for viscosity of water
 - h = loss of head in length, L , or difference in piezometer readings = $h_1 - h_2$, cm
 - A = cross-sectional area of specimen, cm²
 - t = elapsed time, sec.

$$v = ki$$

$$\frac{Q}{At} = \frac{k_{20}}{R_T} \frac{\Delta h}{\Delta L}$$

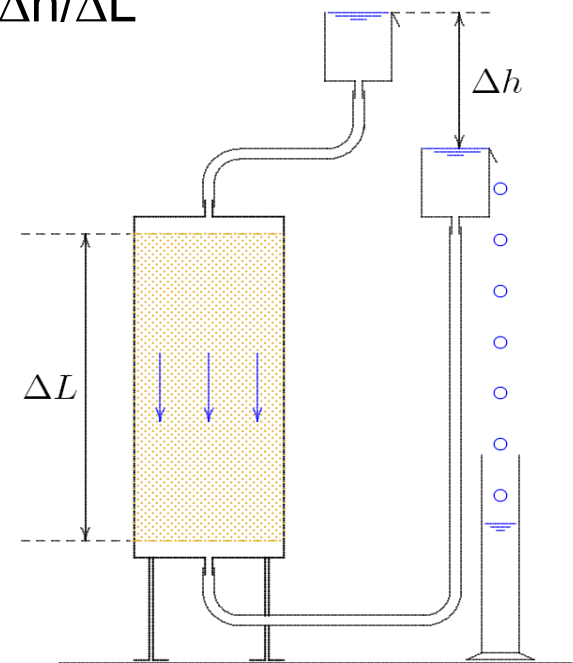
Solving,

$$k_{20} = \frac{Q\Delta LR_T}{\Delta hAt}$$

Sample Case:

Constant Head Permeameter

- Given:
 - Sand Sample
 - 15 cm high
 - 5.5 cm diameter (round)
 - Test Results
 - Measured head across sample: 40 cm
 - Time of flow: 6 sec.
 - Amount of water discharged: 400 cc
 - Assume test run at 20° C (no temperature/viscosity correction)
 - Find: Coefficient of Permeability
- Governing Equation
 - $q = kiA$
- Definition of Variables in Governing Equation
 - Flow rate $q = Q/t$
 - Sample area $A = \pi D^2/4$
 - Hydraulic Gradient $i = \Delta h/\Delta L$



Sample Case:

Constant Head Permeameter

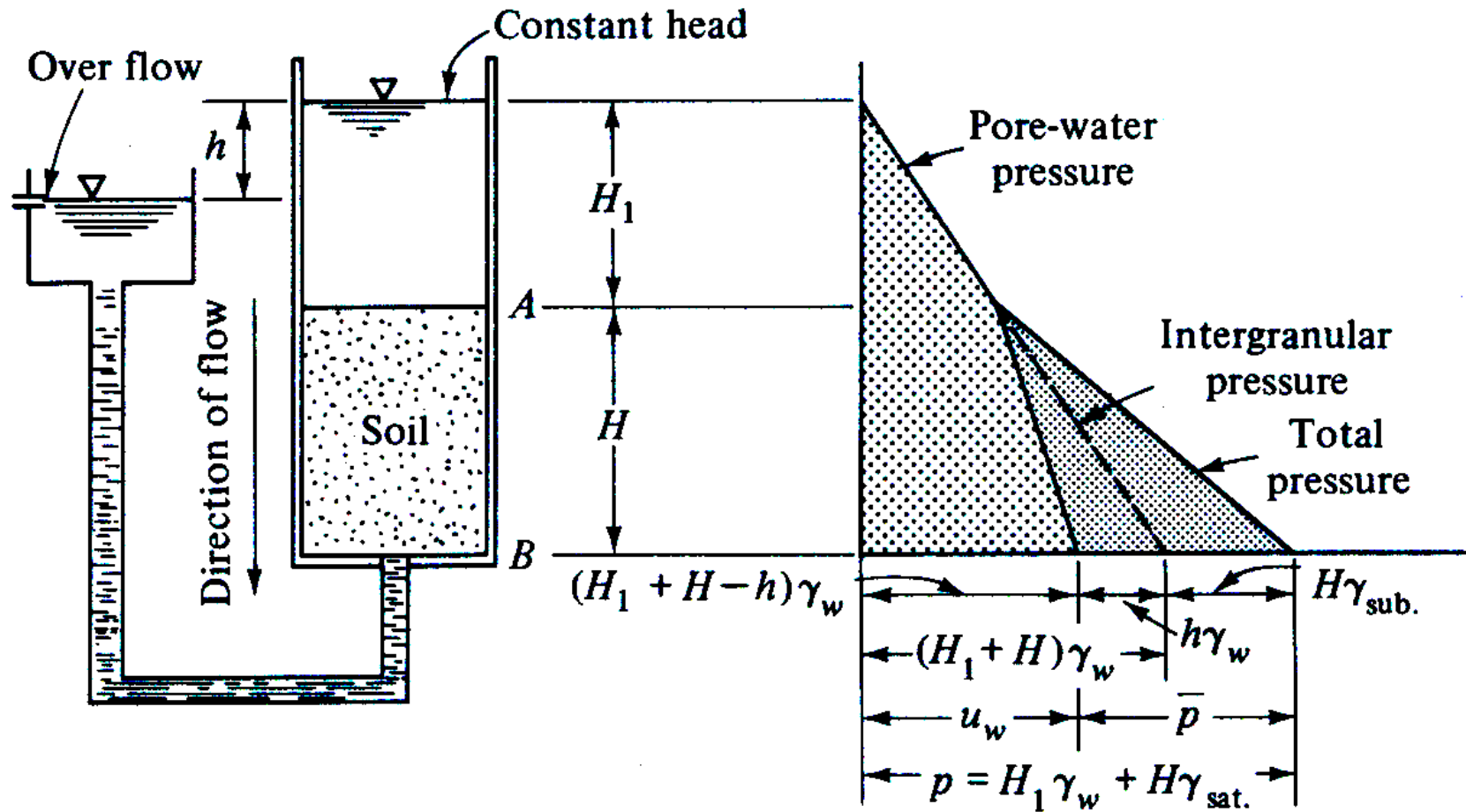
$$k_{20} = \frac{QLR_T}{hAt}$$

$$A = \frac{\pi D^2}{4}; R_T = 1$$

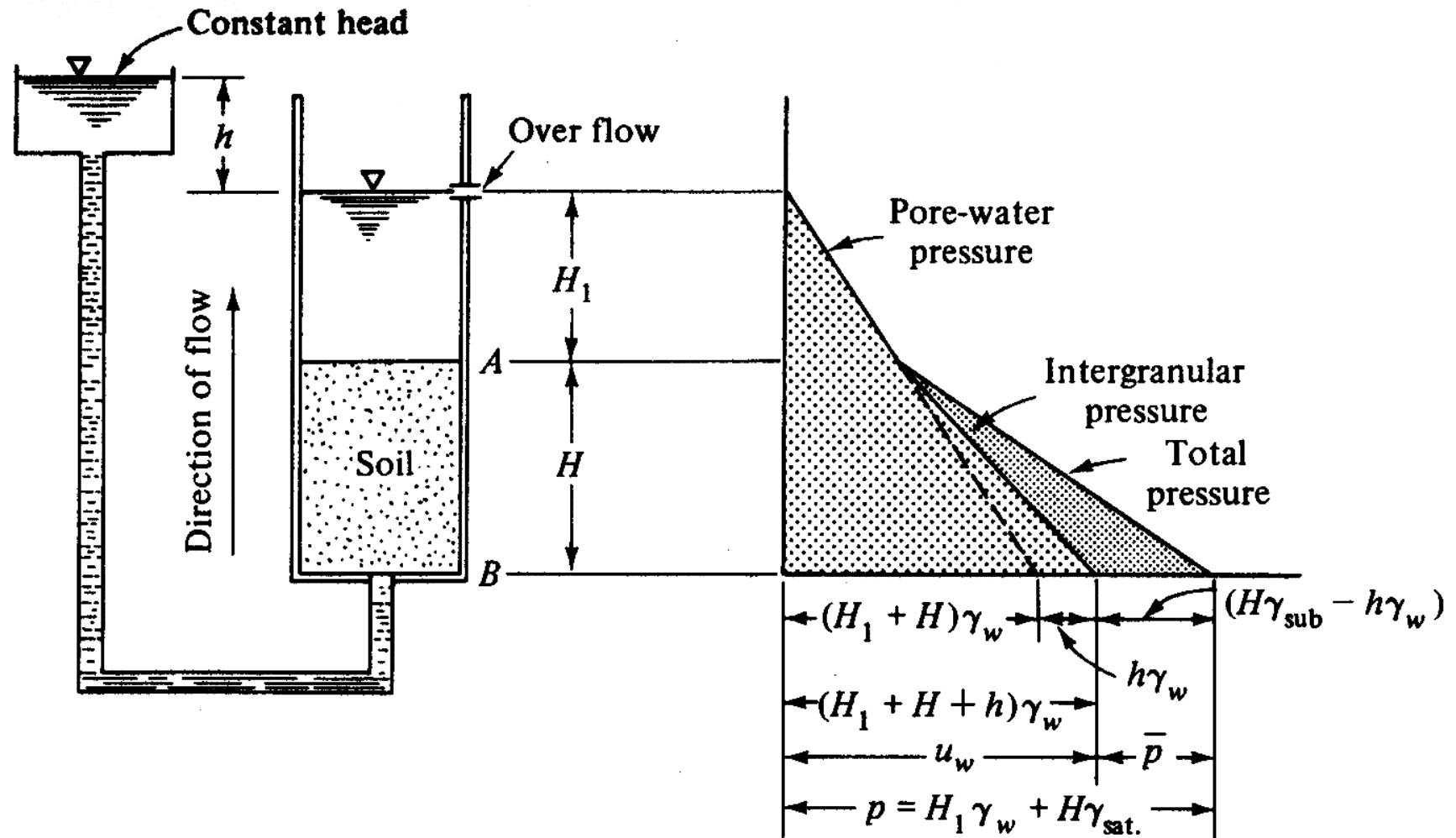
$$k_{20} = \frac{4QL}{\pi D^2 ht}$$

- Rearrange Equation
- Substitute Variables and solve:
- $k = ((4)(400)(15))/((3.1416)(5.5)^2(40)(6)) = 1.052 \text{ cm/sec}$

Soil and Water Pressure with Downward Flow

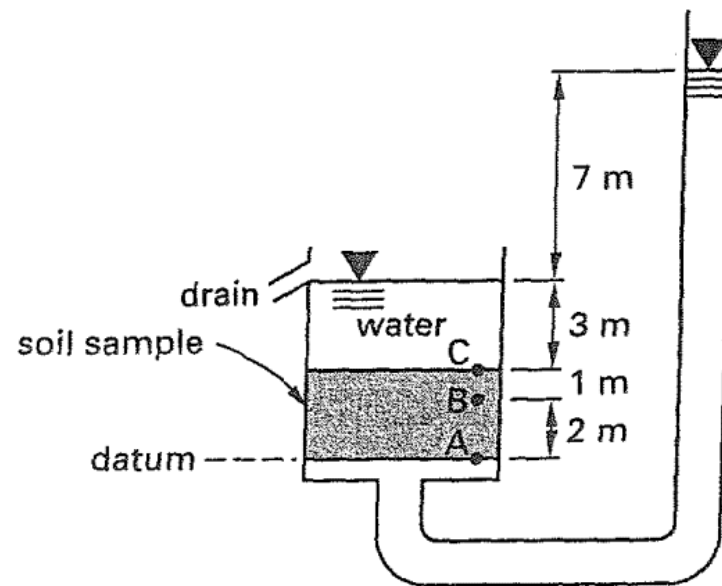


Soil and Water Pressure with Upward Flow



Example of Upward Flow

A constant-head permeameter is shown. The soil is homogeneous, isotropic, and saturated.



