Hydrological Measurements

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Discharge Structures, Dillution

TUDelft

CEI 4440 Soil Hydrology

Set up of lecture today

1. Soil physics; Measuring soil moisture
2. Hydrostatics; Measuring soil tension
3. Soil hydraulics; pF curves
4. Soil infiltration and field tests
5. Soil hydraulics; Permeability

Soil moisture content

Method	Advantages	Disadvantages
Gravimetric	Easy Whole range	Destructive Laborious
Electric resistance	Reproducible In situ cheap	Calibration needed Sensitive contact soil – electrode Influence salt content Hysteresis Installation disturbance
TDR	Reproducible In situ Very accurate Calibration not always needed	Sensitive equipment Very expensive Influence salt content Installation disturbance
FDR / Capacitance	Reproducible In situ Accurate Relatively cheap	Influence salt content More soil depending calibration then TDR Installation disturbance Less accurate near saturation

Observing moisture content in the lab

Gravitational measurements

- Measure the sample weight m_w
- Saturate the sample and measure the weight m_s
- dry 24 hours in the oven at 105 ^{0}C

Organic soils: dry 48 hours in the oven at 70 °C

- Measure the sample weight again: m_d
- If *V* is the volume of the sample container:

$$\theta = \frac{m_w - m_d}{\rho_w V}$$

$$\theta_s = \frac{m_s - m_d}{\rho_w V}$$

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Observing moisture content in the field

Electrical resistance

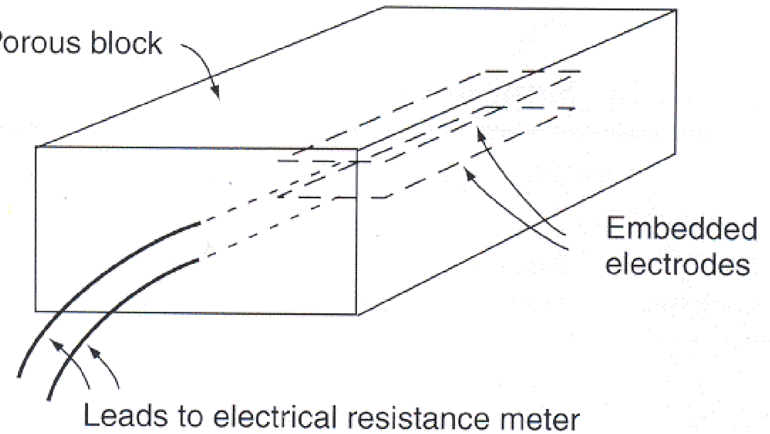


Fig. 6.1. An electrical resistance block. The embedded electrodes may be plates, screens, or wires in a parallel or concentric arrangement.

Must be calibrated gravimetrically

Observing moisture content in the field

Frequency-Domain Reflectometry (FDR)

Measuring the dielectric constant of the soil by gauging the electromagnetic field by sending radio waves.

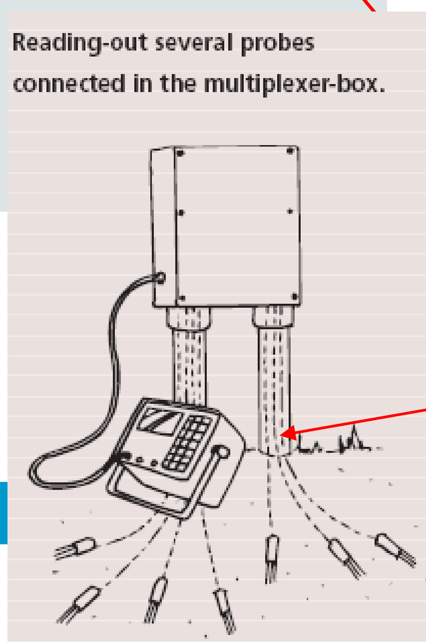
Measures impedance of capacitor formed by rod and soil. This gives relative permittivity.

Due to relative low frequencies (20-70 MHz) more soil specific calibration

Observing moisture content in the field

Time-Domain Reflectometry (TDR)

Source uknown



Measuring the propagation time of an electromagnetic wave along the pins.

Propagation velocity depends on permittivity.

Arrival time and wave shape can be analysed.

Every “nest” needs a separate cable tester

TDR equipment (travel time electrical wave)

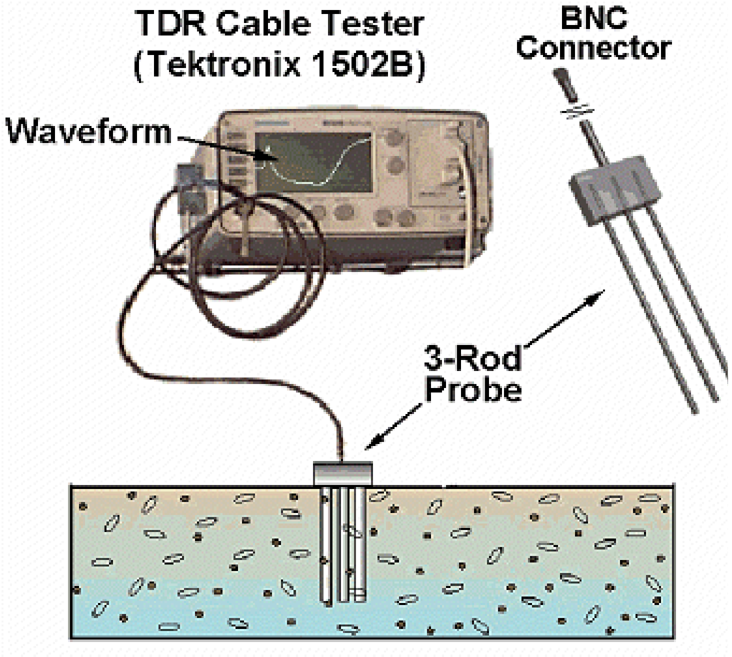


Fig. 1-9: Diagram of a TDR cable tester.

CHAPTER 6 WATER CONTENT AND POTENTIAL

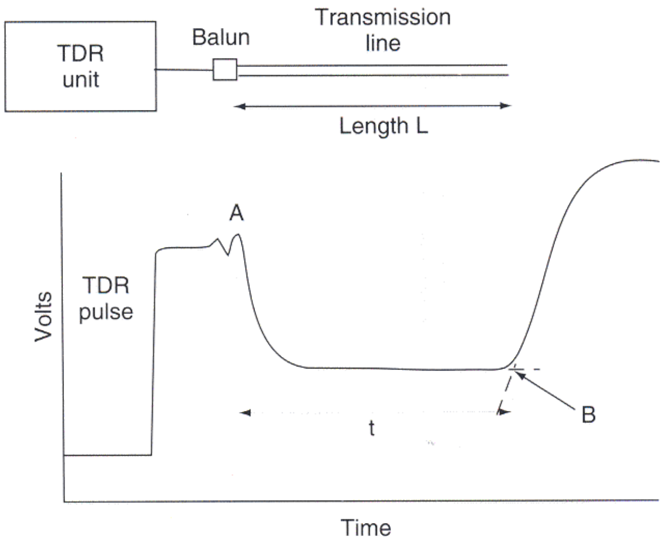
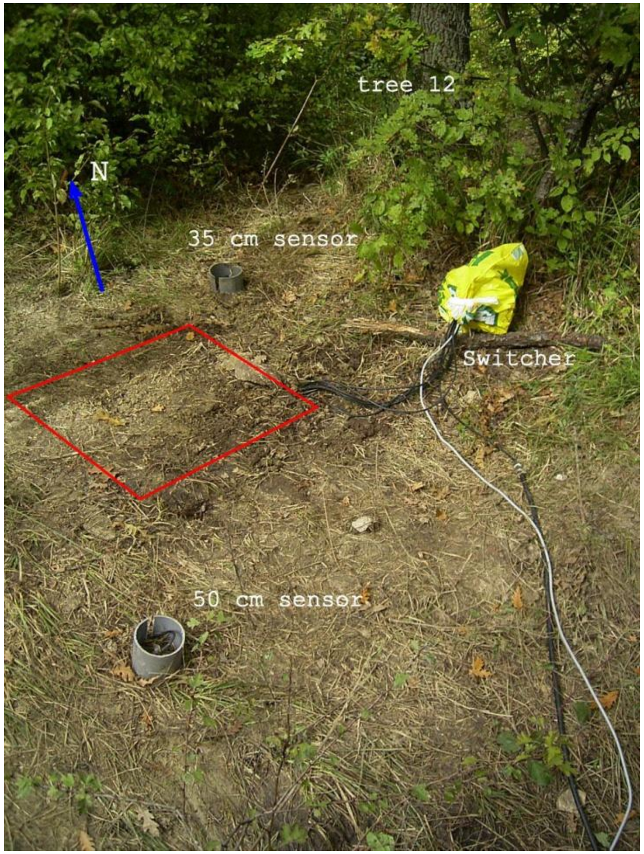


Fig. 6.4. The essential components of a TDR system (above) and an idealized TDR output trace (obtainable with an oscilloscope) showing how the propagation time is determined. (After Topp and Davis, 1985.)

TDR equipment (travel time electrical wave)



TDR soil moisture pits

Soil moisture content

Non-destructive methods

- GPR
- Neutron probe
- Gamma logging
- Remote sensing

Observing moisture content in the field

Ground penetrating radar (GPR)

Huisman et al.
Vadose Zone Journal, 2003.

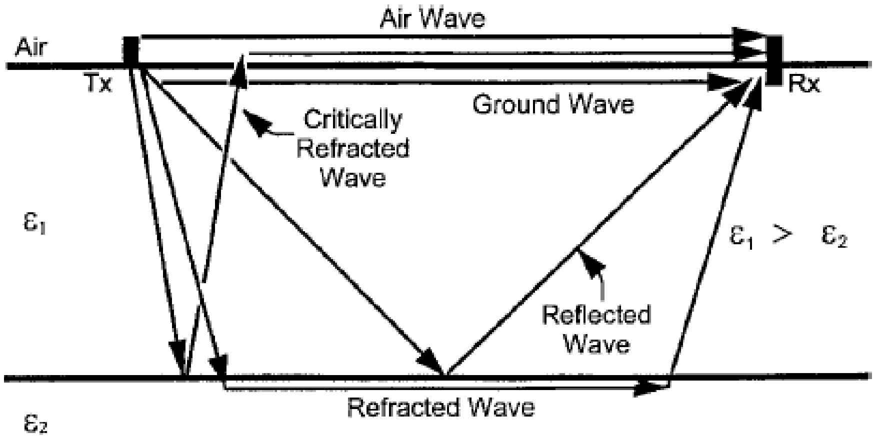
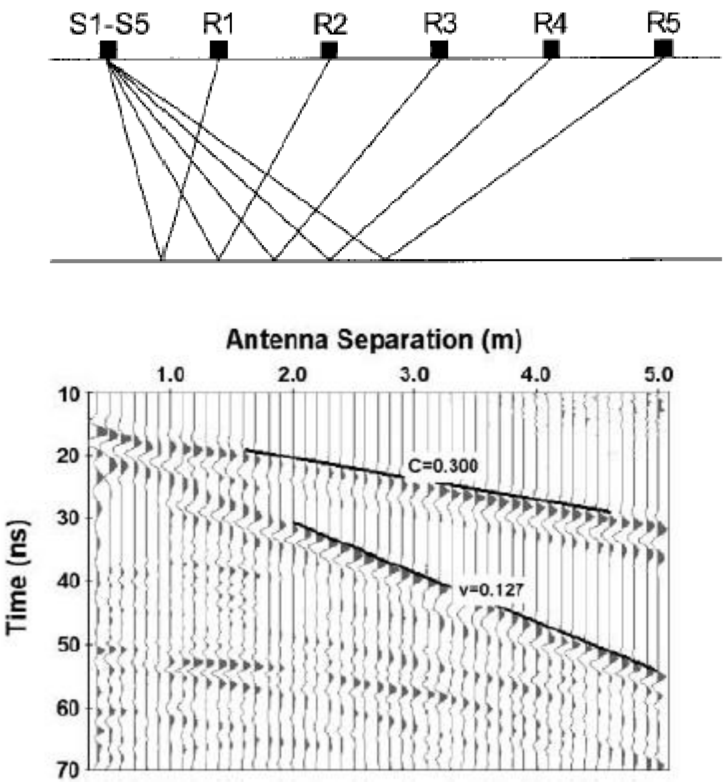


Fig. 3. Propagation paths of electromagnetic waves in a soil with two layers of contrasting dielectric permittivity (ε_1 and ε_2) (after Sperl, 1999).

Observing moisture content in the field

Ground penetrating radar (GPR): multi-point methods



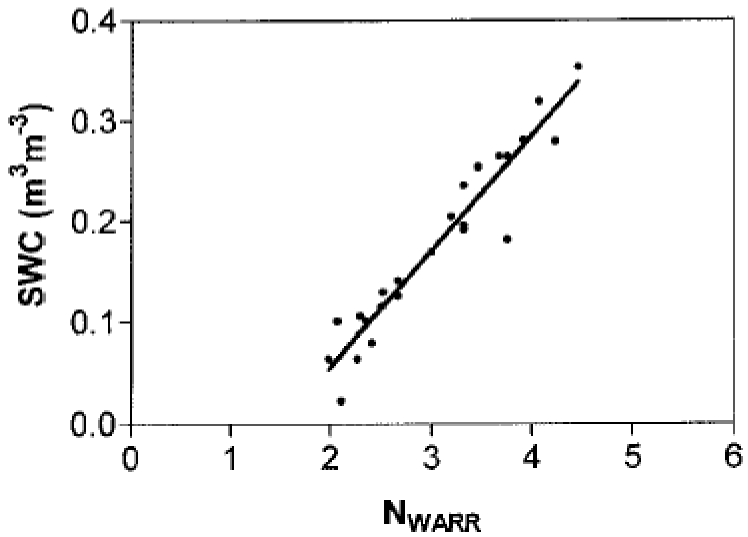


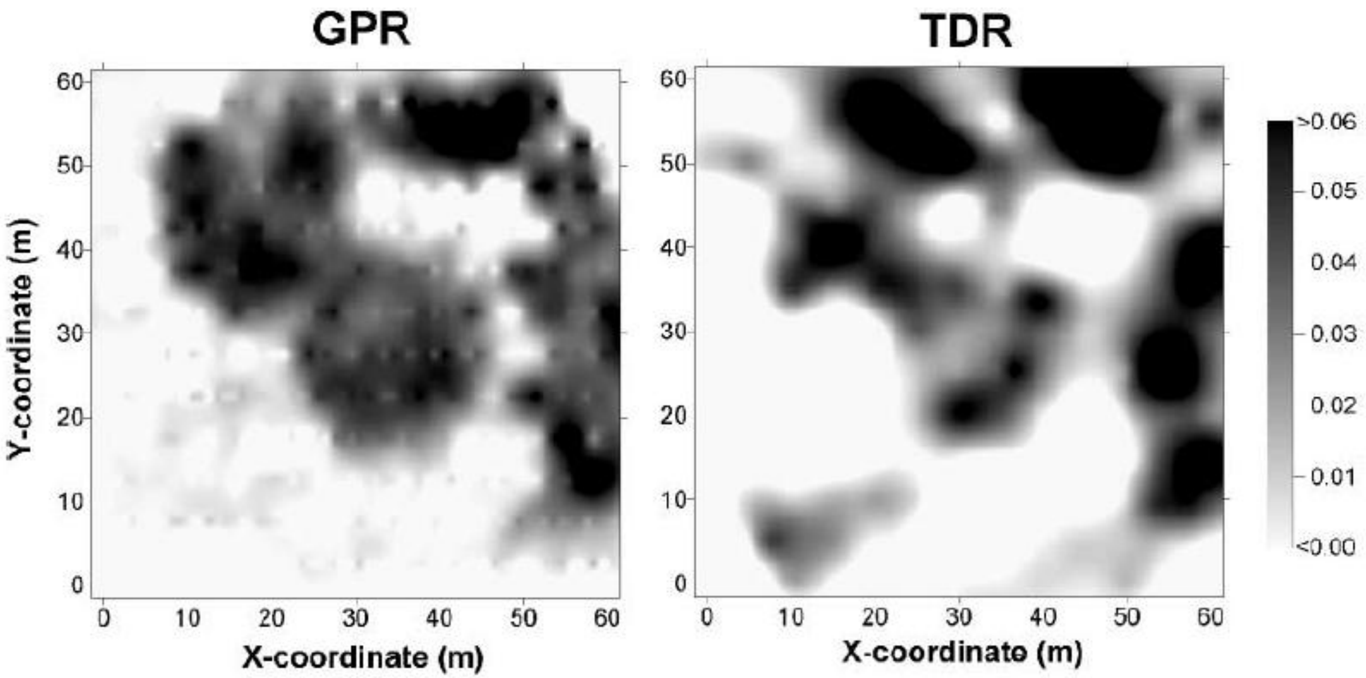
Fig. 10. Calibration equation between gravimetrically determined soil water content (SWC) and refractive index (n_{WARR}) determined from the ground wave velocity obtained with 225-MHz ground penetrating radar (GPR) antennas.

$$\varepsilon = \left(\frac{c}{v}\right)^2 = \left[\frac{c(t_{GW} - t_{AW}) + x}{x}\right]^2$$

Huisman et al.
Vadose Zone Journal, 2003.

Observing moisture content in the field

Ground penetrating radar (GPR): results



Advantage GPR: quick to map larger areas; relatively accurate estimate: stdv 2-3 %.

Disadvantage: Large initial investment; lower resolution; not continuous in time.

Huisman et al.
Vadose Zone Journal, 2003.

Observing moisture content in the field

Neutron soil moisture measurements

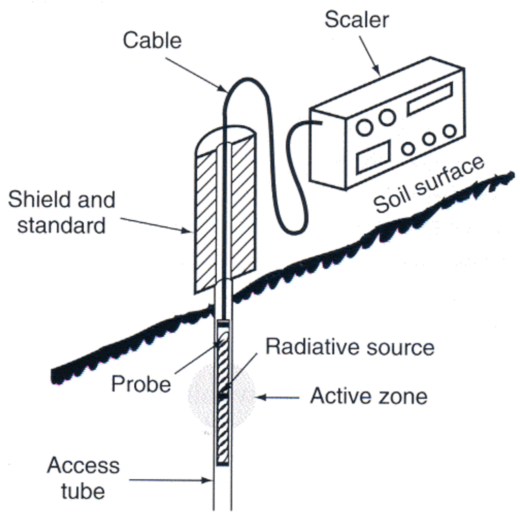


Fig. 6.2. Components of a portable neutron soil-moisture meter, including a probe (with a source of fast neutrons and a detector of slow neutrons) lowered from a shield containing hydrogenous material (e.g., paraffin, polyethylene) into the soil via an access tube. A scaler-rate meter is shown alongside the probe. Recent models incorporate the scaler into the shield body, and the integrated unit is lightweight for easy portability.

Observing moisture content in the field

Gamma ray soil moisture measurements

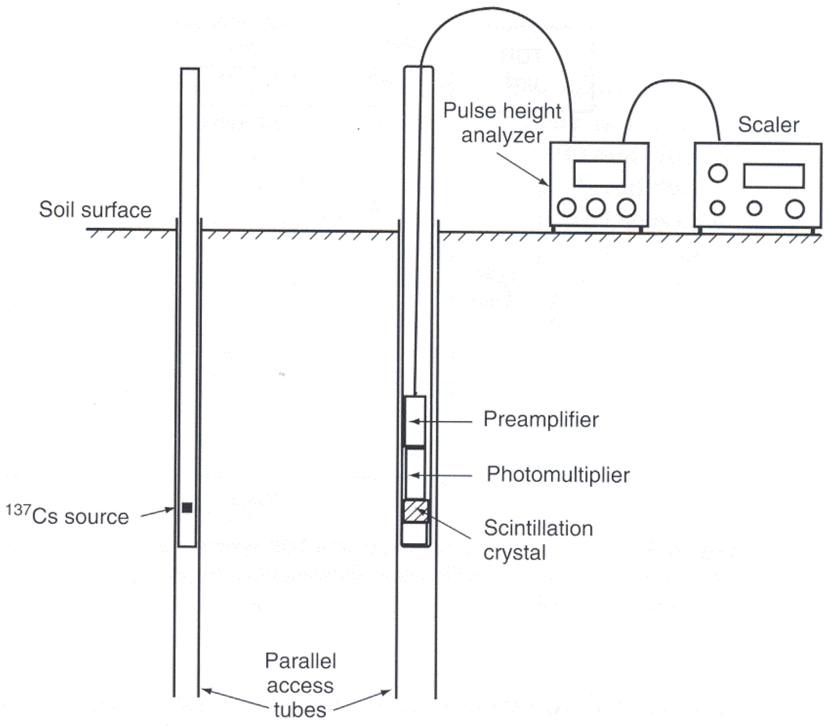


Fig. 6.3. Double-probe gamma-ray apparatus for monitoring soil moisture or density.

