HWRS 505: Vadose Zone Hydrology

Lecture 19

10/31/2023

Today:

- Comments on midterm oral exam
- Measurement methods (Reading: Stephens. Chapter 5)

Comments on Midterm Oral Exam

1. Explain the insights from the Taylor-Aris dispersion. Use the insights to argue why we may describe solute transport in a porous medium by an advection-dispersion equation.

Comments on Midterm Oral Exam

2. Richards' equation

a. Consider a special two-phase system: air and water. Explain the assumptions and the line of reasoning to derive the Richards' equation from the two-phase flow equations.

b. If for some reason, the density of air becomes comparable to that of water, everything else remains the same. Is Richards' equation still valid for describing water flow in the vadose zone? If not, how would you modify the Richards' equation for this particular air-water system?

Richards' Assumptions.

Air flux: $\boldsymbol{q}_a = -\frac{k_{r,a}\mathbf{k}}{\mu_a}\boldsymbol{\nabla}(p_a + \rho_a g z)$

$\mu_a \ll \mu_w$. Air is essentially inviscid. In that sense, almost no gradient of energy potential is required to drive air flow.

$\Rightarrow \underset{\sim}{\nabla}(P_a + \rho_a g z) \simeq 0 \Rightarrow P_a + \rho_a g z \simeq \text{const}.$

At ground surface ($z=0$), $P_a \simeq 0$

$\Rightarrow$ in the unsaturated zone.

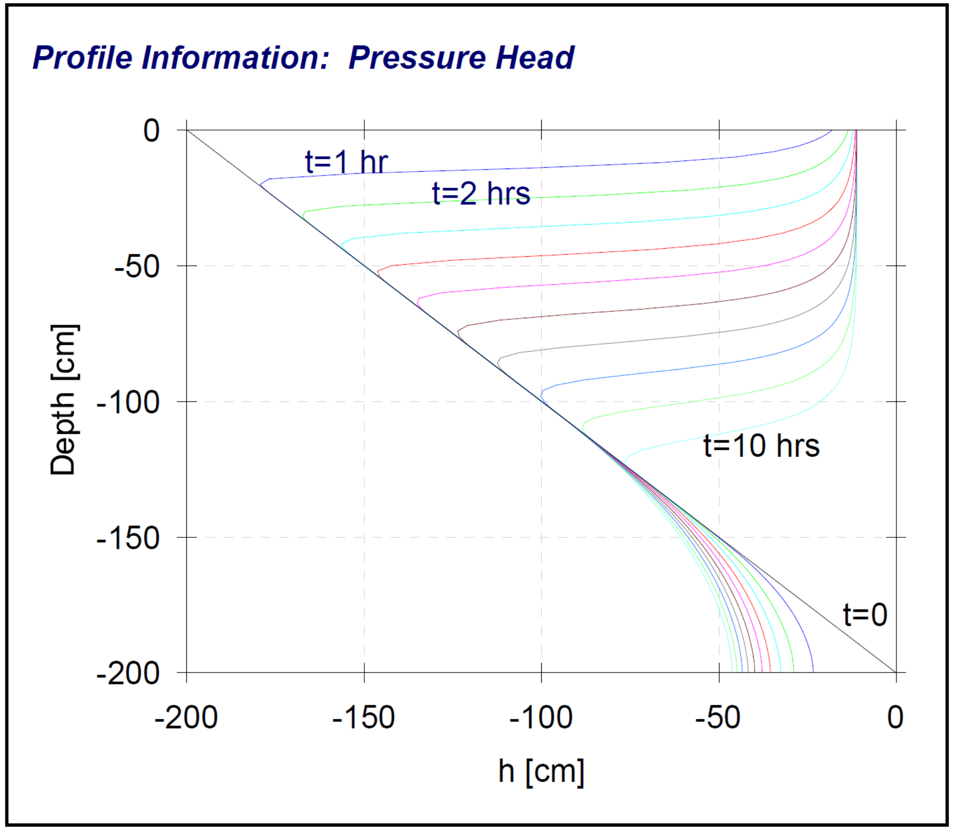
$p_w = p_a - p_c \quad \Rightarrow h = -\frac{\rho_a}{\rho_w}z - \frac{p_c}{\rho_w g}$

Comments on Midterm Oral Exam

3. The Green–Ampt solution may be used to describe water infiltration in soils. Draw the SWC for the soil considered in the Green-Ampt model. Explain why this SWC is compatible with the assumptions of the Green-Ampt model.