The pressure head at point B in the soil sample is most nearly

- (A) 6.00 m
- (B) 6.33 m
- (C) 6.67 m
- (D) 6.75 m

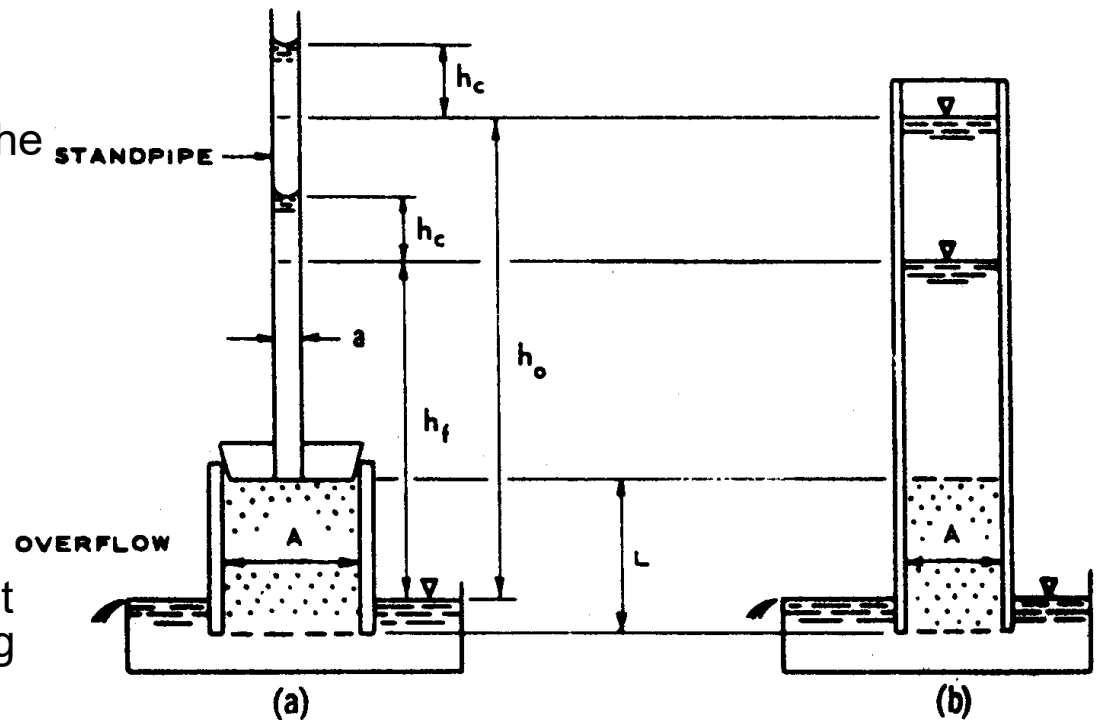
Modified From Verruijt:

$$\Delta p = \gamma z(1 + i)$$

(z downward positive)

Falling Head Test

- A clay sample is enclosed by a circular ring, placed in a container filled with water.
- The lower end of the sample is in open connection with the water in the container, through a porous stone below the sample.
- At the top of the sample it is connected to a thin glass tube, in which the water level is higher than the constant water level in the container.
- Because of this difference in water level, water will flow through the sample, in very small quantities, but sufficient to observe by the lowering of the water level in the thin tube.
- In this case the head difference h is not constant, because no water is added to the system, and the level h_o is gradually reduced to h_f .