Measurements in general

- Macropores are seldom measured because of the size of the pores with respect to the size of the sample (this may cause measurement results to be unreliable)
- Continuous in-situ measurements of the moisture content give direct results and thus the temporal variability, but are expensive and quite vulnerable
- Destructive measurements of the moisture content give a good impression of the spatial variability, but are laborious; the methods are cheap and robust
- FDR: this is a good alternative: quick, not destructive, but with a larger uncertainty

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Hydrostatics

- Study of the forces in the soil-water system when there is static equilibrium
- All forces are in equilibrium and there is no water movement: the fluxes (*rates*) in the soil are zero; the moisture content (*state*) does not change

- PS: The moisture content differs at different depths

Forces in the soil

- Gravity
- Capillary forces
- Adsorption

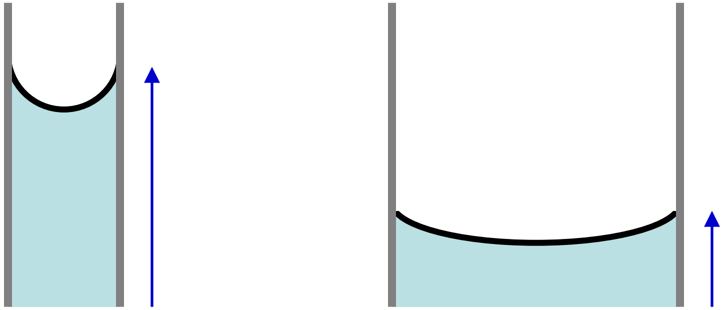
Adsorption

- Macroscopic: absorption of water vapour throughout the soil
- Microscopic: electrical attraction beween positively charged water particles and negatively charged soil particles (electrical double layer of clay)
- Adsorption of water (water does not flow; this water is only loosened by heating)
- Residual water content θ_r

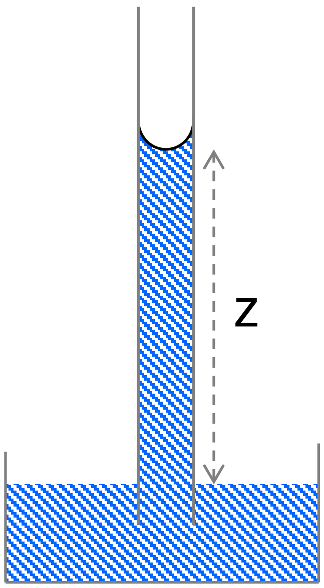
$$\theta_E = \frac{\theta - \theta_r}{\theta_s - \theta_r} \approx \frac{\theta}{P}$$

Capillary forces

- Contact plane between soil, water and air
- Surface tension provides meniscus and contact angle α between water and solid
- Capillary rise in pores: the smaller the pores the larger the capillary rise and capillary binding



Capillary rise



Capillary rise depends on the radius r of the pore:

$$|z| = 2\,\gamma \cos\alpha \,/(\rho\, g\, r)$$

where γ = surface tension between water-air (= 0.07 N/m)

z = 0.5 m

r = (2 γ cos α) /(ρgz) = 2*0.07 / (1000*10*0.5) = 28 μm

when taking the contact angle of water to approximate 0°

a) to empty the pore 0.5 m suction is needed

b) a pore with a radius of 28 μm can suck up water till 0.5 m

c) this pore can hold water against suctions of 0.5 m and lower

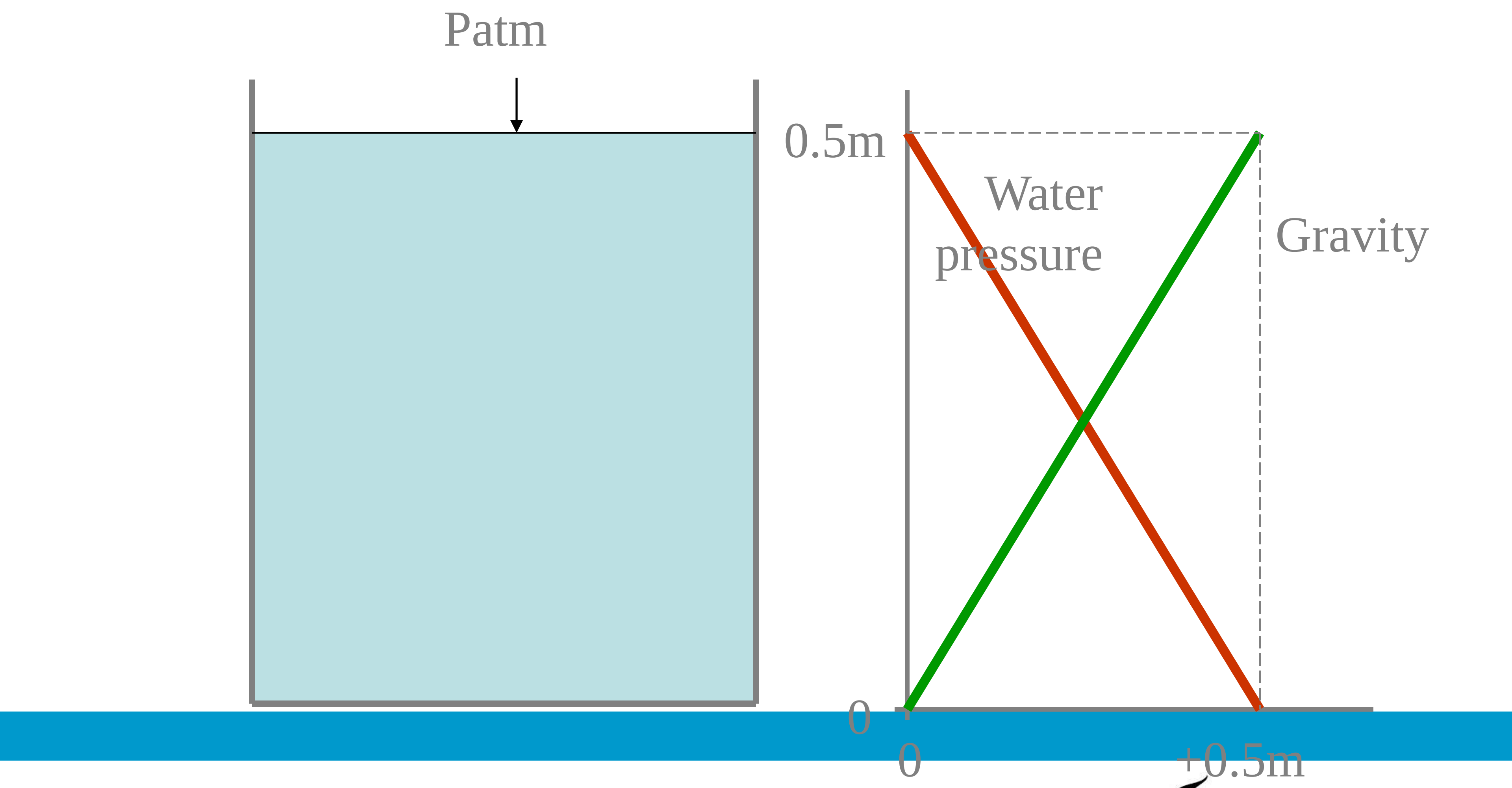
Specific surface

The contact surface between solid matter and water in a soil depends on the type of material:

fine sand	1.2 m^2/g
silt	0.2 m^2/g
loam	25-80 m^2/g
kaolinite	4-10 m^2/g
montmorillonite	150-500 m^2/g

Capillary binding strongly depends on the type of material: shape and size of the pores and the size and contact surface of the material

Pressure in a glass of water, plane of reference soil, hydrostatic equilibrium



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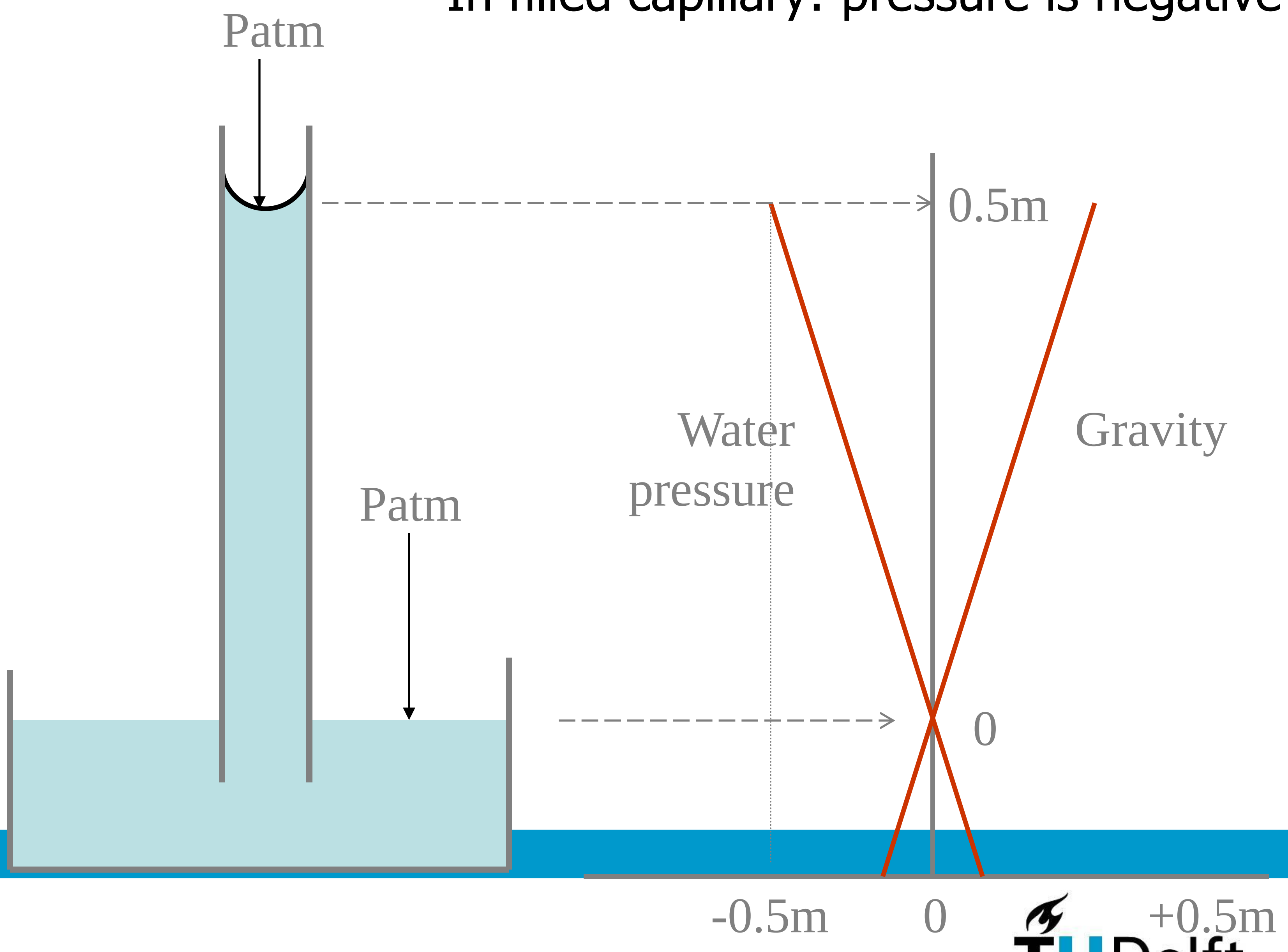
In filled capillary: pressure is negative !



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Potentials in the unsaturated zone

All potentials:

$$\varphi_t = \varphi_m + \varphi_g + \varphi_a + \varphi_e + \varphi_o$$

- Matric potential (capillary binding)
- Gravitational potential
- Pneumatic potential (trapped air)
- Envelope potential (external load)
- Osmotic potential (difference in concentration)

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Important are:

$$\varphi_t = \varphi_m + \varphi_g$$

- Hydraulic potential (φ_t)
- Matric or pressure potential ($\varphi_{\mathbf{m}}$)
- Gravitational potential (φ_g)

The pressures are in static equilibrium:

$$\varphi_t = \varphi_m + \varphi_g$$

$$p + \rho g z = \text{constant}$$

ρ = density water (1000 kg/m^3)

g = gravitational acceleration (~10 m/s^2 ,N/kg)

z = place with respect to plane of reference (m)

p = pressure (Pa=N/m^2)

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Potential

on the basis of mass (kg)

- J/kg

on the basis of volume (m3)

- $J/m^3 = N.m/m^3 = N/m^2 = Pa$ (pressure)

on the basis of weight (N)

- $J/N = N.m/N = m$ (length)

Mostly we use length as unit

- $\varphi_{\mathbf{g}}$ /g = z (m)
- φ_m /g = h (m)

$$H = h + z$$

hydraulic head = pressure head + elevation head

Equivalent:

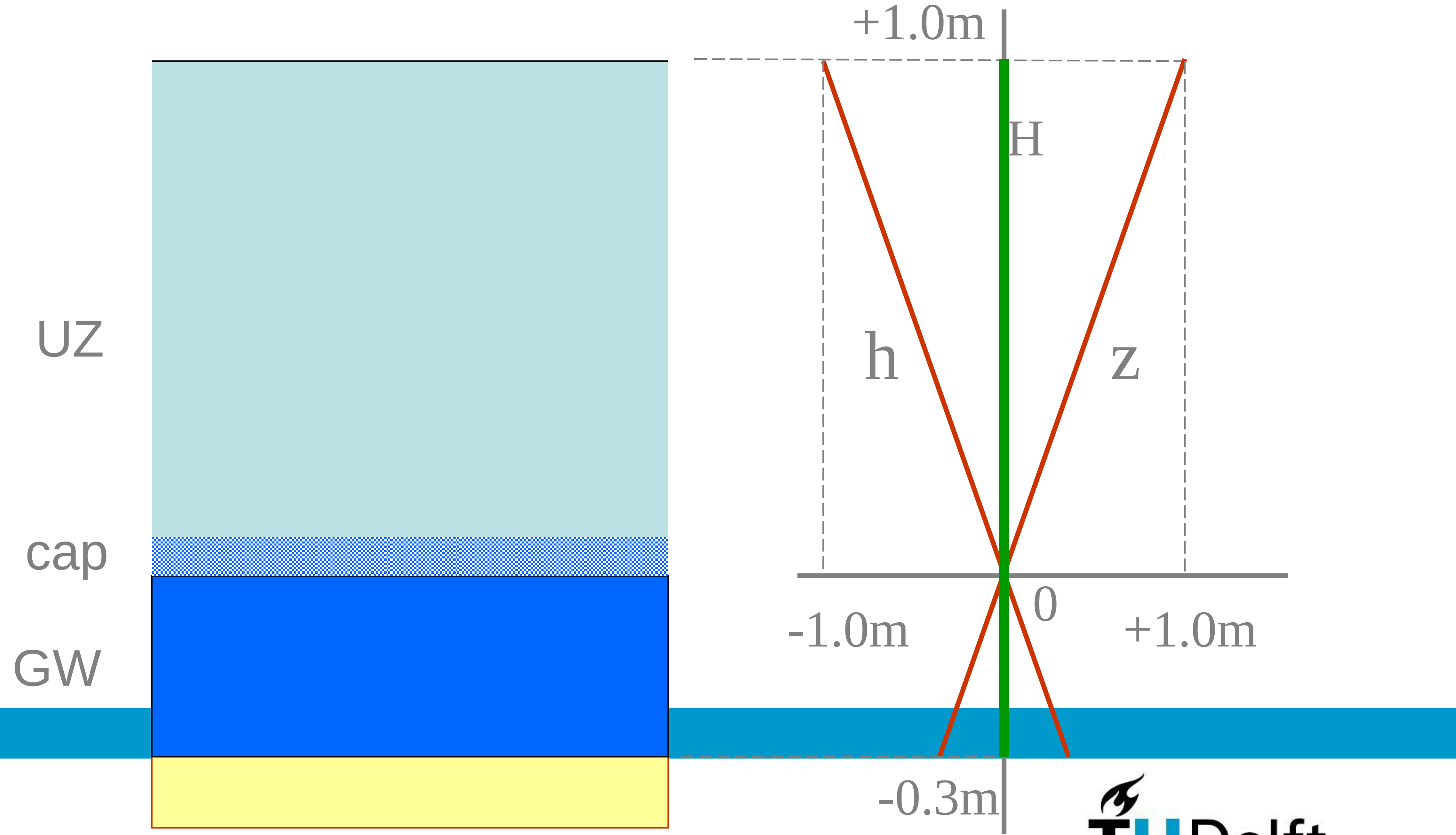
hydraulic potential = matric potential + gravitational potential

Conversion between units is easy:

- mass: φ = 1.0 J/kg
- volume: $\rho\ \varphi$ = 1.0 kPa (factor 1.0)
- weight: φ /g = 1.0/10 = 0.1 m (factor 0.1)

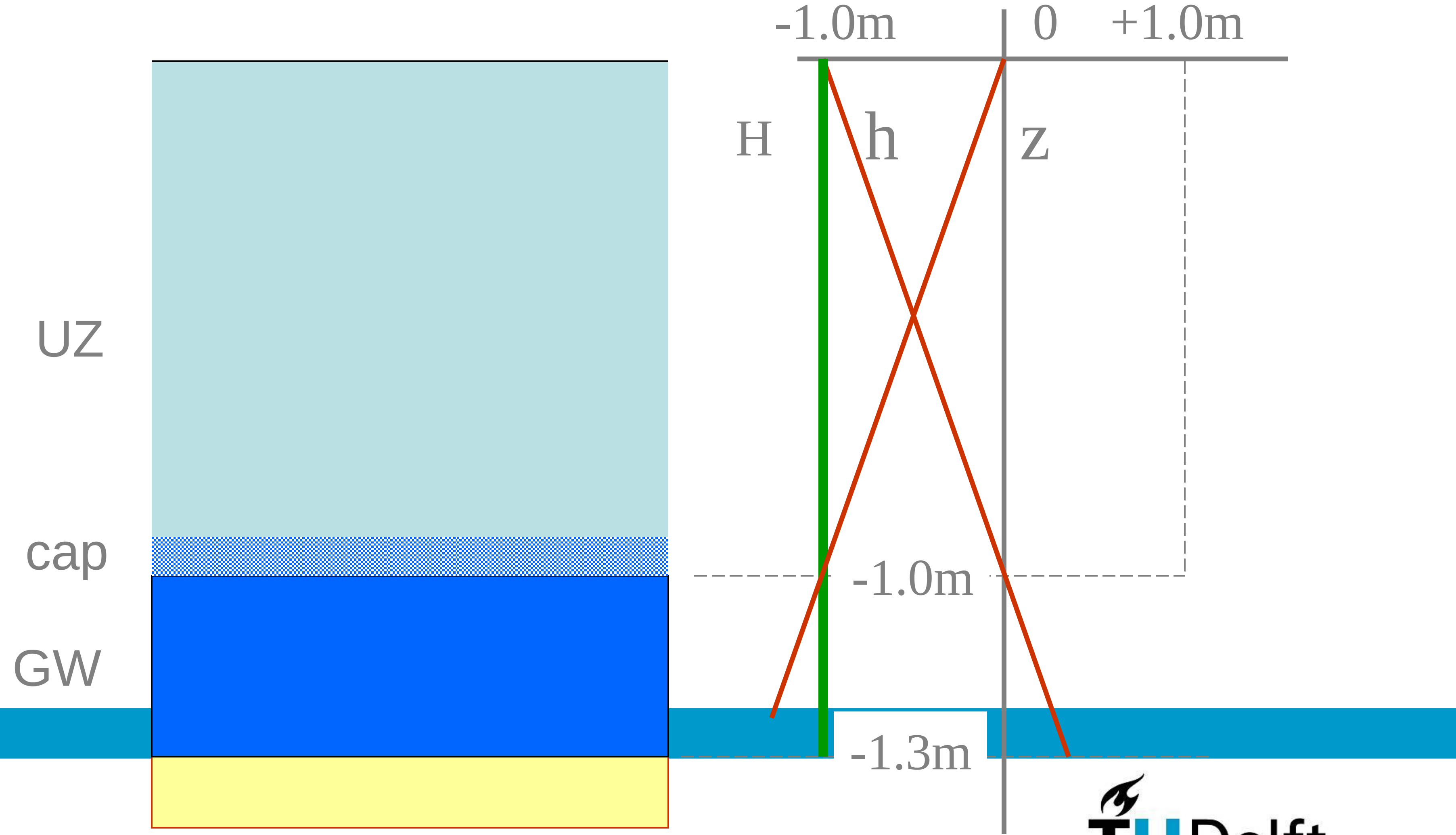
hydrostatic equilibrium: plane of reference groundwater