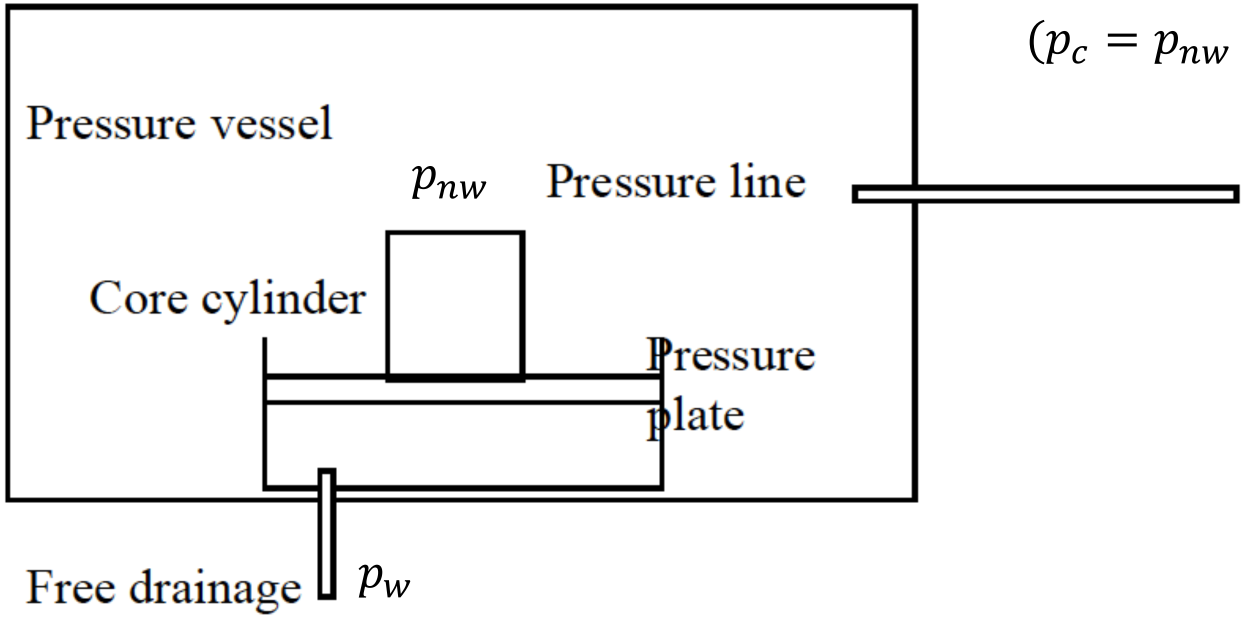
Comments on Midterm Oral Exam

4. Interpret the following results from HYDRUS. What are the initial and boundary conditions (both top and bottom)?

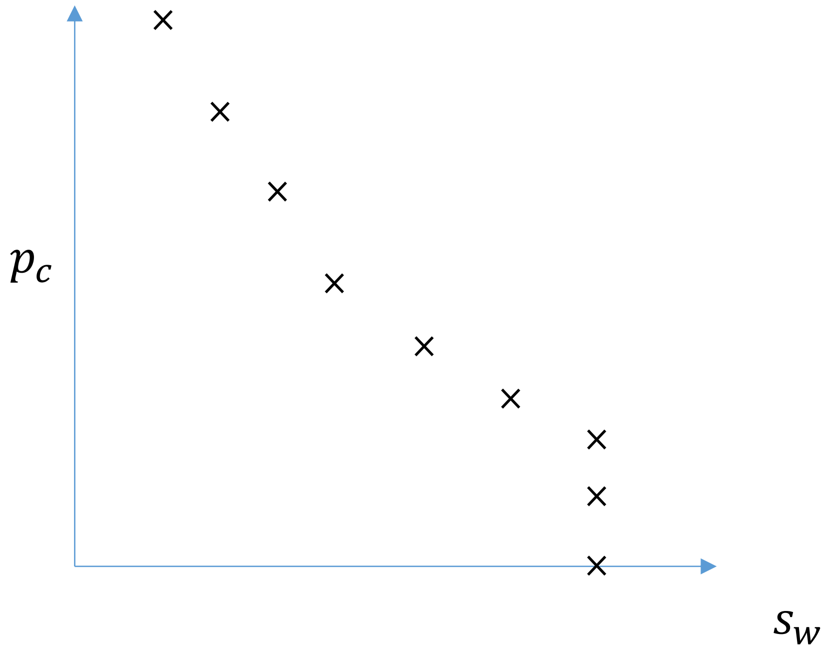


Pressure Cell Method: SWC