Computations

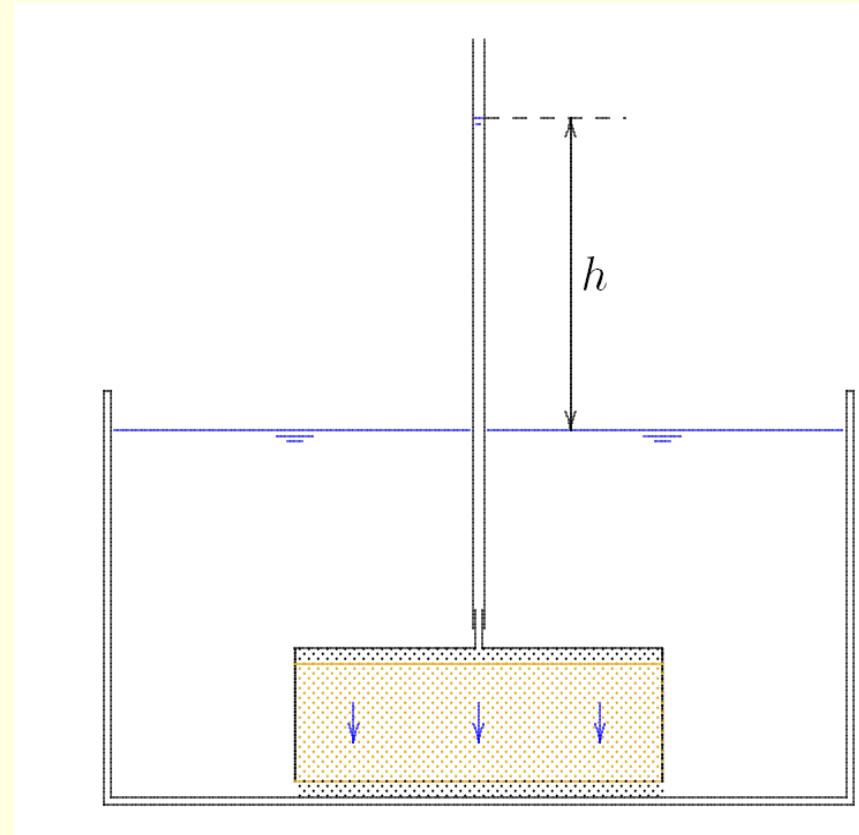
- Compute the coefficient of permeability, k

$$k = \frac{aL}{At} \left(\ln \frac{h_o}{h_f} \right) R_T$$

- a = inside area of standpipe, cm^2
- A = cross-sectional area of specimen, cm^2
- L = length of specimen, cm
- t = elapsed time ($t_f - t_o$), sec
- h_o = height of water in standpipe above discharge level at time t_o , cm
- h_f = height of water in standpipe above discharge level at time t_f , cm
- R_T = temperature correction factor for viscosity of water obtained from , degrees C.

Falling Head Permeameter Sample Problem

- Given: Clay Sample
 - Sample Diameter: 2.5"
 - Sample Thickness: 1"
 - Standpipe Diameter: 1.7 mm
 - Initial elevation of water = 32 cm
 - Time of Test = 395 seconds
 - Final elevation of water = 30 cm
- Find
 - Coefficient of Permeability of clay



Falling Head Permeameter Sample Problem

- Governing Equation

$$k = \frac{L}{t_f - t_o} \frac{a}{A} \ln\left(\frac{h_o}{h_f}\right)$$

- Definition of variables in governing equation

$$A = \frac{1}{4} \pi D_o^2$$

$$a = \frac{1}{4} \pi d_o^2$$

- Substitution of defined variables

$$k = \frac{L}{t_f - t_o} \frac{d_o^2}{D_o^2} \ln\left(\frac{h_o}{h_f}\right)$$

- Substitution of input quantities

$$k = \frac{2.54}{395 - 0} \frac{0.17^2}{(2.5 \times 2.54)^2} \ln\left(\frac{32}{30}\right)$$

$$k = 2.974 \times 10^{-6} \text{ cm / sec}$$

Questions?