h = 0 at boundary atm/water, z = 0 at plane of ref.; H = 0m

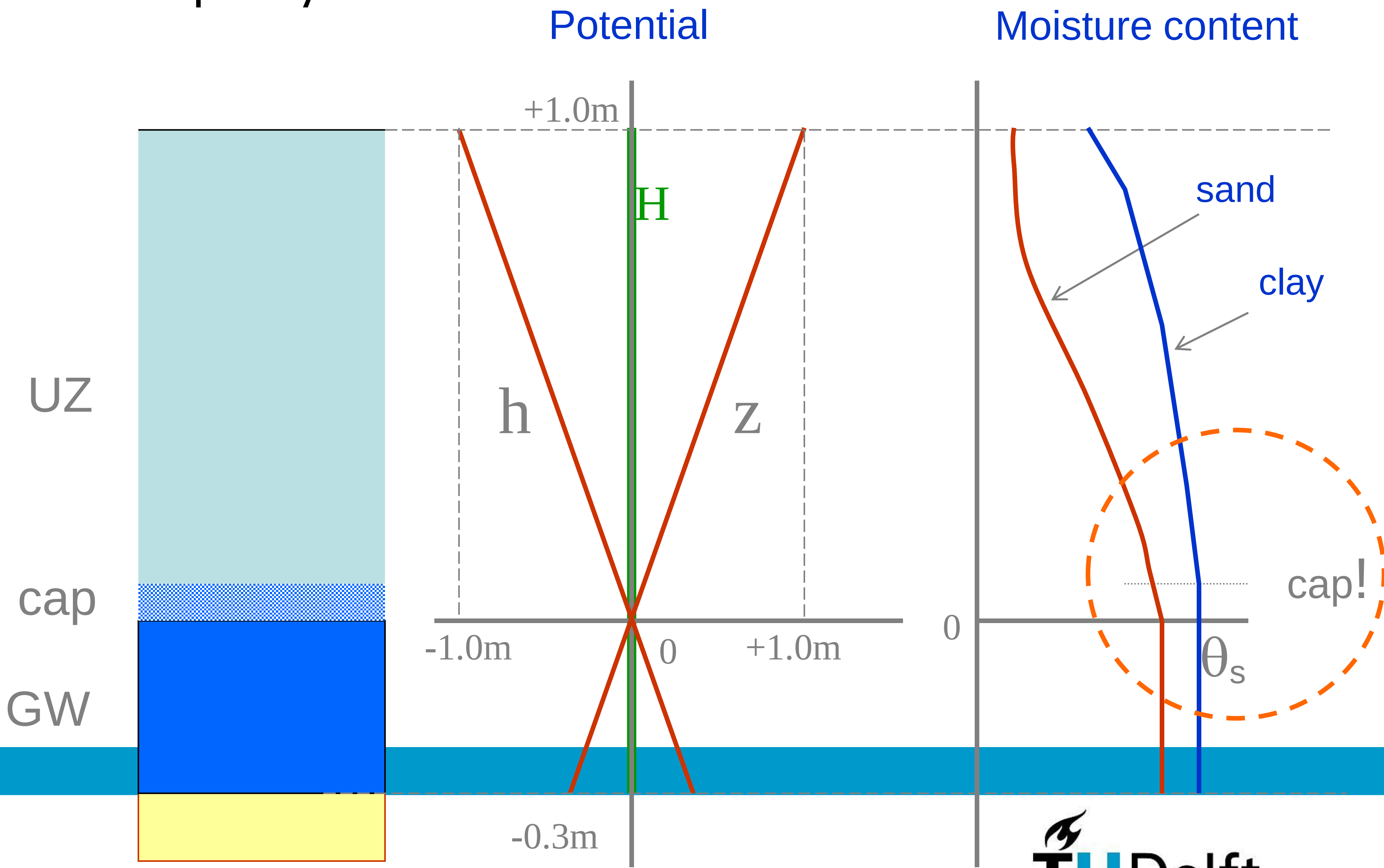


hydrostatic equilibrium: plane of reference soil surface

h = 0 at boundary atm/water, z = 0 at plane of ref.; H = -1m



Above the water table part of the pores is saturated even if h < 0: capillary zone



Static equilibrium: H = h+z = constant

- the matric potential is positive (+) below the water table
- the matric potential is negative (-) between the water table and the soil surface
- gravitational potential is 0 at plane of reference, 1:1 linear and positive in an upward direction; 1:1 linear and negative in a downward direction

Observing water potential

Pressure head

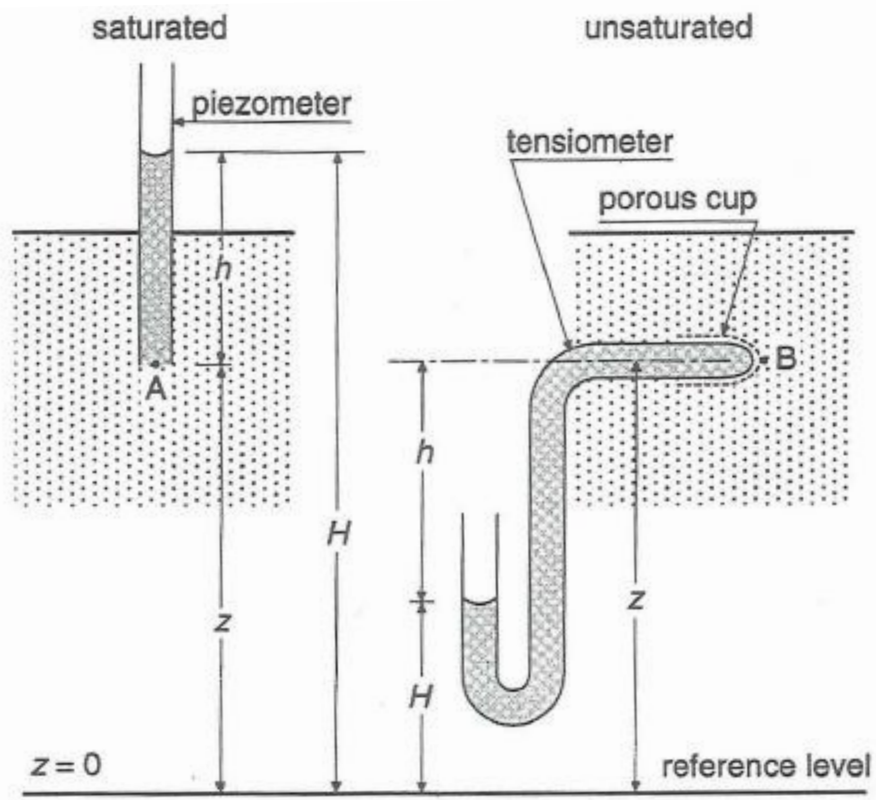


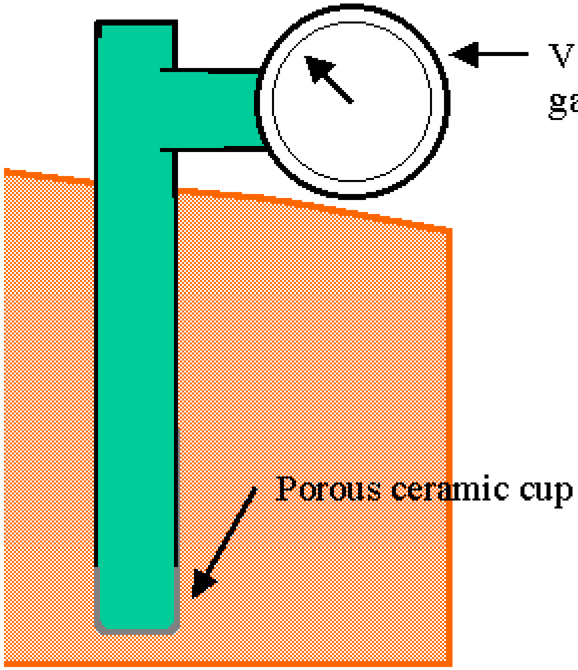
Fig. 4.1: Diagram of relationship between hydraulic head, H, pressure head, h, and gravitational head, z, for a piezometer (A) and a tensiometer (B).

Dirksen, 1999

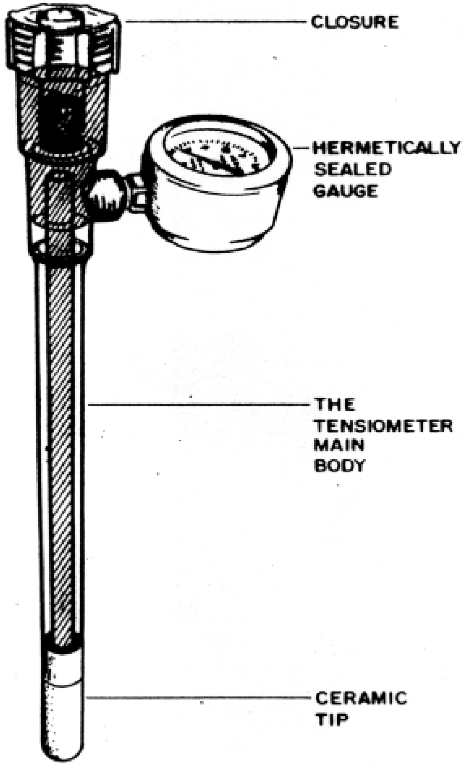
Observing water potential

Pressure head = Matric head : tensiometer

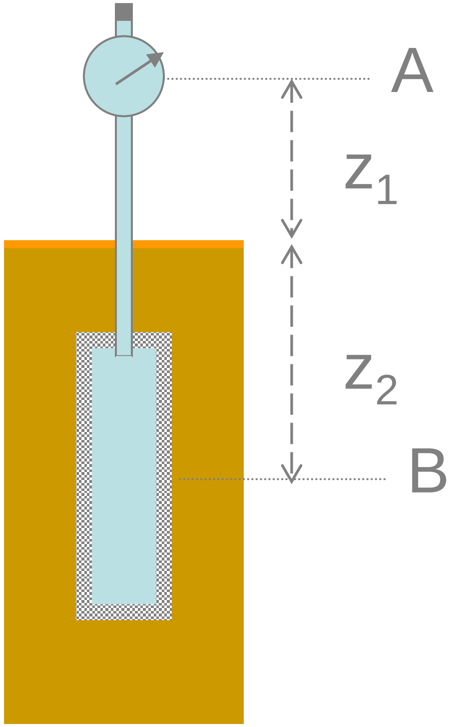
Max reading: pF=3 (ψ = -10 m)



Schematic diagram
of a tensiometer



Observing water potential



Example:

The pressure at level B is:

$p_B = p_A + \rho\ g\ (z_1+z_2)$

The pressure head is consequently:

$h = h_A + z_1 + z_2$

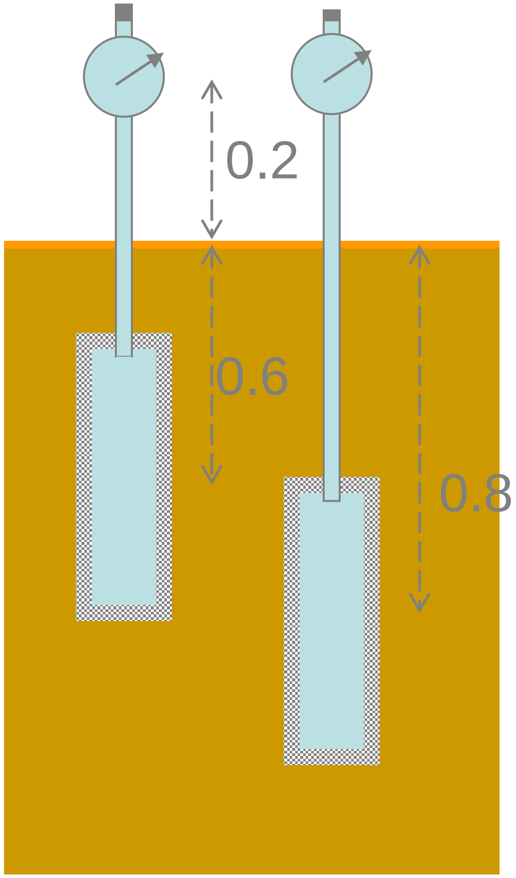
$z_1 = 30$ cm

$z_2 = 65$ cm

when -1.1m is read then the pressure in the cup is -1.1 + 0.95 = -0.15m

This is the pressure head or matric head

Observing water potential



Given: -0.9m pressure for both tensiometers; there is static equilibrium. Determine the potential diagram and depth of the water table.

h_1 = -0.9+0.8 = -0.1m

h_2 = -0.9+1.0 = +0.1m (!)

H = h+z

H_1 = -0.1 - 0.6 = -0.7m

H_2 = +0.1- 0.8 = -0.7m

Water table: h = 0:

H = -0.7 = z + 0 => at -0.7m depth

CEI 4440 Soil Hydrology

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Now what is the moisture content in the profile ?

We know:

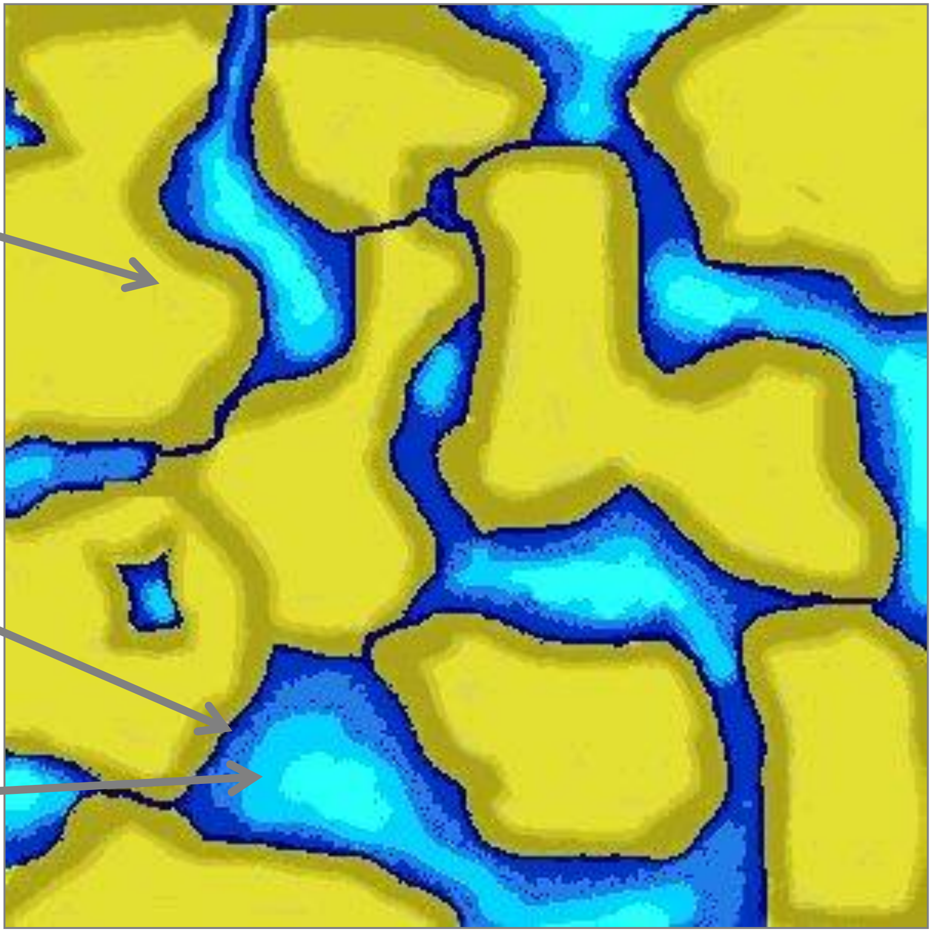
- Pore-size distribution depends on type of soil
- Capillary binding is larger as diameter of pores is smaller
- There is more pressure (potential) needed to empty pores when they are smaller
- Adsorptive water is strongly bound

Heterogeneous soil

Closed pores

Adsorption

Capillary forces



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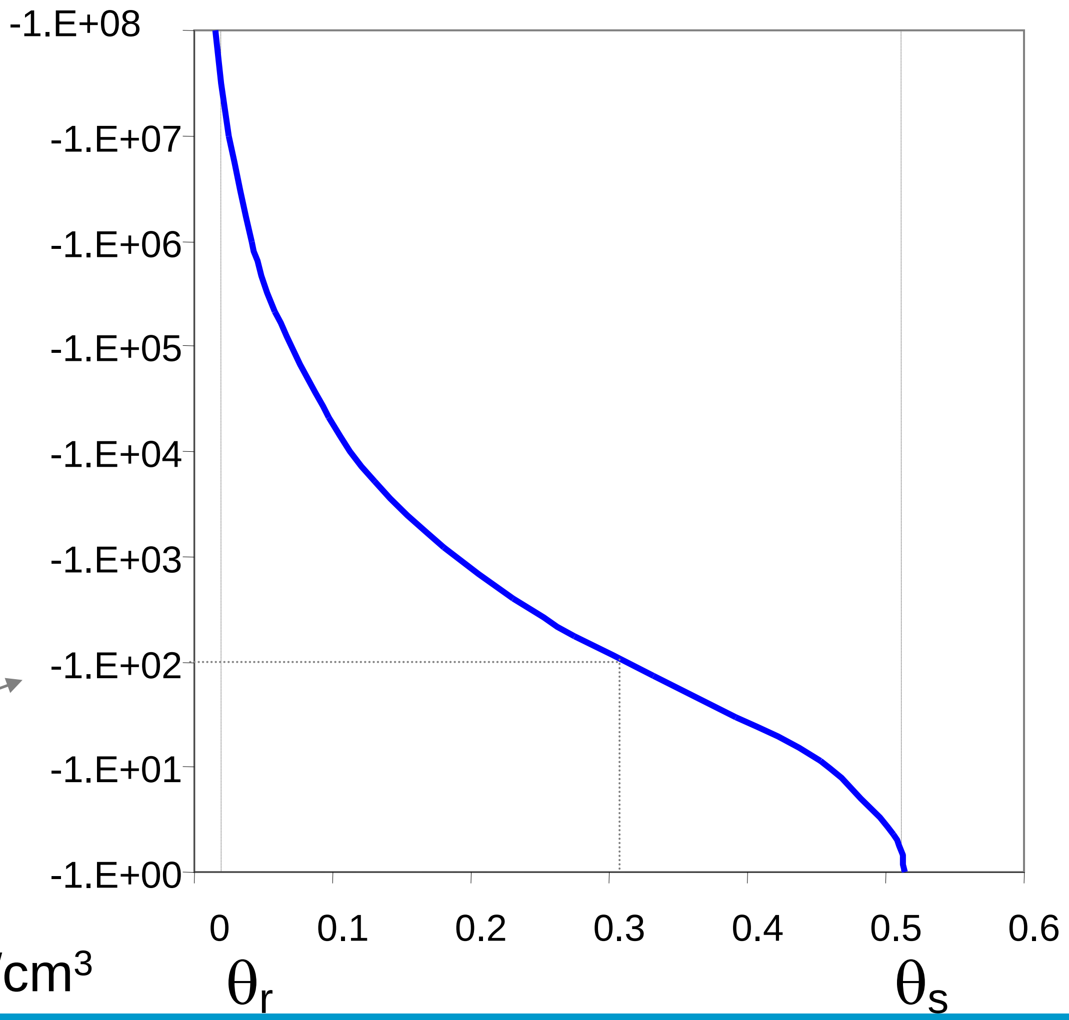
pF curve (soil moisture retention curve)

$$pF = \log(-h)$$

(h in cm)



In soil profile

soil surface: h = -100 cm

moisture content = 0.31 cm^3/cm^3

pF curve (soil moisture retention curve)