Sometimes also referred to as the **Tempe cell method**

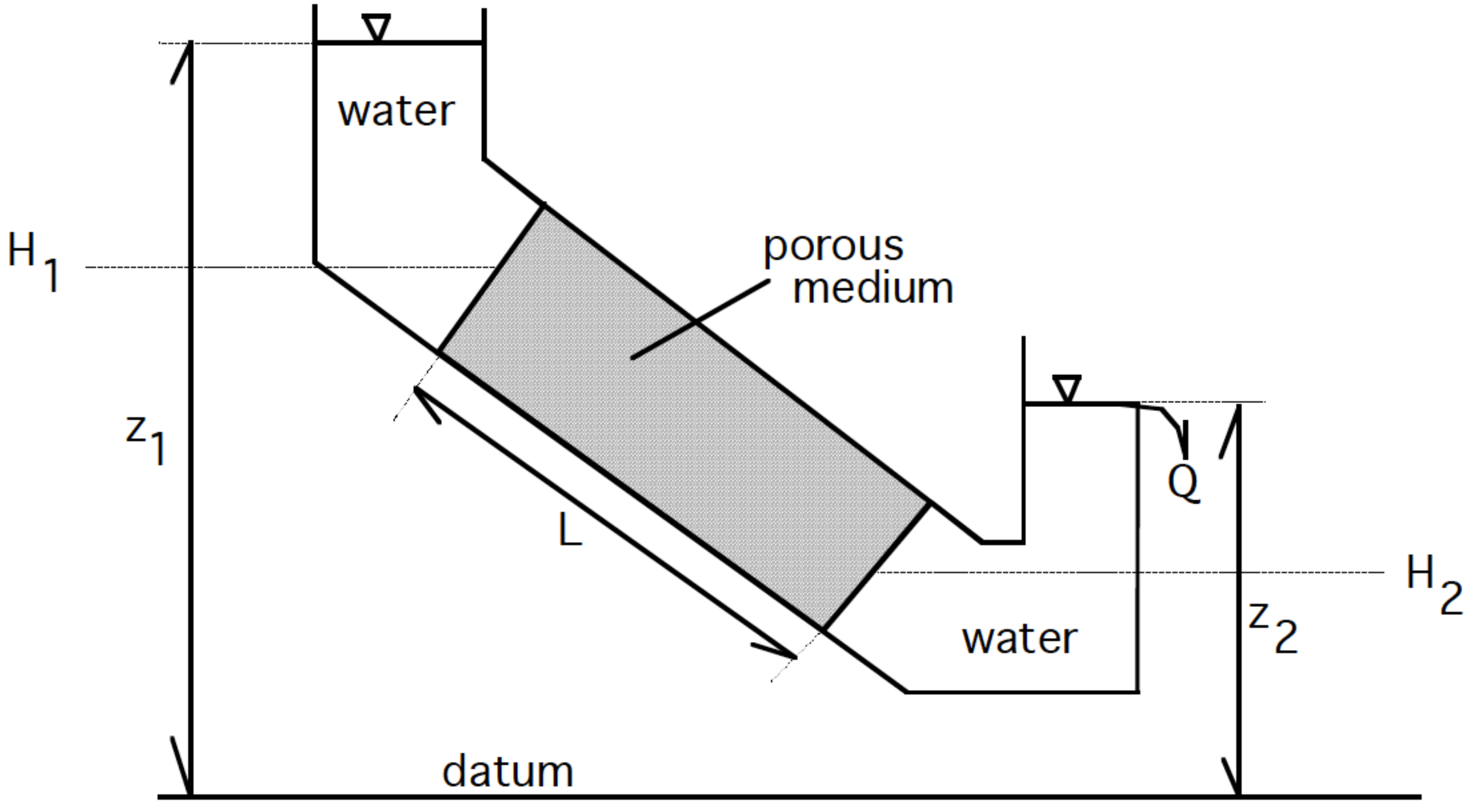


$(p_c = p_{nw} - p_w)$

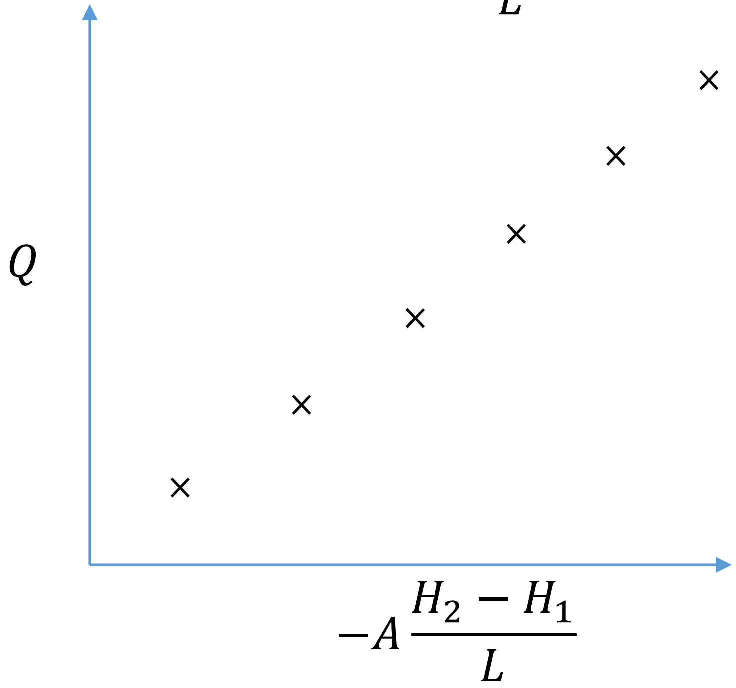


1. Increase p_{nw} step by step. At each step, wait until equilibrium, obtain one data point. Then start the next step.
2. The time-scale to reach equilibrium will increase as $s_w \downarrow$
3. Once the bubbling pressure (air entry pressure) of the plate is reached. No pressure increase can be applied.
4. At the end of the sequence of pressure increments, the final water content is measured by oven-drying.