Clayey soil

many small pores

water is liberated

Gradually

Sandy soil

large pores

water is liberated

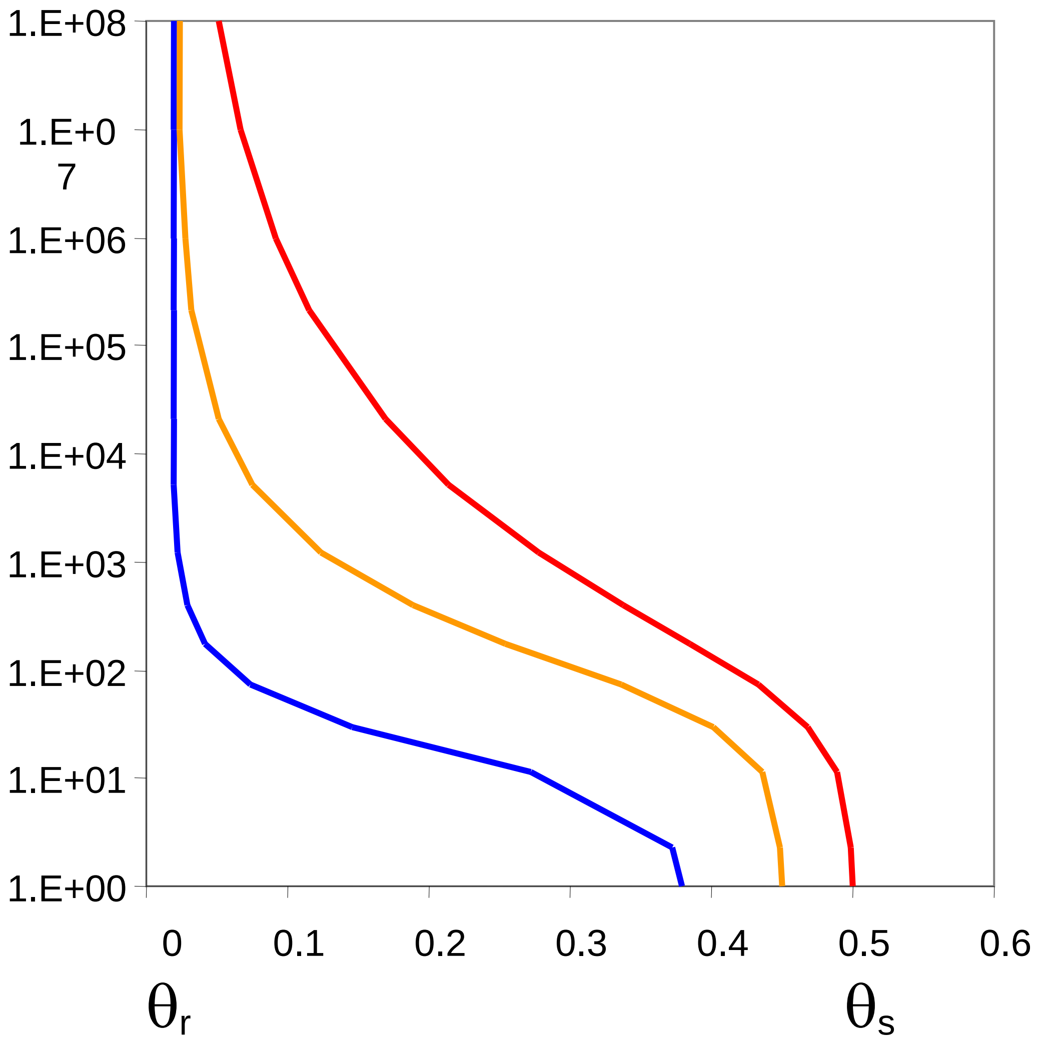
Suddenly

Loamy soil (silt)

mixed pores

good retention capacity

mixed behaviour

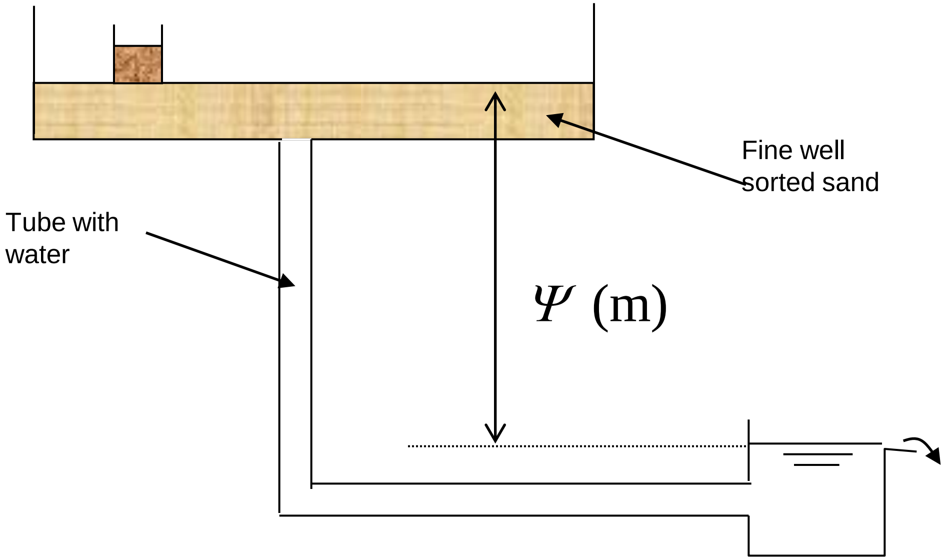


Determining soil physical parameters: standard laboratory

pF-curve (soil water retention curve; draining part)

pF: 0-2.0: sandbox method

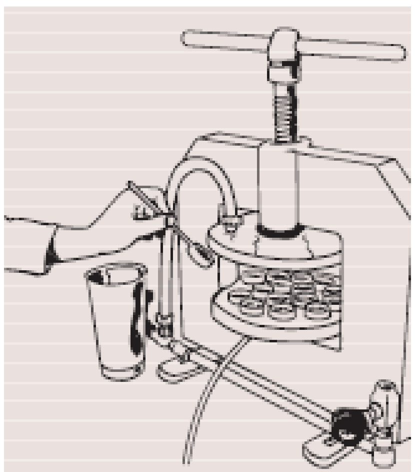
pF 2.0-2.7: sandbox with kaolinite clay

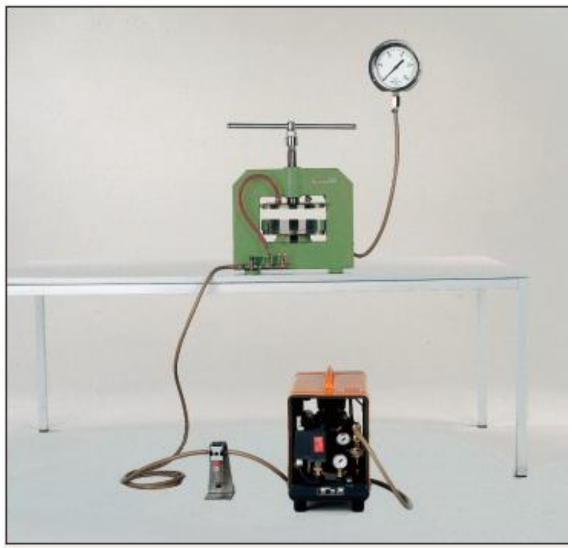


Determining soil physical parameters: standard laboratory

pF: 2.7-4.2: membrane pressure apparatus

pF: 6 ~ air dry





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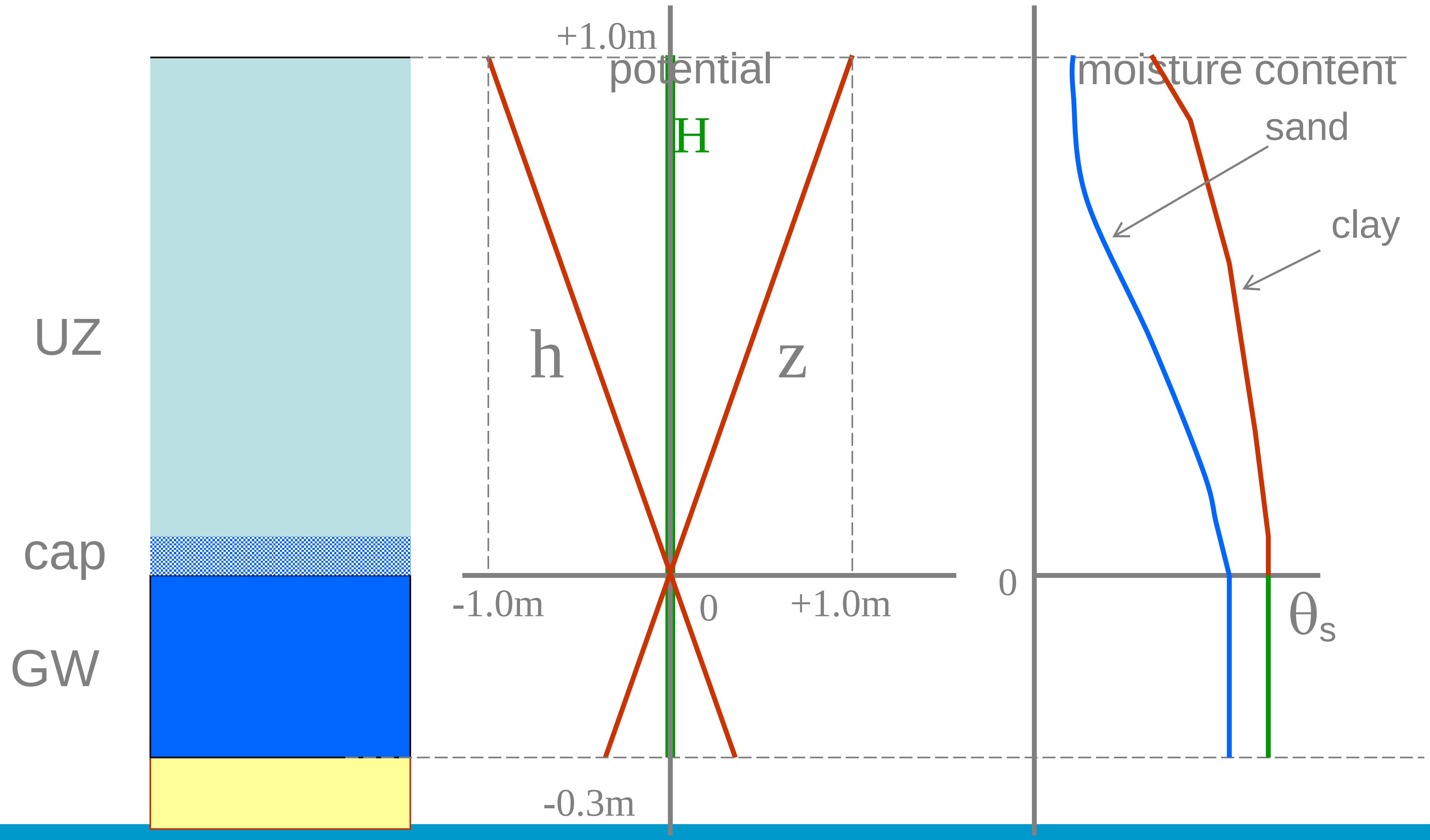
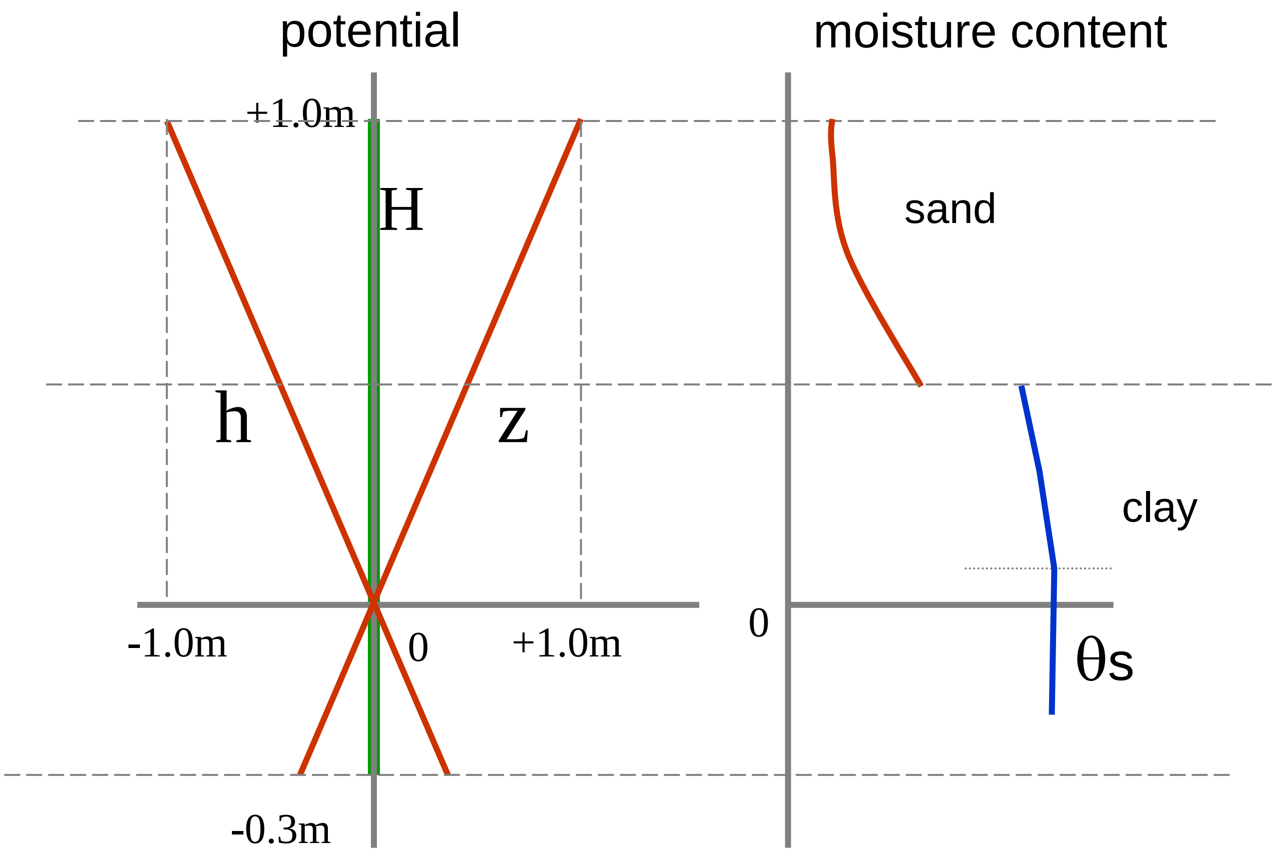
Moisture profile with groundwater at 1 meter depth

hydrostatic equilibrium: the shape of a pF curve



Difference potential and soil moisture in soil hydrology

Hydrostatic equilibrium but discontinuity in soil moisture content !



Plant available moisture

The pF curve can be used to calculate the available soil moisture for plants

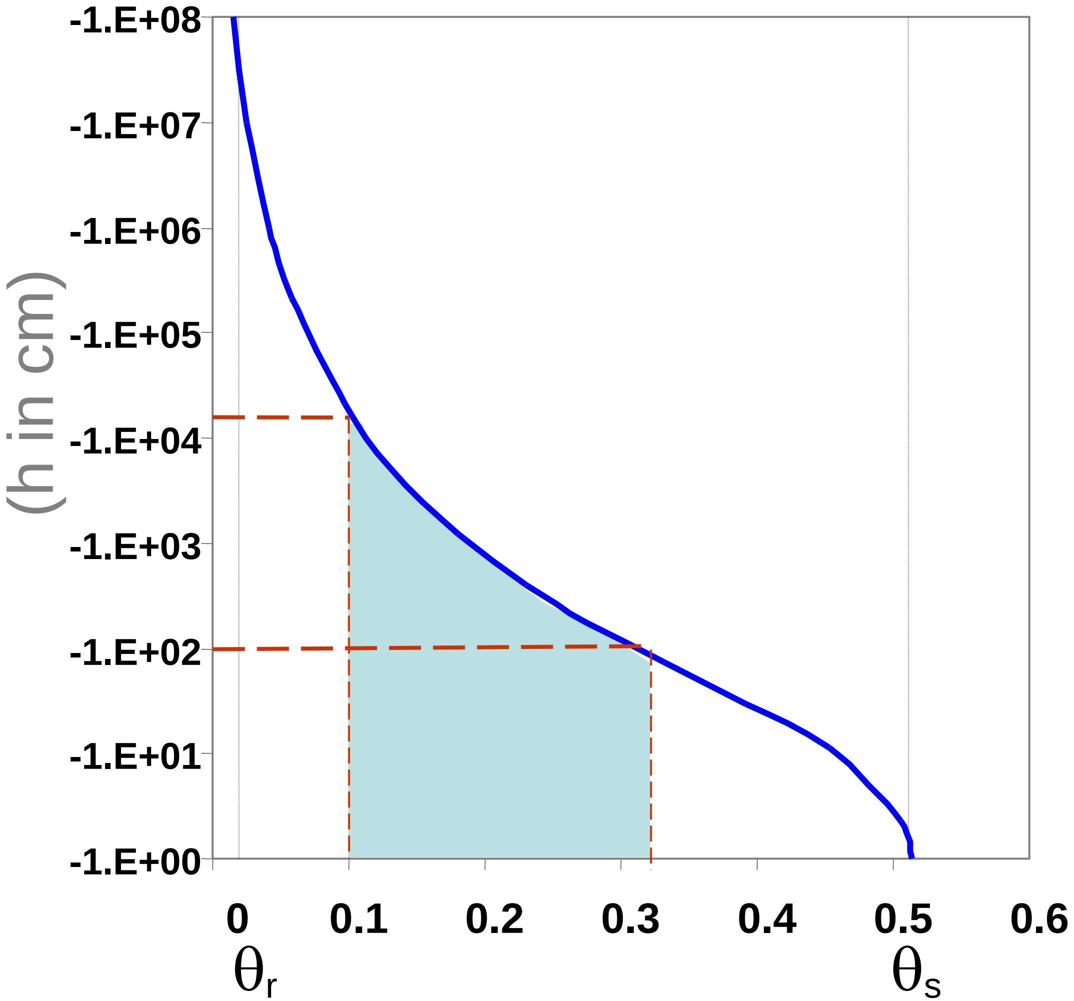
- Plants can - on average - produce a suction till 16 x atmospheric pressure: matric potential h = -16000 cm. This is pF 4.2, the wilting point of a plant

- The soil is often at field capacity. This is the matric potential in the root zone when the soil is in static equilibrium with gravity forces. If the depth to the water table is moderately deep or unknown: h = -100 cm = pF 2 is taken as field capacity

Plant available moisture

Moisture between pF2 and pF 4.2 is available for plants.

A conservative estimate, because when the soil is wetter than field capacity, this water is also available, but not for a long time; this water drains/percolates relatively fast.

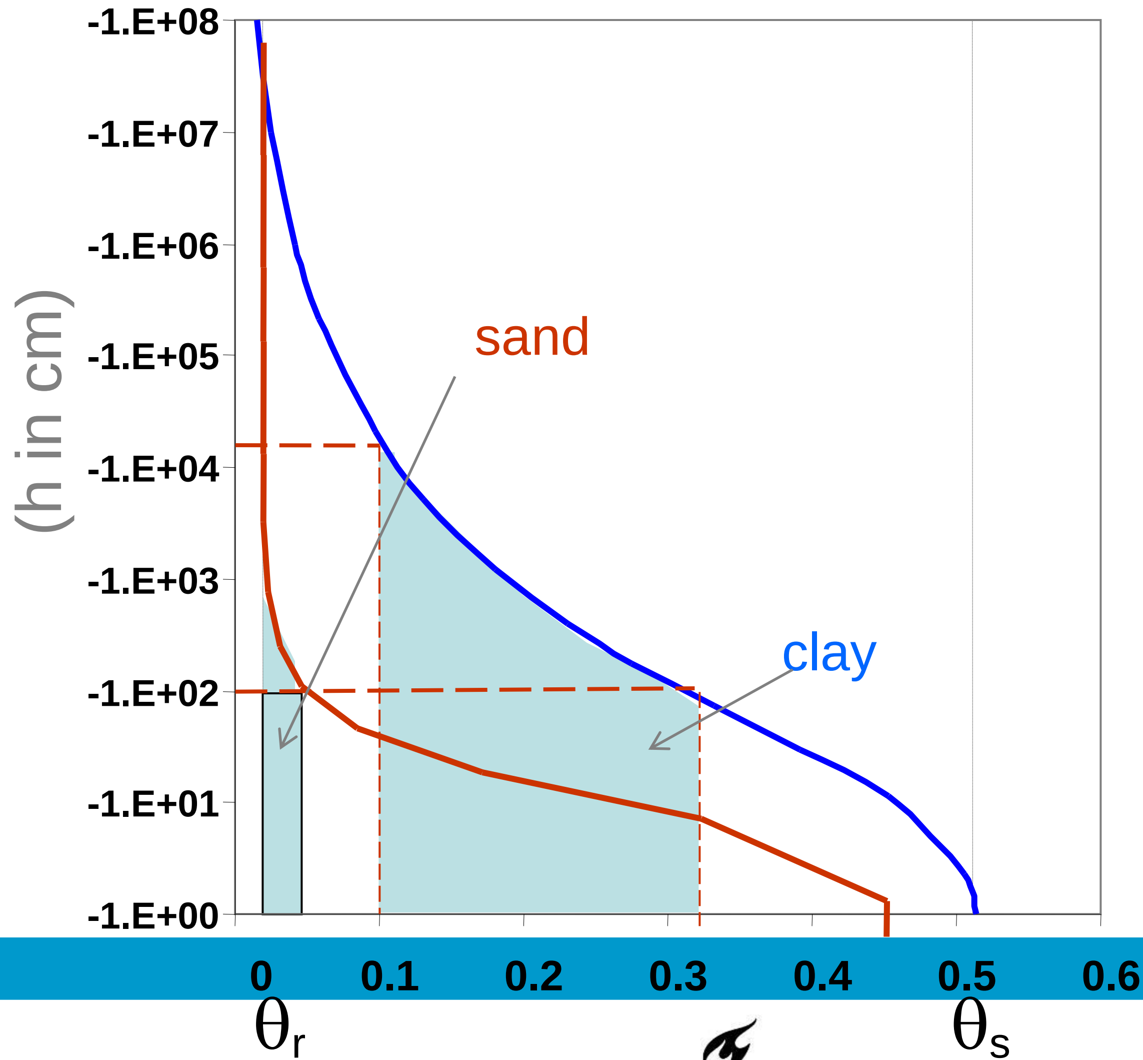


Plant available moisture

Moisture content between pF2 and pF 4.2 differs per soil

A sandy soil has far less available moisture than a clayey soil

This is important for agriculture: what crops can be grown, how much water is needed to irrigate and drain?

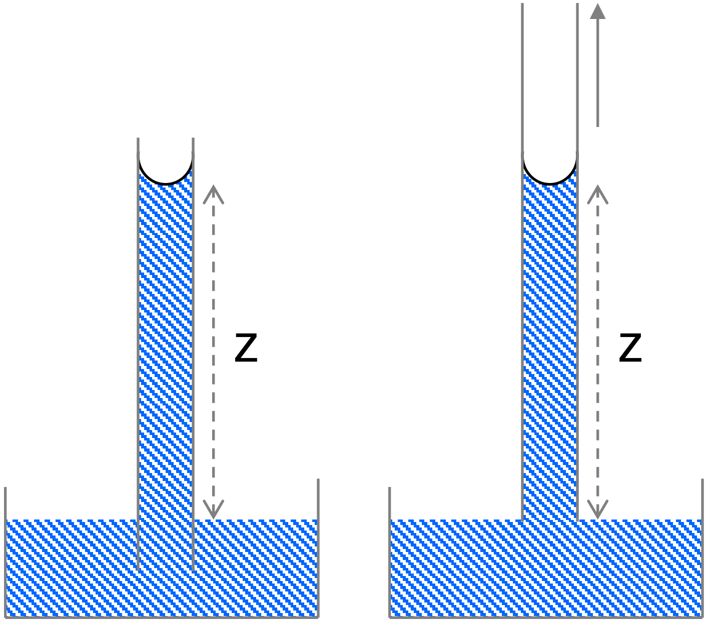


Air-entry value

Water rises in a capillary till equilibrium is reached between adhesive forces and the gravity

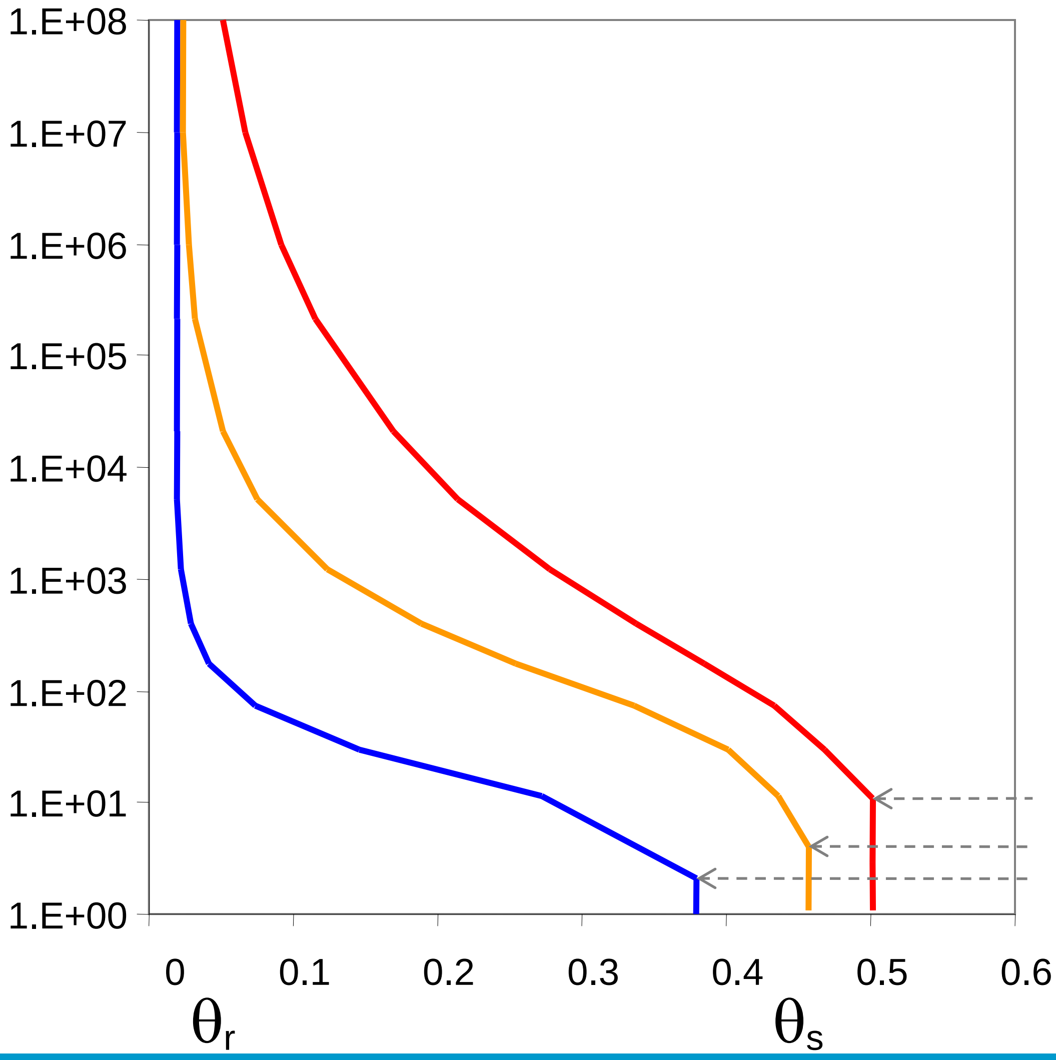
This level z is the <u>air-entry value</u>

Only when $h < h_A$ the pore empties



is used in different formulas to describe pF curves

Air-entry value



Theoretically the air-entry value is present in the pF curve, but in practice it is very difficult to determine it because of the heterogeneous character of soils

Air-entry potential

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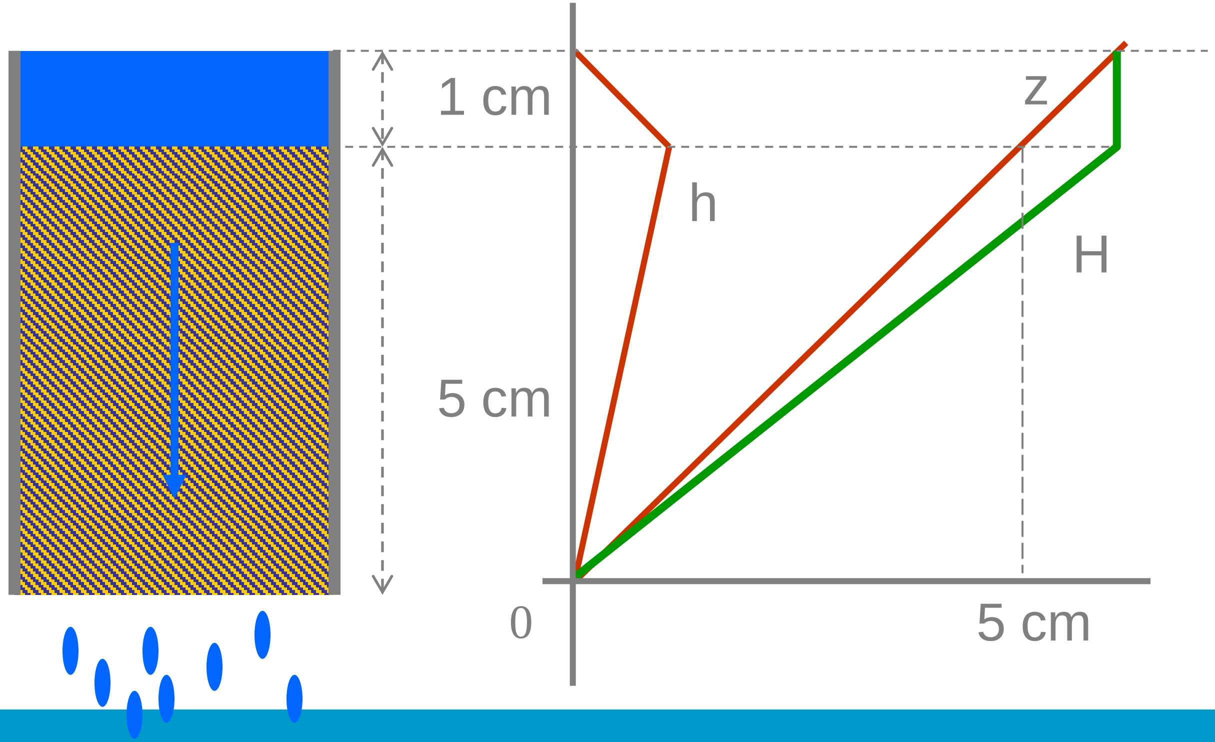
Infiltration

The saturated hydraulic conductivity k_s can be determined by measuring the flux Q using the below experimental setup. Suppose that the flux Q = 1.4 cm^3/min and the surface area = 20 cm^2



Calculation:

q =Q/A= -1.4/20 = -0.07 cm/min

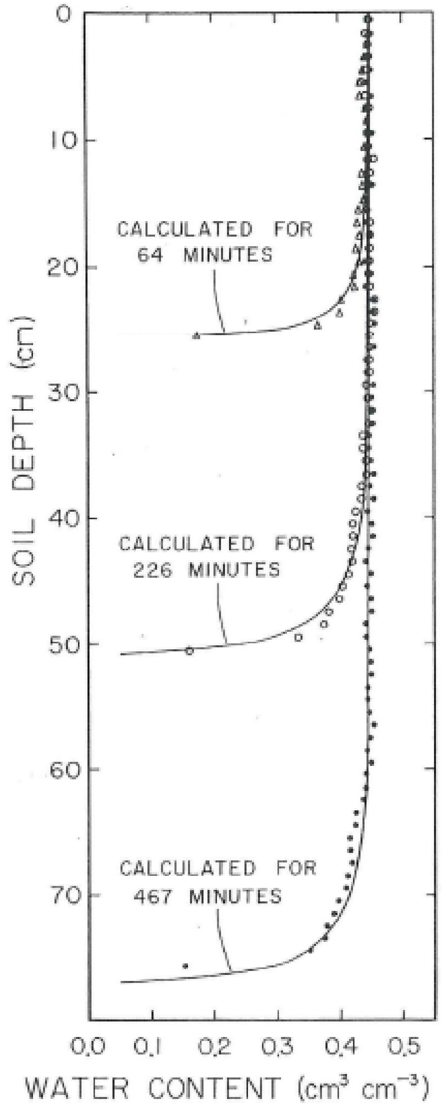
dH/dz = dh/dz+dz/dz = 1/5+5/5 = 1.2

k_s = -(q/(dH/dz)) = -(-0.07/1.2) = 0.058 cm/min

Infiltration

Measured and modelled soil water content distribution during vertical infiltration experiment into a vertical column of air-dry silt loam soil.

Why is it taking more time for the infiltration front to do 50 to 75 cm compared to 0 to 25 cm?



64 min

162 min

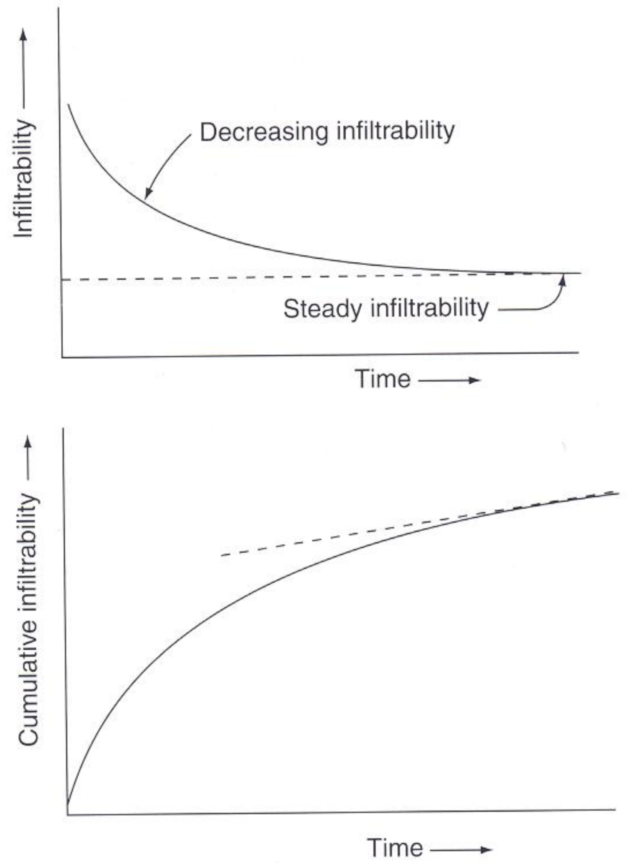
241 min

Davidson et al., 1963
Brutsaert, 2005

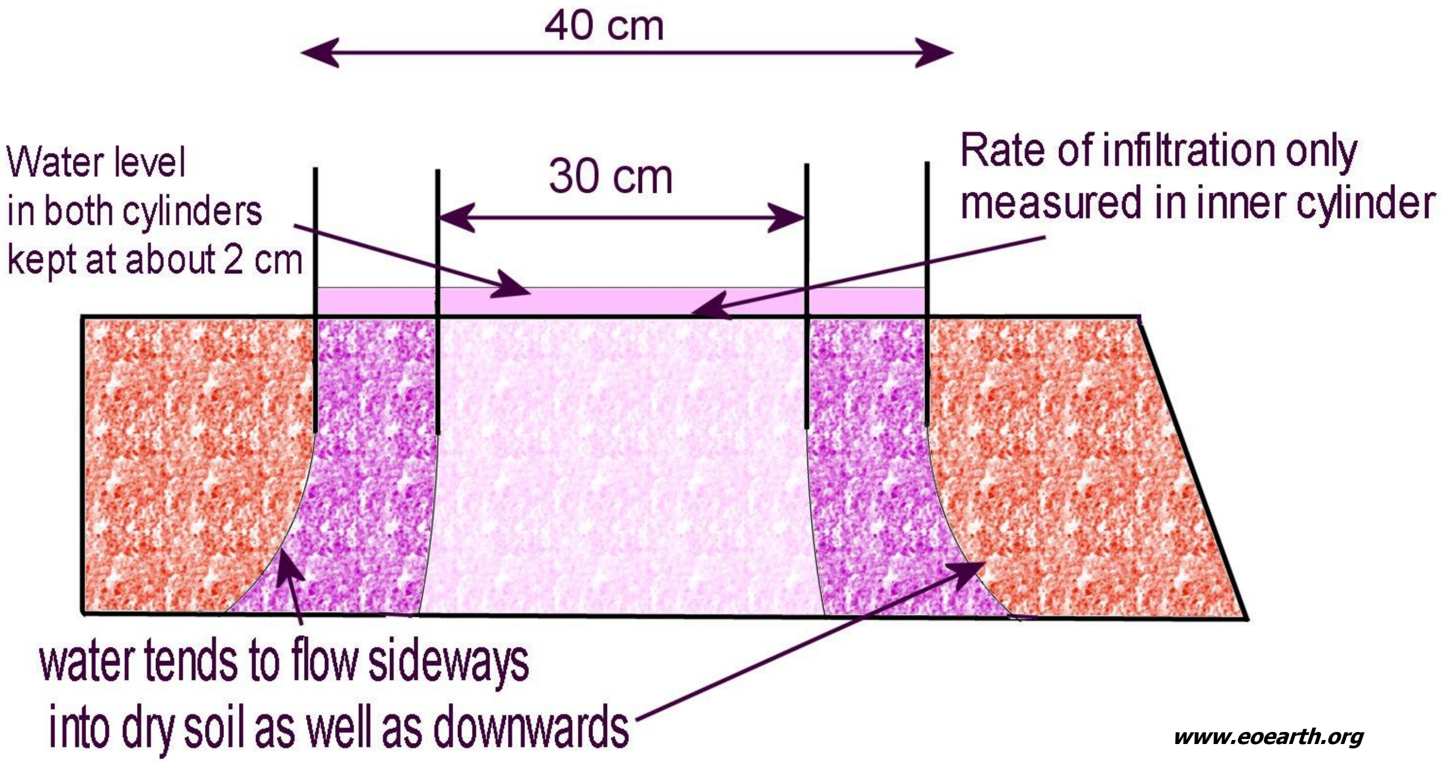
Infiltration rate and infiltration capacity

Infiltration rate = volume flux of water flowing into the soil per unit of soil surface area;

infiltrability = infiltration capacity = maximum infiltration rate of a soil at atmospheric pressure and a certain antecedent moisture condition



Double ring infiltrometer



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Infiltration

Infiltration is the process of downward entry of water into the soil surface (ISSS, 1996).

Measurements:

* Sprinkler installations ('rain')
* Infiltrometres (several types)
* Ksat-tests and pF-curves

Examples of infiltration models:

* Green & Ampt (= Darcy's law)
* Horton
* Philip
* A lot more ………

Double ring infiltrometer

The outer ring is too small compared to the inner ring

… but any shape will do

Sprinkler infiltration test

Nozzle type / spray

Drip plates

Double ring tension infiltrometer

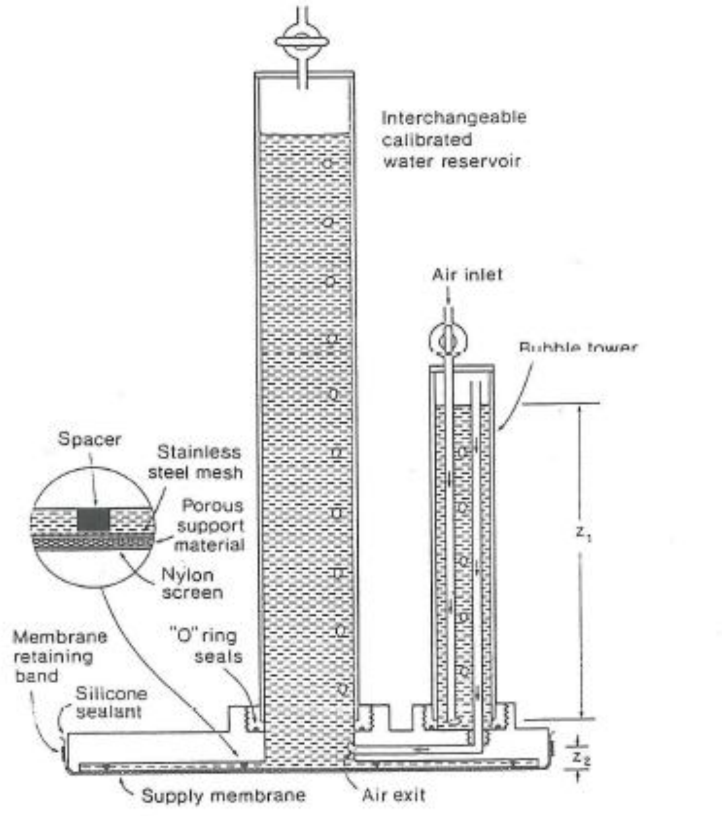
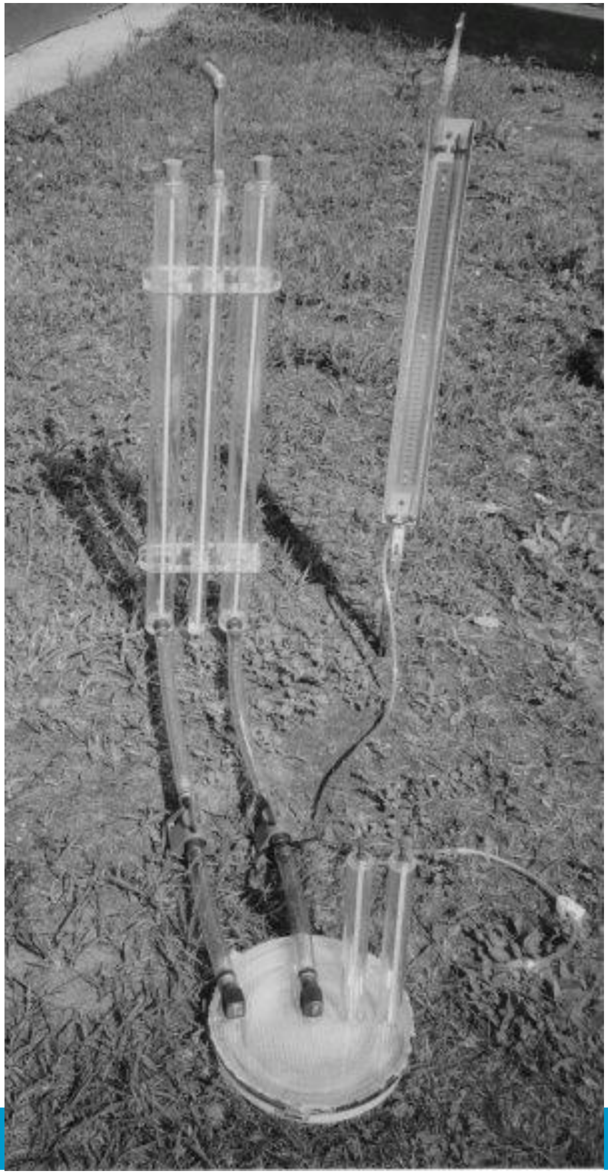


Fig. 7.9: Tension disc infiltrometer. Arrows show direction of air flow.