Constant Head Permeameter: Ksat

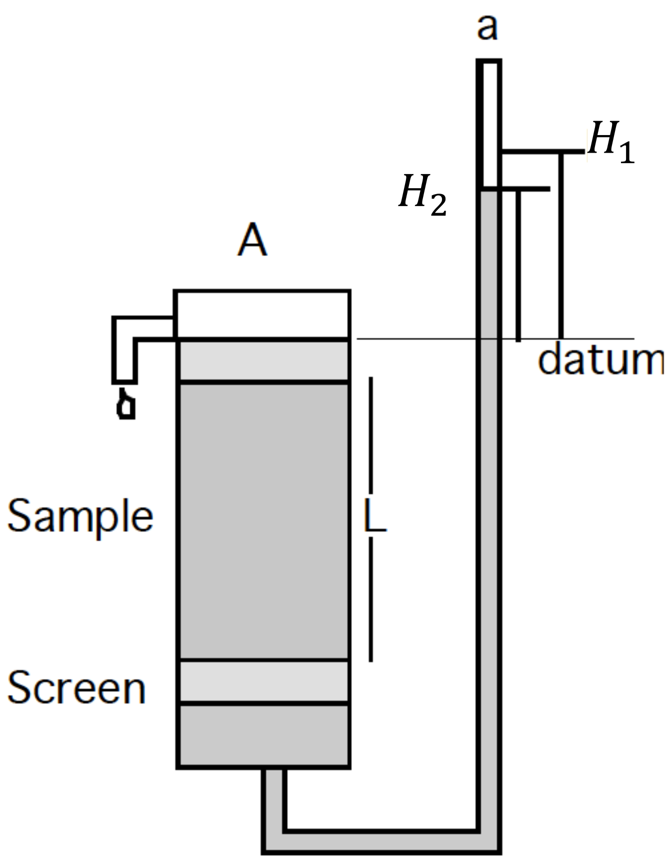


$$Q = -K_{sat}A\frac{H_2 - H_1}{L}$$



Note: commonly used for $K_{sat} > 10^{-5}$ cm/s

Falling Head Permeameter: Ksat



$$-K_{sat} A \frac{H}{L} \mathrm{d}t = a \, \mathrm{d}H$$

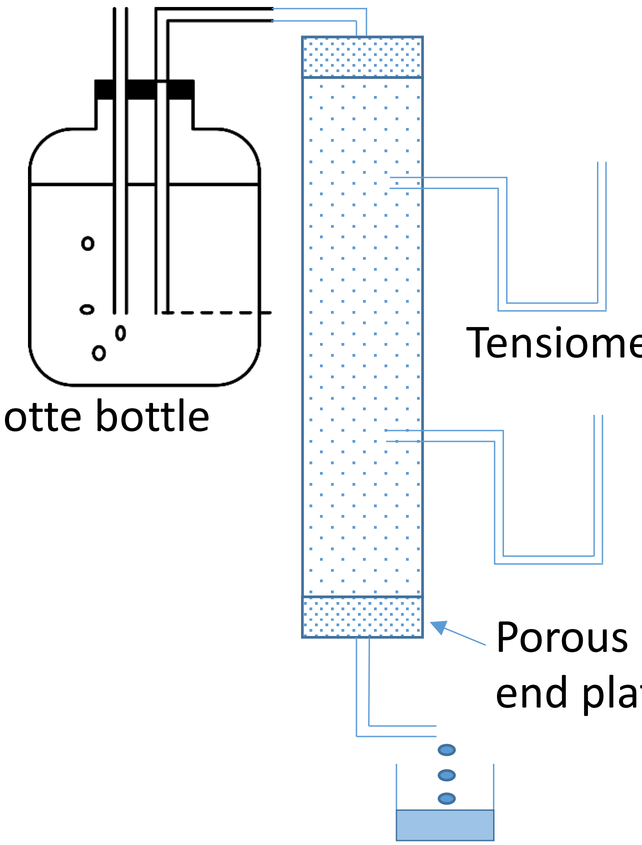
$$\Rightarrow -\frac{K_{sat} A}{aL} \mathrm{d}t = \frac{1}{H} \mathrm{d}H$$

$$\Rightarrow -\frac{K_{sat} A}{aL} \Delta t = \ln H_2 - \ln H_1$$

$$\Rightarrow -K_{sat} = \frac{aL}{A\Delta t} \ln \frac{H_2}{H_1}$$

Note: commonly used for 10^{-3} cm/s $> K_{sat} > 10^{-7}$ cm/s

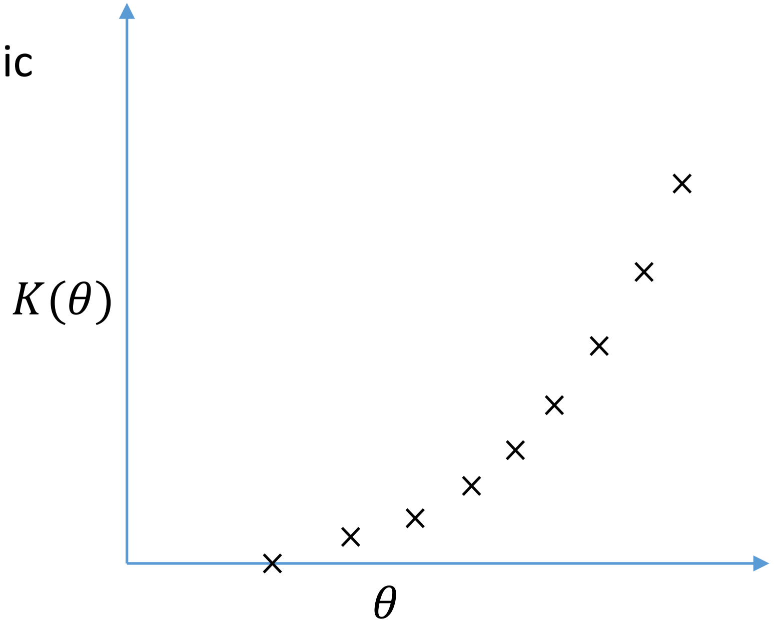
Steady State Flux Method: K(θ) or K(h)