Dirksen, 1999

Note: $h_0 = -z_1 + z_2$

(Empirical) infiltration models

- **Kostiakov model**
  (purely empirical, needs fitting data)

$$f_p = K_k t^{-\alpha}$$

- **Horton model**
  (Only for Horton conditions, $i > f_c$, also needs fitting)

$$f_p = f_c + (f_0 - f_c) e^{-\beta t}$$

- **Holtan model**
  (Land use important, use of database/tables, more physical)

$$f = a F_p^n + f_c$$

- **Philip model**
  (series solution of Richards equation)

$$f = \tfrac{1}{2} S t^{-1/2} + A$$

CEI 4440 Soil Hydrology

Set up of lecture today

1. Soil physics; Measuring soil moisture
2. Hydrostatics; Measuring soil tension
3. Soil hydraulics; pF curves
4. Soil infiltration and field tests
5. Soil hydraulics; Permeability

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Darcy's law (Darcy-Buckingham Equation)

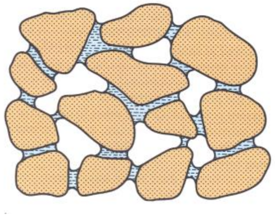
1D:

$$q = -K(h)\frac{dH}{dz} \qquad \left(H = \frac{\psi_m}{\rho_w g} + z = h + z \right)$$

$$q = -K(h)\left[\frac{dh}{dz} + 1\right]$$

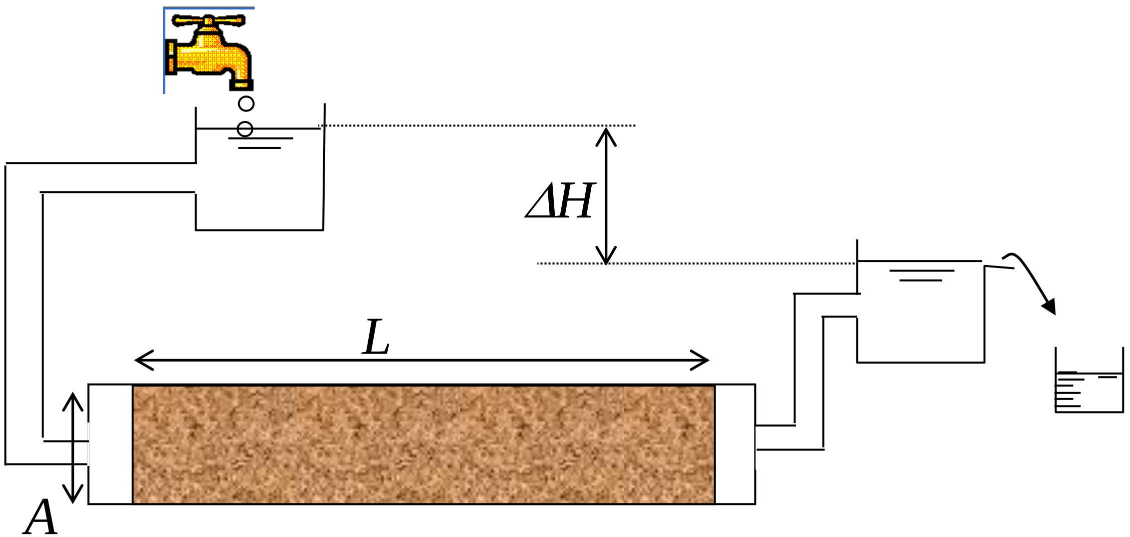
3D isotropic:

$$\mathbf{q} = -K(h)\begin{pmatrix} \frac{\partial H}{\partial x} \\ \frac{\partial H}{\partial y} \\ \frac{\partial H}{\partial z} \end{pmatrix} = -K(h)\nabla H$$

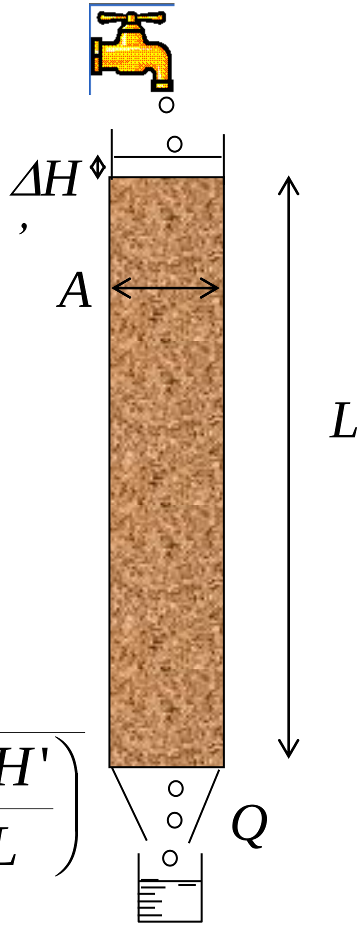


Determining soil physical parameters: standard laboratory

Saturated hydraulic conductivity: two experiments



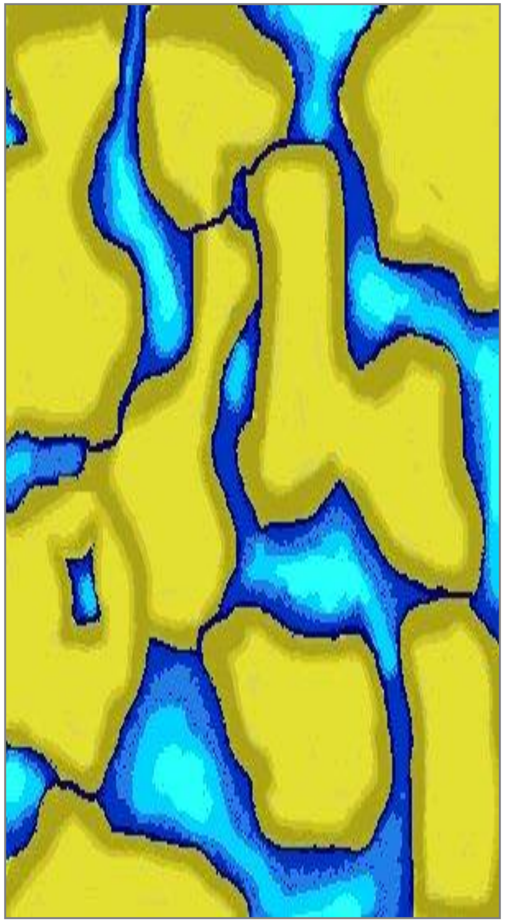
$$K = \frac{QL}{A\Delta H}$$



$$K_{sat} = \frac{Q}{A\left(1+\frac{\Delta H'}{L}\right)}$$

Generally: $K_{sat} < K$??

Unsaturated hydraulic conductivity



The conductivity is strongly dependent on the moisture content (or matric potential)

The drier the soil the smaller the conductivity, because upon drying the larger pores are emptied first:

- water is binded stronger and it experiences more friction in smaller pores;
- the film of water along the soil particles becomes interrupted

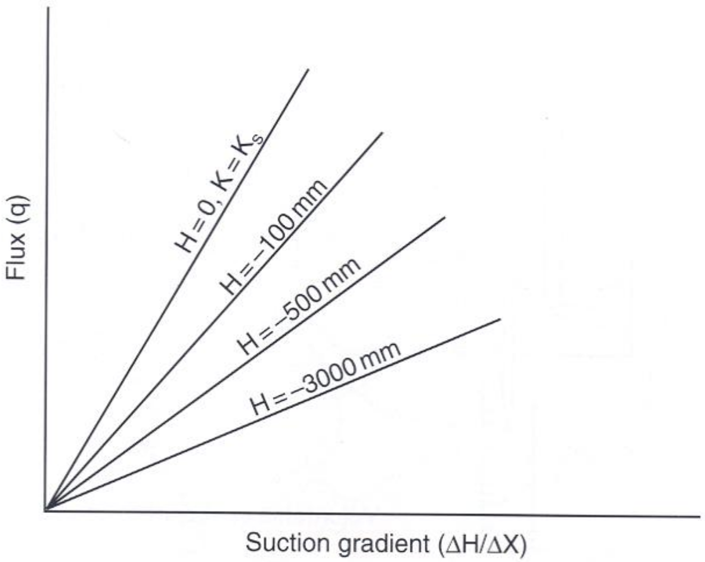
The conductivity is the highest at saturation (K_s)

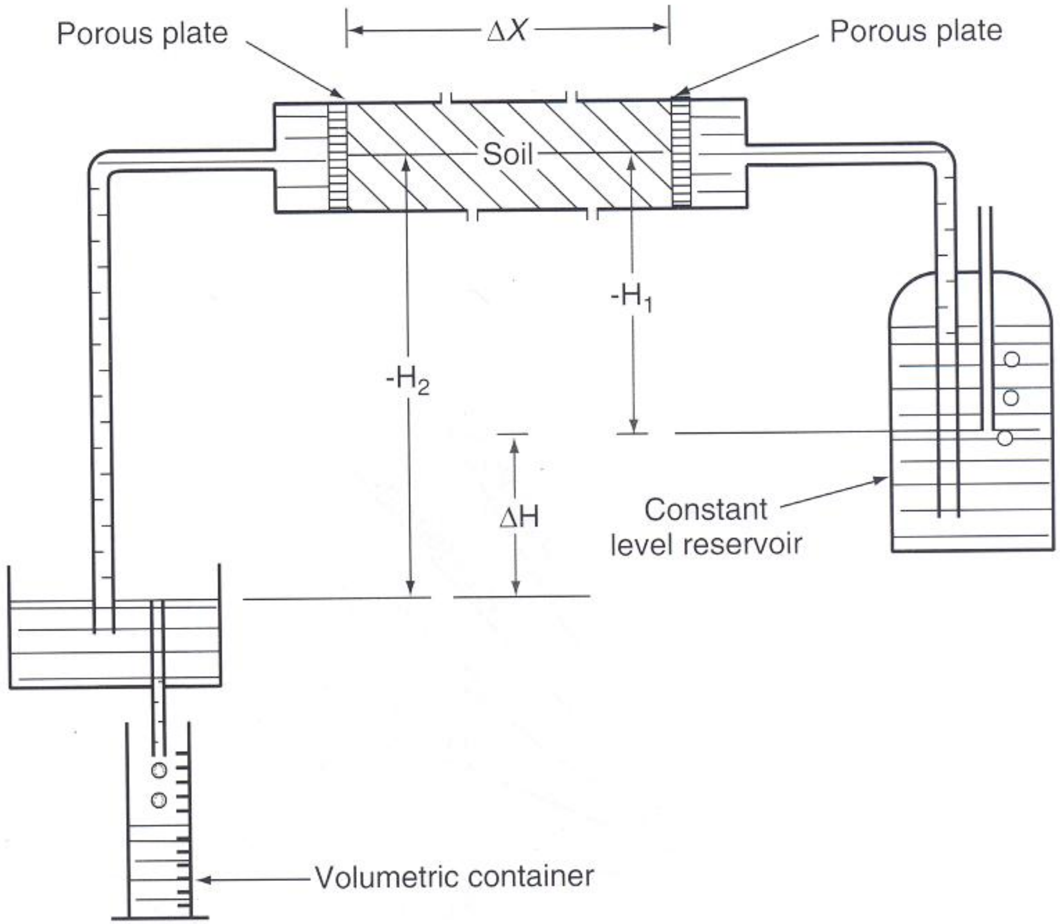
With unsaturated flow the conductivity is a function of the moisture content or the matric potential:

$$K(\theta) \text{ or } K(h)$$

Unsaturated hydraulic conductivity

An experiment:





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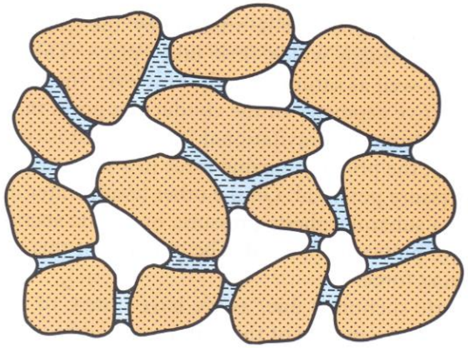
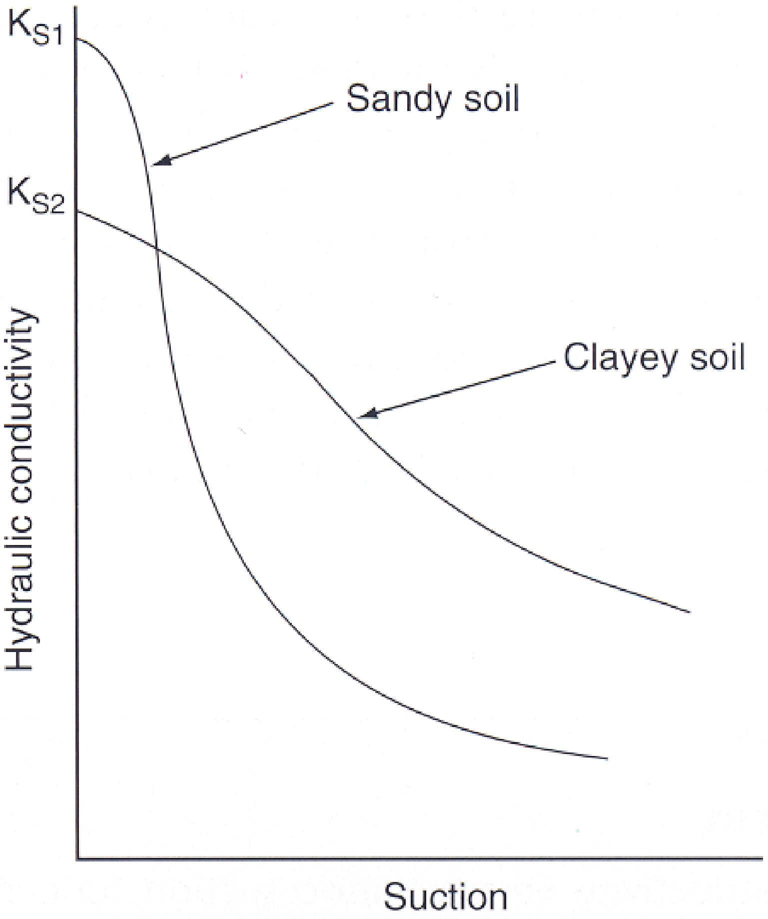
Unsaturated hydraulic conductivity

Unsaturated conductivity

of two soils





Q: Explain why the curves look like that?

Unsaturated hydraulic conductivity: models

Two approaches:

- Physical: Hagen-Poisseuille + pore size distribution (SWRC)
- Empirical approaches

Gardner: $K(\theta)$

$$K(\theta) = a\theta^m$$

$$K(\theta) = K_s \left(\frac{\theta - \theta_r}{\theta - \theta_r} \right)^m$$

Clapp and Hornberger

Gardner: $K(h)$

$$K(h) = a|h|^{-m} \quad h \le 0$$

$$K(h) = \frac{a}{b + |h|^m} \quad h \le 0$$

$$K(h) = \frac{K_s}{1 + (h/h_a)^m} \quad h \le h_a$$

$$K(h) = \exp\left[c(h - h_a)\right] \quad h \le h_a$$

Unsaturated hydraulic conductivity: models

Physical: Hagen-Poiseuille + pore size distribution (SWRC)

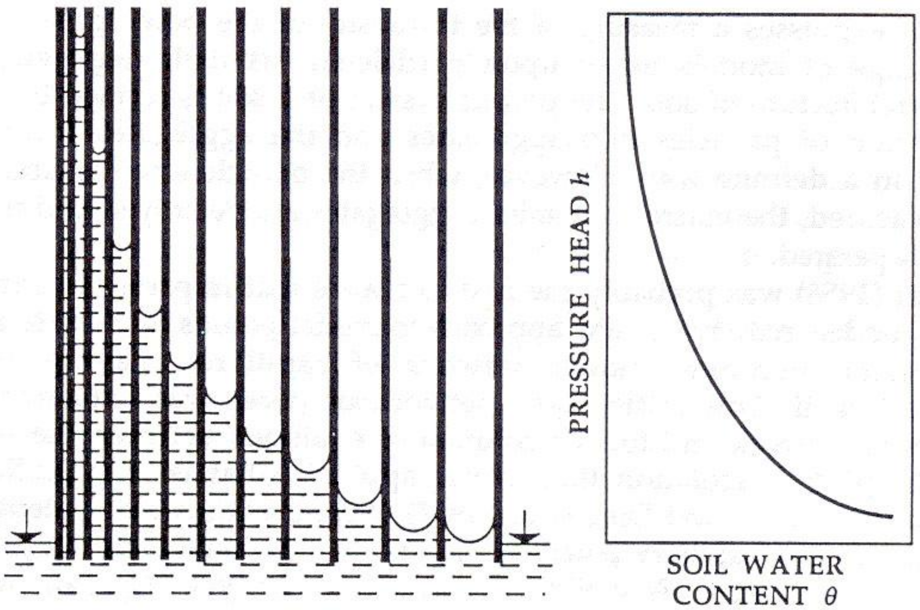


Figure 4.19. Model of SWRC consisting of parallel capillary tubes (left) and the resulting SWRC (right).

$$v(r) = \frac{r^2 \rho_w g}{8\mu} \cdot \frac{\Delta H}{L}$$

Unsaturated hydraulic conductivity: models

Physical: Hagen-Poiseuille + pore size distribution (SWRC)

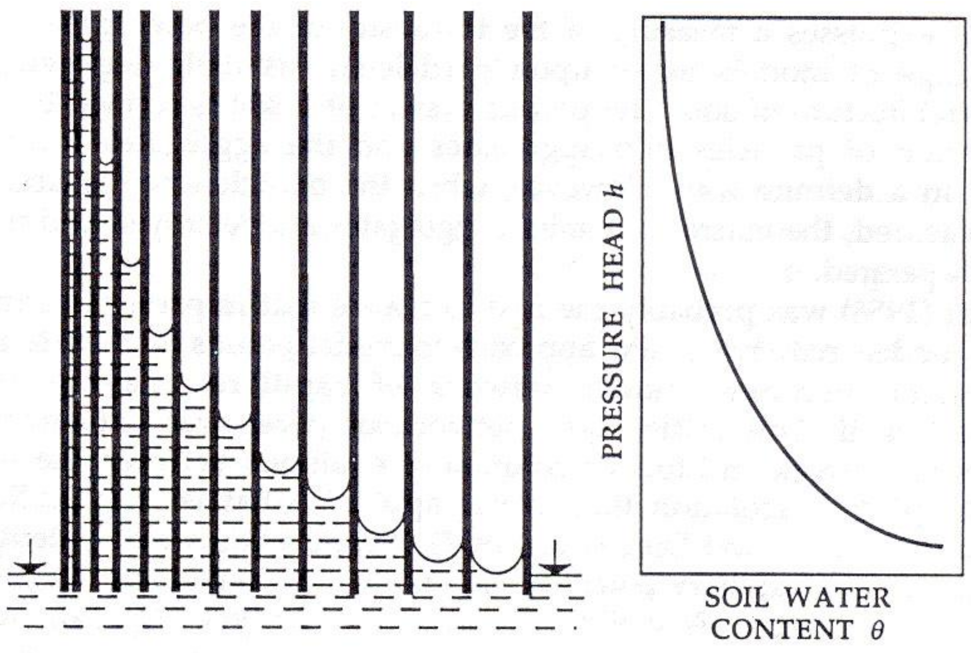


Figure 4.19. Model of SWRC consisting of parallel capillary tubes (left) and the resulting SWRC (right).

$$a = \frac{\rho_w g}{8\mu}$$

$$q(r) = \frac{1}{\tau}\int_0^r v(r)\, f(r)\,dr$$

$$\text{unit gradient}: q(r) = K(r):$$

$$K(r) = \frac{1}{\tau}\int_0^r a r^2 f(r)\,dr$$

Unsaturated hydraulic conductivity: models

Physical: Hagen-Poiseuille + pore size distribution (SWRC)

$$K(r) = \frac{1}{\tau}\int_0^r ar^2 f(r)dr$$

$$\text{with } f(r)dr = ds \quad (s = \frac{\theta - \theta_r}{\theta_s - \theta_r} \text{ and } r = \frac{c}{|h|}):$$

$$K(s) = \frac{1}{\tau}\int_0^s \frac{a}{h^2(s)}ds$$

Unsaturated hydraulic conductivity: models

Physical: Hagen-Poiseuille + pore size distribution (SWRC)

$$\text{with } [\tau_s / \tau(s)] = s^b$$

$$K_r(s) = K(s)/K_s = s^b \left[\int_0^s \frac{1}{h^2(s)} ds \Big/ \int_0^1 \frac{1}{h^2(s)} ds \right]$$

$$\textit{Mualem}\ (1976)\ (b = 0.5) + \text{change micro} \rightarrow \text{macro}:$$

$$K_r(s) = s^{0.5} \left[\int_0^s \frac{1}{h(s)} ds \Big/ \int_0^1 \frac{1}{h(s)} ds \right]^2$$

Unsaturated hydraulic conductivity: models

Two well-known models:

Mualem-van Genuchten:

$$s = \left[1 + \alpha |h|^n\right]^{\frac{1}{n}-1} \quad \Rightarrow \quad K(s) = K_s s^{0.5}\left[1 - \left(1 - s^{\frac{n}{n-1}}\right)^{1-\frac{1}{n}}\right]^2$$

$$\Rightarrow K(h) = K_s \frac{\left\{1 - \alpha |h|^{n-1}\left[1 + \alpha |h|^n\right]^{\frac{1}{n}-1}\right\}^2}{\left[1 + \alpha |h|^n\right]^{\frac{1}{2}-\frac{1}{2n}}}$$

Unsaturated hydraulic conductivity: models

Two well-known models:

Brooks-Corey:

$$s = \left(\frac{h_a}{h}\right)^{\lambda}$$

$$\Rightarrow \quad K(s) = K_s s^{2.5+\frac{2}{\lambda}}$$

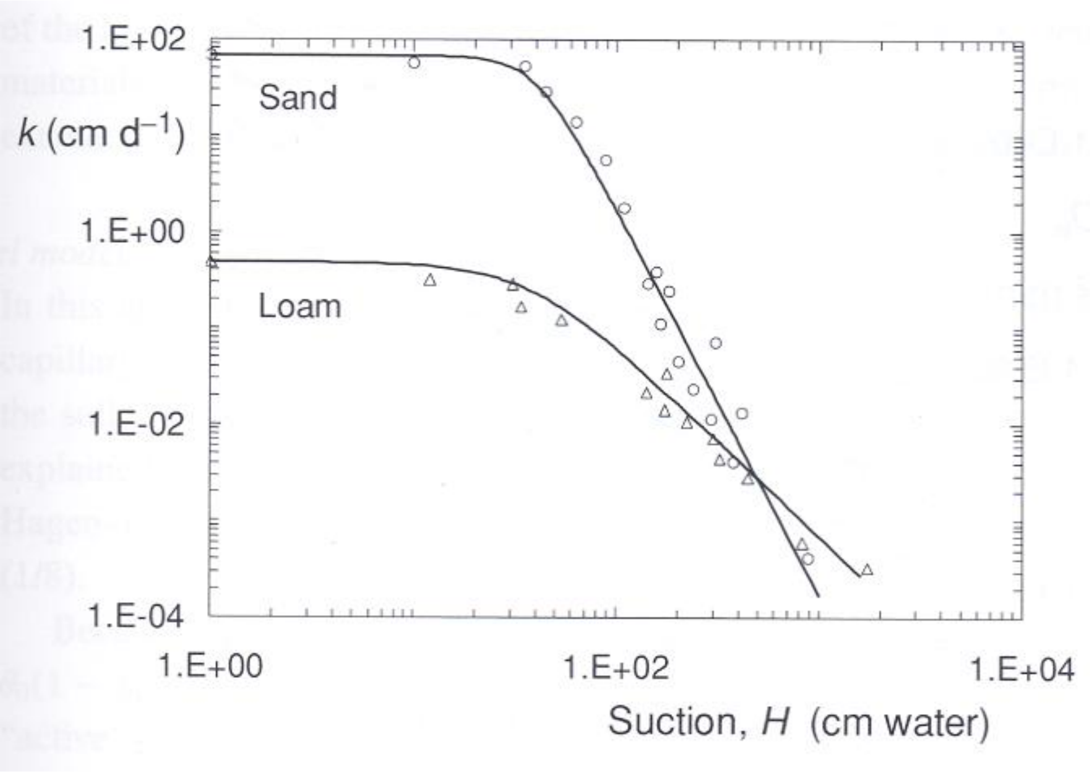
$$\Rightarrow \quad K(h) = K_s \left(\frac{h_a}{h}\right)^{2+\frac{2.5}{\lambda}}$$

Unsaturated hydraulic conductivity: models

Examples

Fitted Gardner model

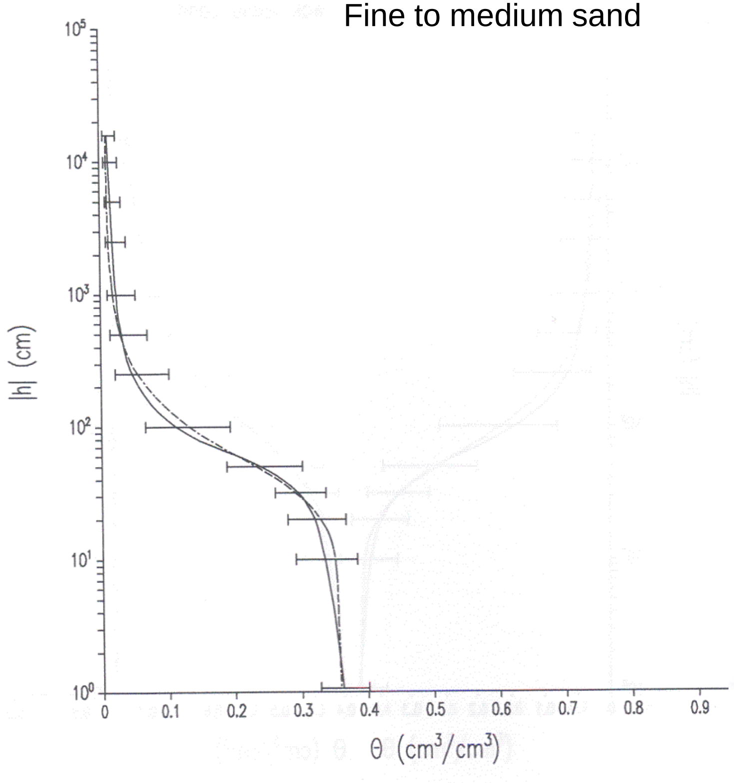
$$K(h) = \frac{a}{b + |h|^m} \quad h \leq 0$$

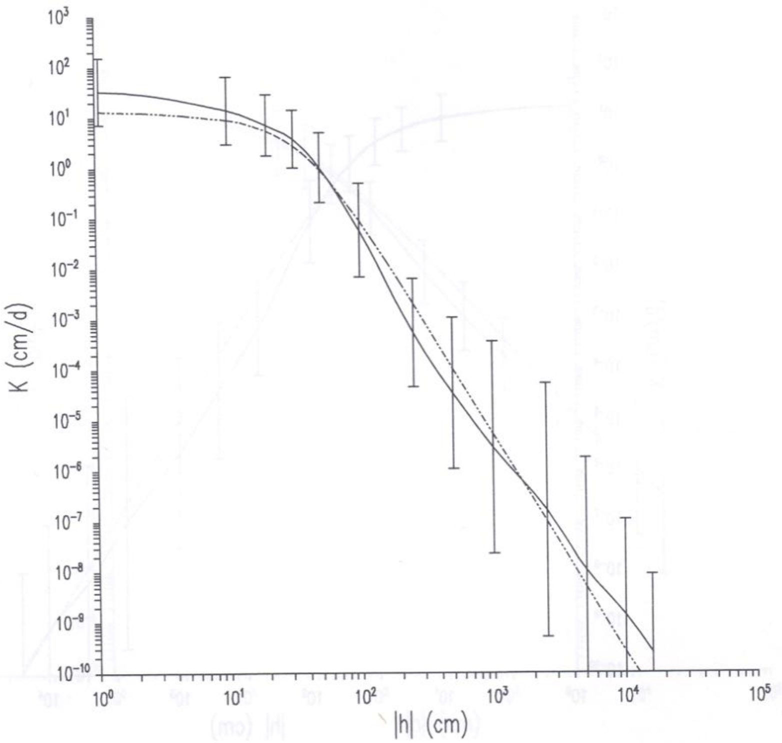


Unsaturated hydraulic conductivity: models

Examples   Mualem- van Genuchten model

Fine to medium sand





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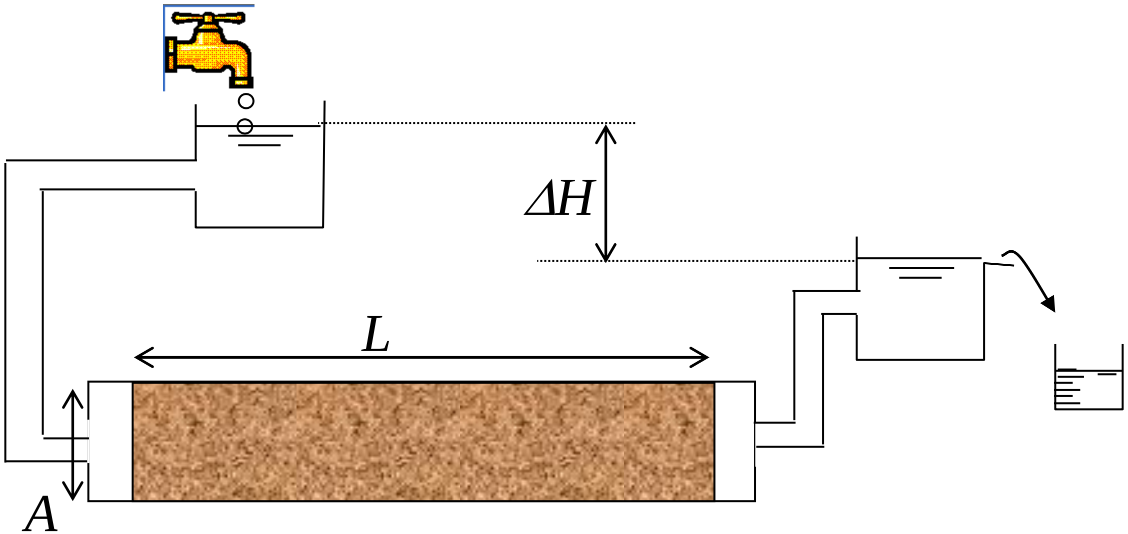
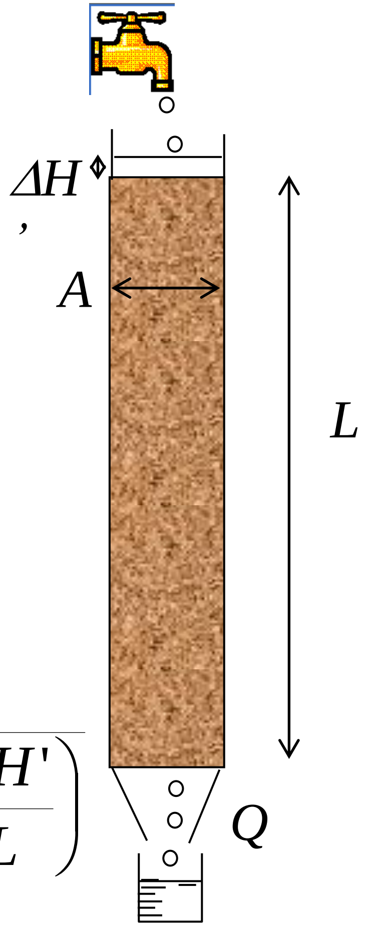
Determining soil physical parameters: standard laboratory

Saturated hydraulic conductivity: two experiments



$$K = \frac{QL}{A\Delta H}$$

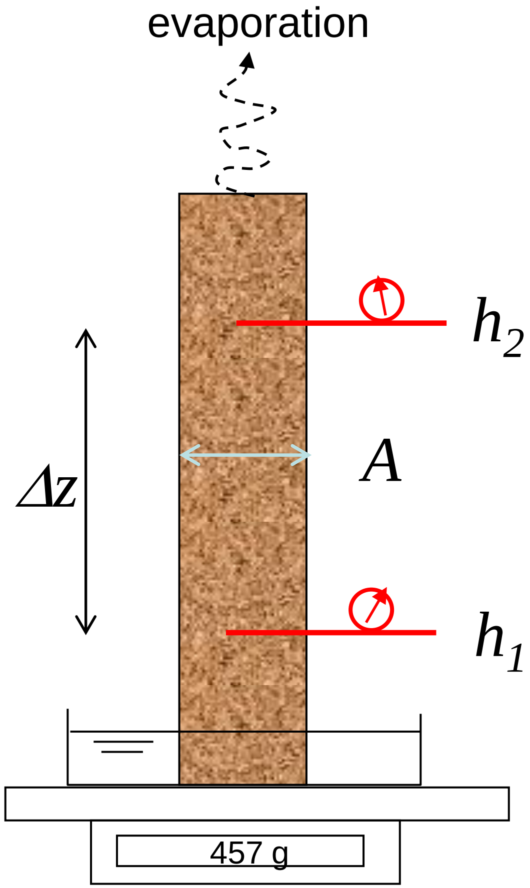


$$K_{sat} = \frac{Q}{A\left(1 + \frac{\Delta H'}{L}\right)}$$

Generally: $K_{sat} < K$??

Determining soil physical parameters: standard laboratory

Unsaturated hydraulic conductivity: Wind's method



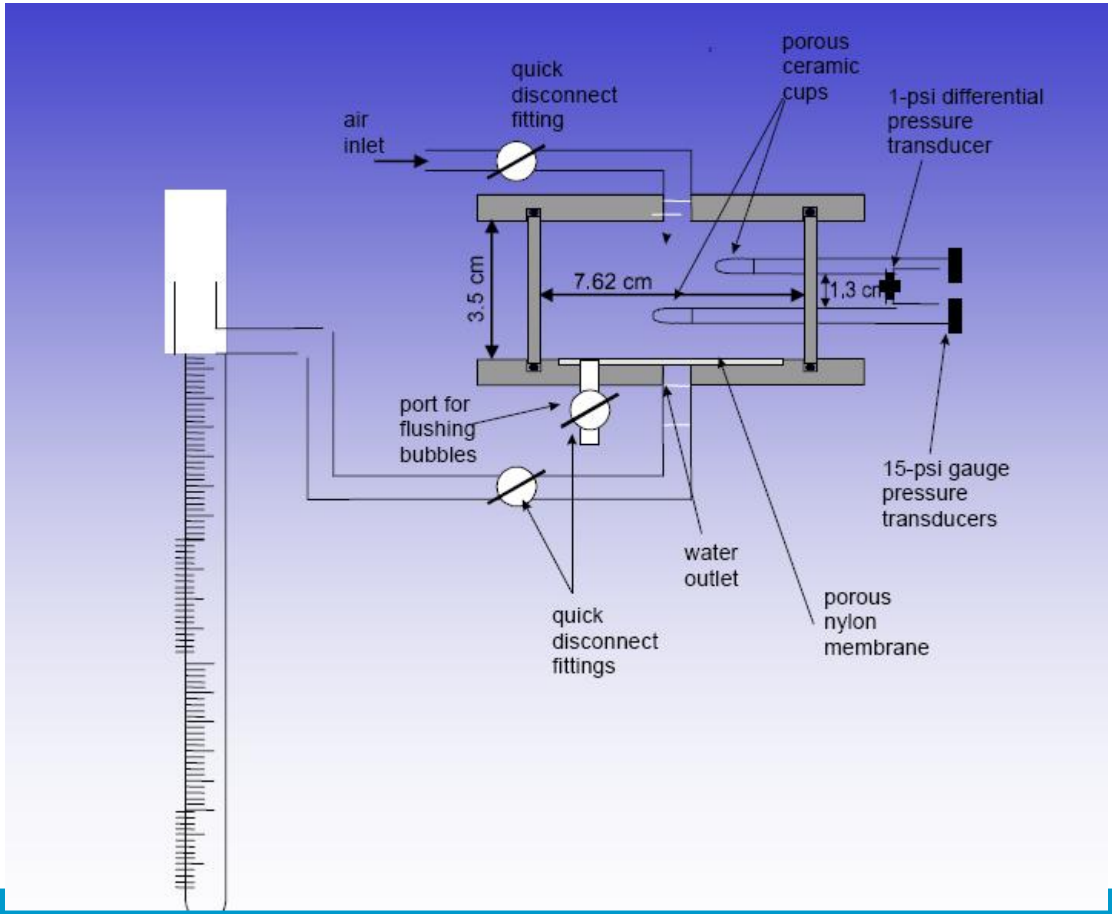
$$Q_t = \frac{m_t - m_{t-1}}{\Delta t \rho_w V}$$

$$K = \frac{Q_t}{A\left(\frac{h_2 - h_1}{\Delta z} - 1\right)}$$

$$\theta_t = \frac{m_t - m_d}{\rho_w V}$$

Determining soil physical parameters: inverse method

Multi-step outflow experiment



To determine Van Genuchten parameters

$$S_e = \left[\frac{1}{1+(\alpha h)^n} \right]^m$$

$$K_r = S_e^l \left[1 - \left(1 - S_e^{1/m} \right)^m \right]^2$$

Courtesy of Jan Hopmans (Davis, CA)

Determining soil physical parameters: inverse method

Experiment:

- Multi-step outflow, with tensiometric measurements inside soil core;
- Apply a sequence of air pressure steps to initially near-saturated soil core;
- Monitor cumulative drainage volume and tensiometer pressure with pressure transducers;
- Measure boundary and initial conditions

Courtesy of Jan Hopmans (Davis, CA)

Determining soil physical parameters: inverse method

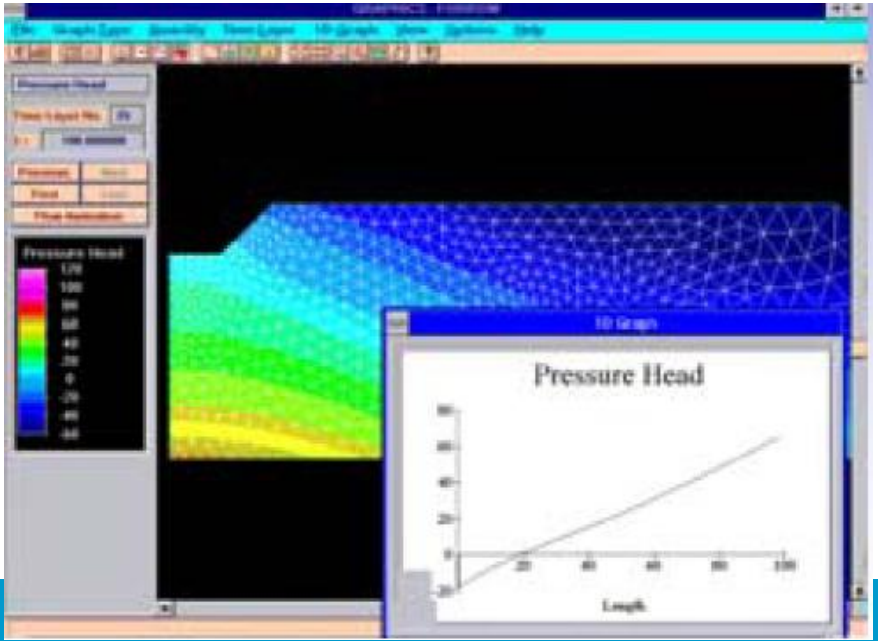
Multi-step outflow: analysis

Estimate the Van Genuchten parameters $\alpha, n, \theta_s, \theta_i K_{sat}, \lambda$

by solving Richards equation (e.g. Hydrus) for the same problem and minimising differences between observed and simulated outflow.