1. Apply the same negative pressure at top and bottom.
2. A large number of steady-state conditions are needed to obtain $K(\theta)$ curve.

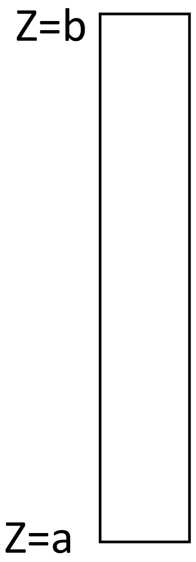
$$\frac{\partial \theta}{\partial t} = 0 \qquad \frac{\partial \theta}{\partial z} = 0$$

$$q = -K(\theta)\left(\cancel{\frac{\partial h}{\partial z}}^{\,0} + 1\right) \Rightarrow q = -K(\theta)$$



Instantaneous Profile Method: K(θ) or K(h)

It is a transient method



$$q_{a,t} = q_{b,t} - \frac{1}{\Delta t}\int_b^a \Delta\theta \,\mathrm{dz}$$

$$q_{a,t} = -K(h)\frac{\partial H}{\partial z}\Big|_{z=a}$$

If $q_{b,t} - \frac{1}{\Delta t}\int_b^a \Delta\theta \,\mathrm{dz}$ and $\frac{\partial H}{\partial z}|_{z=a}$ known, we can compute $K(h)$.

Often design the experiments so that $q_{b,t}$ is known.

Can be estimated from measured θ at different locations.

Can be obtained by measuring the h at two locations nears $z = a$.

Field Methods: Neutron Probes

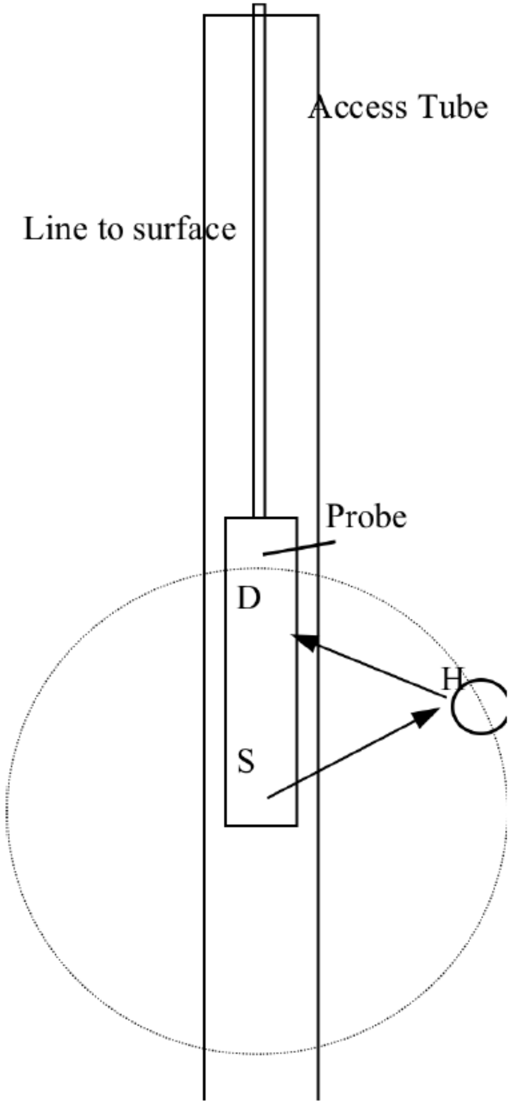
- Based on the amount of thermalized neutron at the detector