Minimization by:

- Levenberg-Marquardt
- Downhill Simplex
- Genetic algorithm



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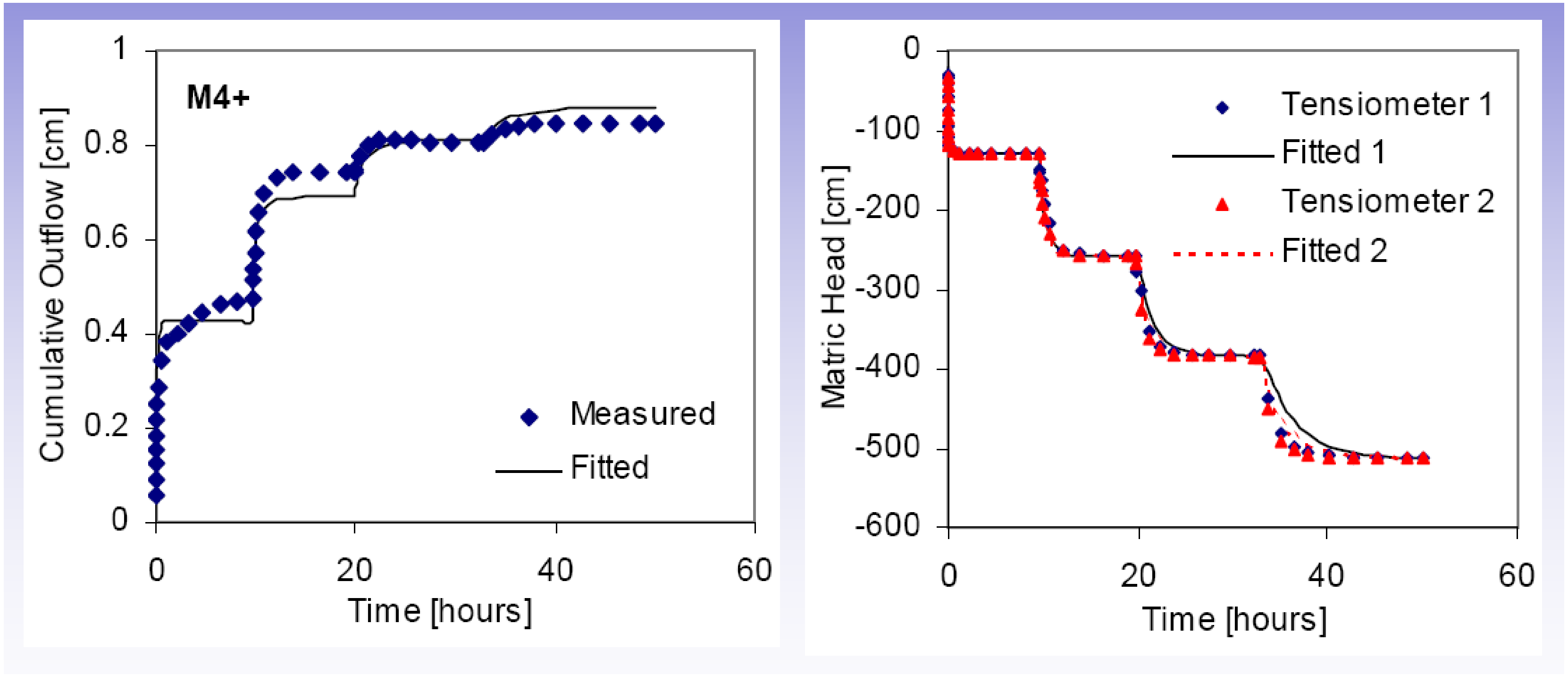
Determining soil physical parameters: inverse method

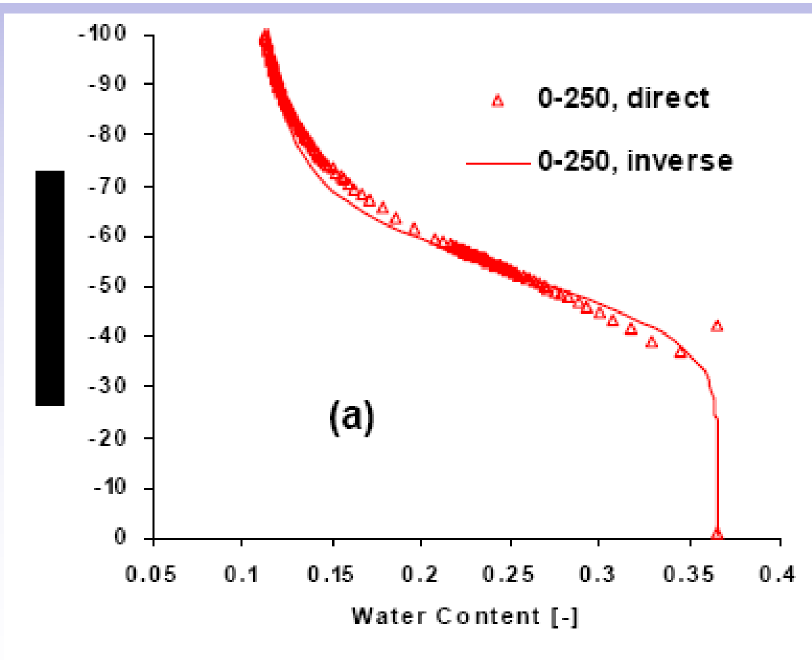
Multi-step outflow: analysis

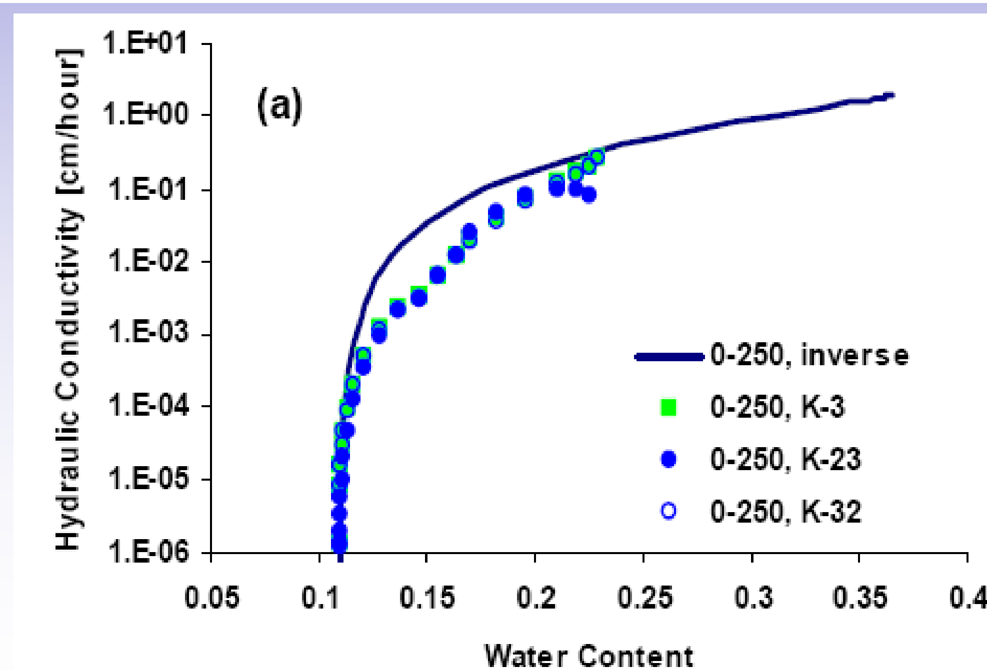


Courtesy of Jan Hopmans (Davis, CA)

Determining soil physical parameters: inverse method

Multi-step outflow: analysis





Courtesy of Jan Hopmans (Davis, CA)

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Determining soil physical parameters: inverse method

Multi-step outflow: analysis

10 samples at the time at UC Davis, Ca, USA

Courtesy of Jan Hopmans (Davis, CA)

Pedotransfer functions

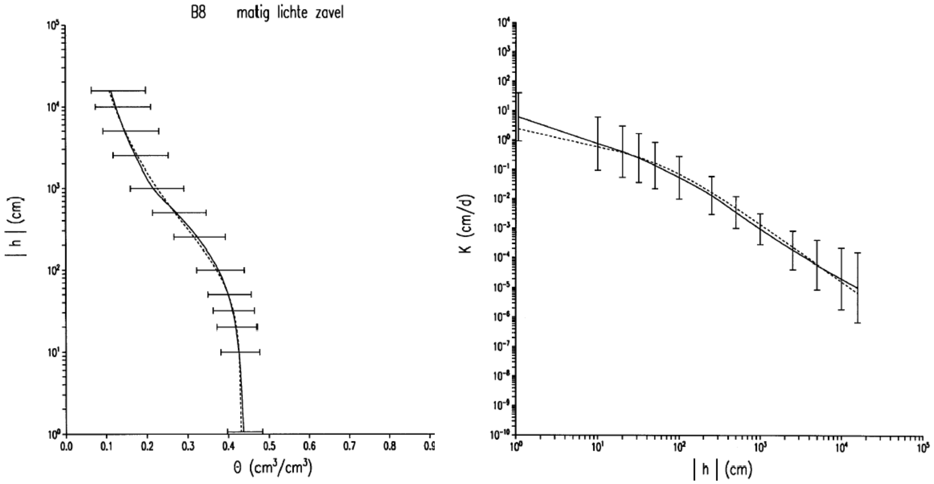
The idea: establish relations between soil physical parameters and mappable soil features (OM, clay content, etc.) and use these to predict parameters at unvisited locations.

Three main types:

- Classes
- Multi-linear regression methods
- Neural networks

Pedotransfer functions

Classes (Example: Staring Series; Alterra)



Bouwsteen		Leem (%)	Lutum (%)	Organische stof (%)	M50 (µm)	Aantal (-)
Zand						
B1	leemarm, zeer fijn tot matig fijn zand	0- 10		0- 15	105- 210	32
B2	zwak lemig, zeer fijn tot matig fijn zand	10- 18		0- 15	105- 210	27
B3	sterk lemig, zeer fijn tot matig fijn zand	18- 33		0- 15	105- 210	14
B4	zeer sterk lemig, zeer fijn tot matig fijn zand	33- 50		0- 15	105- 210	9
B5	grof zand			0- 15	210-2000	26
B6	keileem	0- 50		0- 15	50-2000	8
Zavel						
B7	zeer lichte zavel		8- 12	0- 15		6
B8	matig lichte zavel		12- 18	0- 15		43
B9	zware zavel		18- 25	0- 15		29
Klei						
B10	lichte klei		25- 35	0- 15		12
B11	matig zware klei		35- 50	0- 15		13
B12	zeer zware klei		50- 100	0- 15		9
Leem						
B13	zandige leem	50- 85		0- 15		10
B14	siltige leem	85- 100		0- 15		67
Moerig						
B15	venig zand		0- 8	15- 25		15
B16	zandig veen en veen		0- 8	25- 100		20
B17	venige klei		8- 100	16- 45		25
B18	kleiig veen		8- 100	25- 70		20

	θr (cm3/cm3)	θs (cm3/cm3)	Ks (cm/d)	α (1/cm)	l (-)	n (-)
Zand						
B1	0,02	0,43	23,41	0,0234	0,000	1,801
B2	0,02	0,42	12,52	0,0276	-1,060	1,491
B3	0,02	0,46	15,42	0,0144	-0,215	1,534
B4	0,02	0,46	29,22	0,0156	0,000	1,406
B5	0,01	0,36	52,91	0,0452	-0,359	1,933
B6	0,01	0,38	100,69	0,0222	-1,747	1,238
Zavel						
B7	0,00	0,40	14,07	0,0194	-0,802	1,250
B8	0,01	0,43	2,36	0,0099	-2,244	1,288
B9	0,00	0,43	1,54	0,0065	-2,161	1,325
Klei						
B10	0,01	0,43	0,70	0,0064	-3,884	1,210
B11	0,01	0,59	4,53	0,0195	-5,901	1,109
B12	0,01	0,54	5,37	0,0239	-5,681	1,094
Leem						
B13	0,01	0,42	12,98	0,0084	-1,497	1,441
B14	0,01	0,42	0,80	0,0051	0,000	1,305
Moerig						
B15	0,01	0,53	81,28	0,0242	-1,476	1,280
B16	0,01	0,80	6,79	0,0176	-2,259	1,293
B17	0,00	0,72	4,46	0,0180	-0,350	1,140
B18	0,00	0,77	6,67	0,0197	-1,845	1,154

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Pedotransfer functions

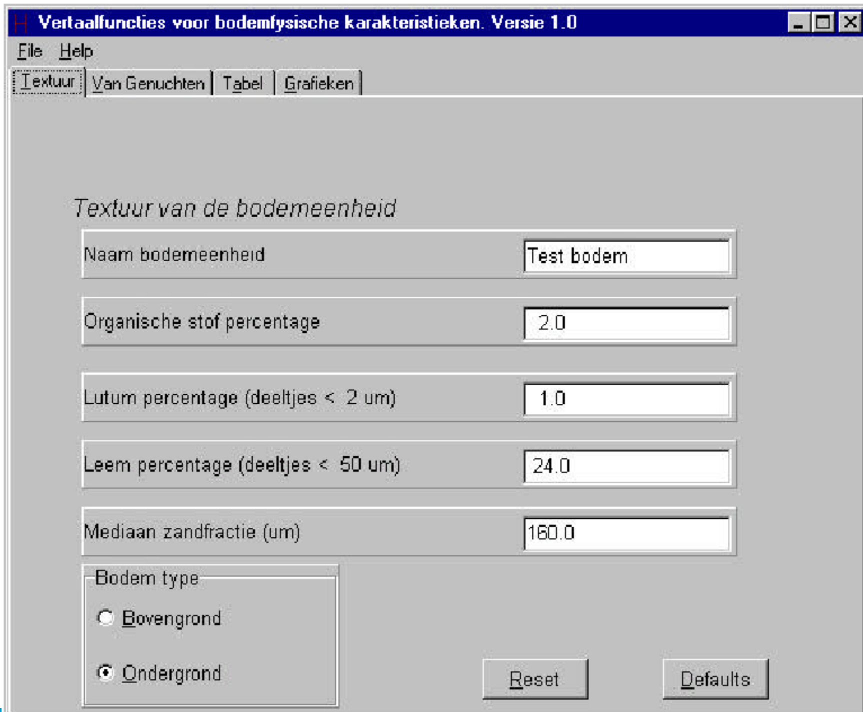
Multi-linear regression

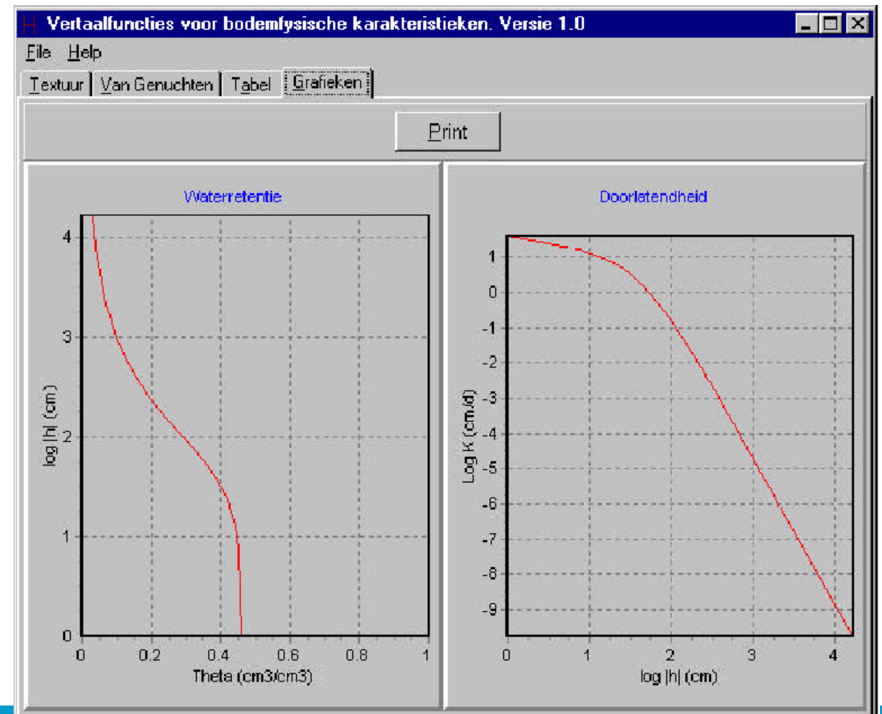
(Staring series: Alterra)

$$\theta_s = 0{,}6311 + 0{,}003383 * LUTUM - 0{,}09699 * DICHTHEID^2 - 0{,}00204 * DICHTHEID * LUTUM \quad (R^2 = 95\ \%)$$

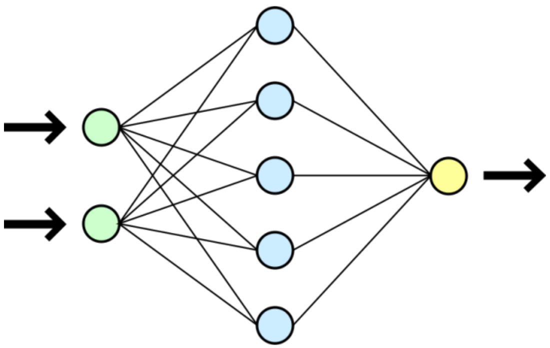
$$K_s^* = -42{,}6 + 8{,}71 * HUMUS + 61{,}9 * DICHTHEID - 20{,}79 * DICHTHEID^2 - 0{,}2107 * HUMUS^2 - 0{,}01622 * LUTUM * HUMUS - 5{,}382 * DICHTHEID * HUMUS \quad (R^2 = 31\ \%)$$

$$\alpha^* = -19{,}13 + 0{,}812 * HUMUS + 23{,}4 * DICHTHEID - 8{,}16 * DICHTHEID^2 + 0{,}423 * HUMUS^{-1} + 2{,}388 * LN(HUMUS) - 1{,}338 * DICHTHEID * HUMUS \quad (R^2 = 51\ \%)$$





Pedotransfer functions



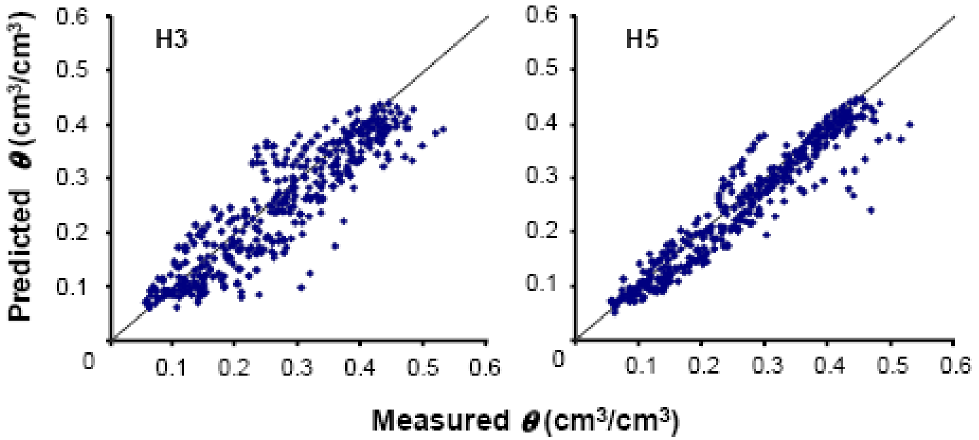
Neural networks

(Rosetta: US Salinity Riverside)

Five levels of input:

- Soil textural class → Lookup Table
- Sand, silt and clay percentages
- Sand, silt and clay percentages and bulk density
- Sand, silt and clay percentages, bulk density and a water retention point at 330 cm (33 kPa).
- Sand, silt and clay percentages, bulk density and water retention points at 330 and 15000 cm (33 and 1500 kPa)

} NN



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CEI 4440 Soil Hydrology

Set up of lecture today

1. Soil physics; Measuring soil moisture
2. Hydrostatics; Measuring soil tension
3. Soil hydraulics; pF curves
4. Soil infiltration and field tests
5. Soil hydraulics; Permeability