- Nondestructive and can go to deep locations

- Need to calibrate for the soil type and measurement conditions

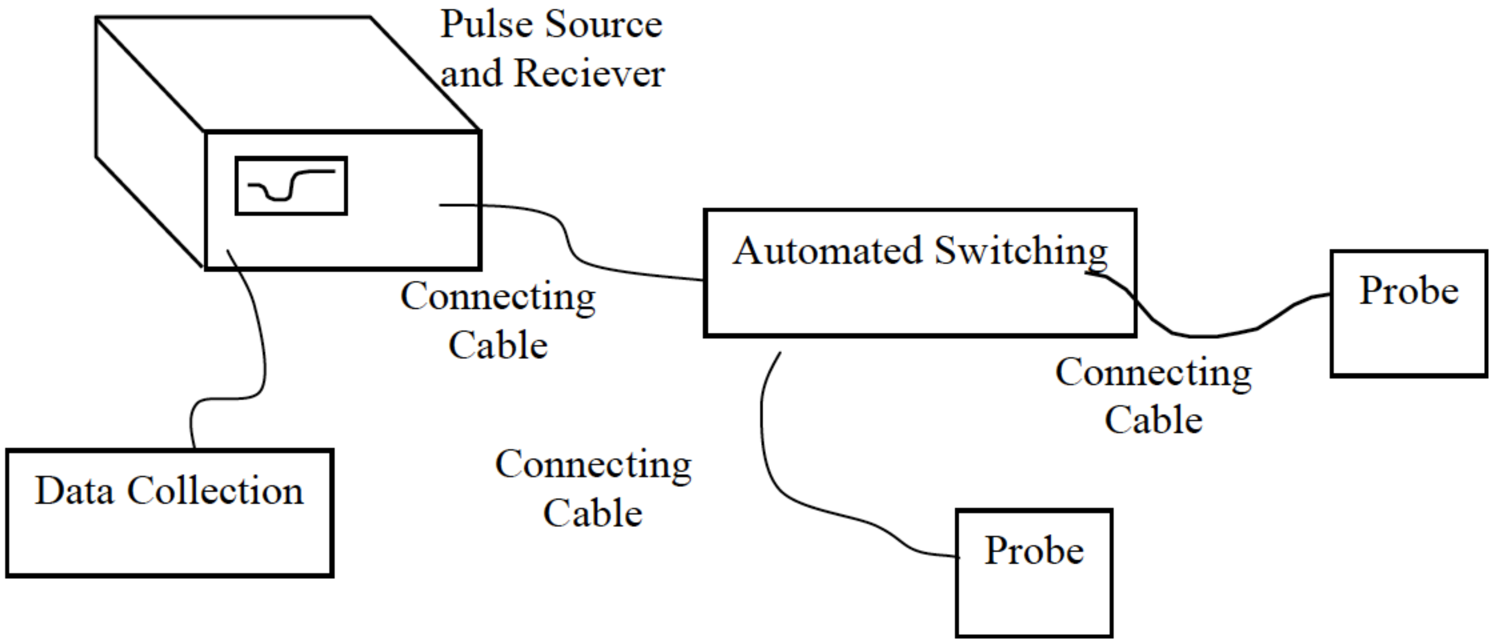
- Measures soil moisture

https://soilsensor.com/articles/neutron-probe/



Field Methods: Time Domain Reflectometry

- Based on dielectric permittivity and electrical conductivity
- Nondestructive
- Measures soil moisture



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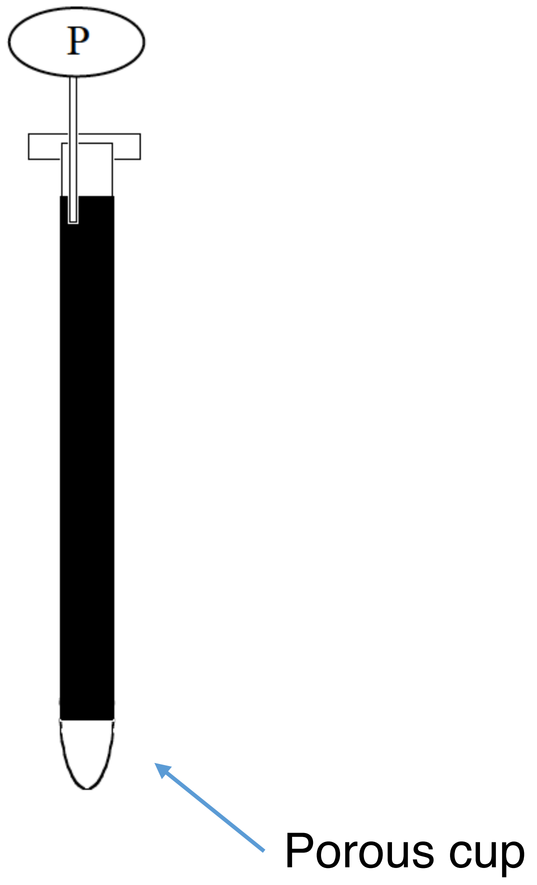
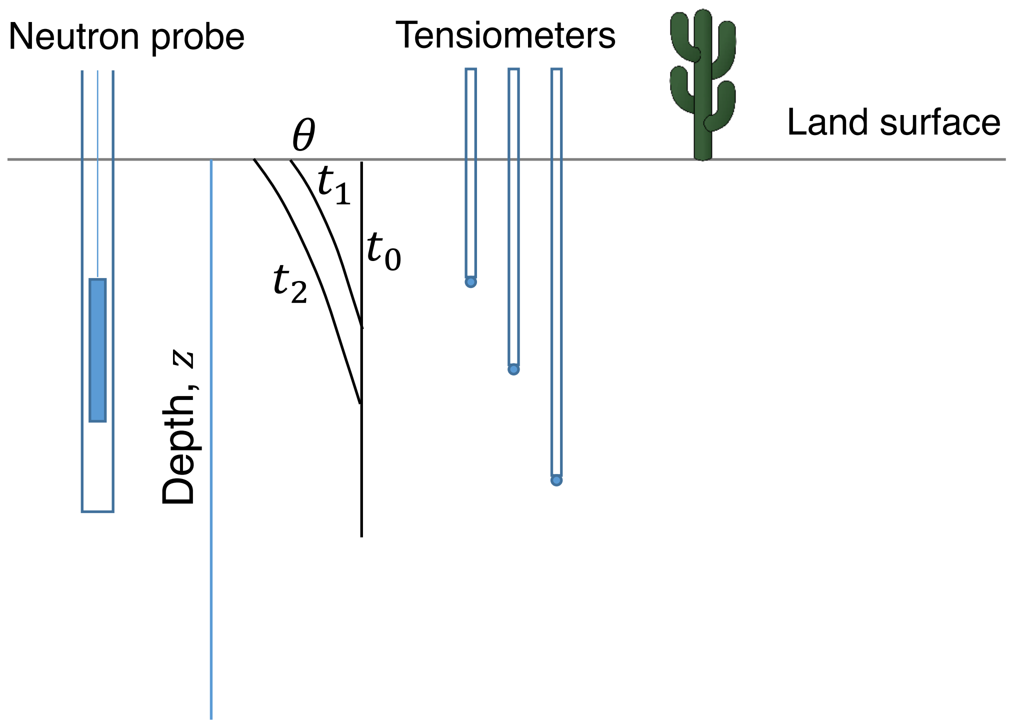
Field Methods: Tensiometer

- Based on pressure equilibrium
- Nondestructive
- Measures water pressure head



Instantaneous Profile Method Applied to the Field



1. Saturate the vadose zone
2. Cover the surface to stop evaporation
3. Monitor as the soil drains

At any location, $z = -L$, below the land surface

$$q = \int_0^{-L} \partial\theta/\partial t \, \mathrm{d}z$$

$$q = -K(\bar{\theta})\Big|_{z=-L} \frac{\mathrm{d}H}{\mathrm{d}z}\Big|_{z=-L}$$

$$K(\bar{\theta})\Big|_{z=-L} = -\frac{\int_0^{-L} \frac{\partial\theta}{\partial t} \mathrm{d}z}{\frac{\mathrm{d}H}{\mathrm{d}z}\big|_{z=-L}}$$