Soil Physical Properties Analysis

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ICARDA
Science for Better Livelihoods in Dry Areas

Soil Physics

Soil physics deals with the dynamics of physical soil components and their phases as solid, liquids, and gases. Lal and Shukla (2004)
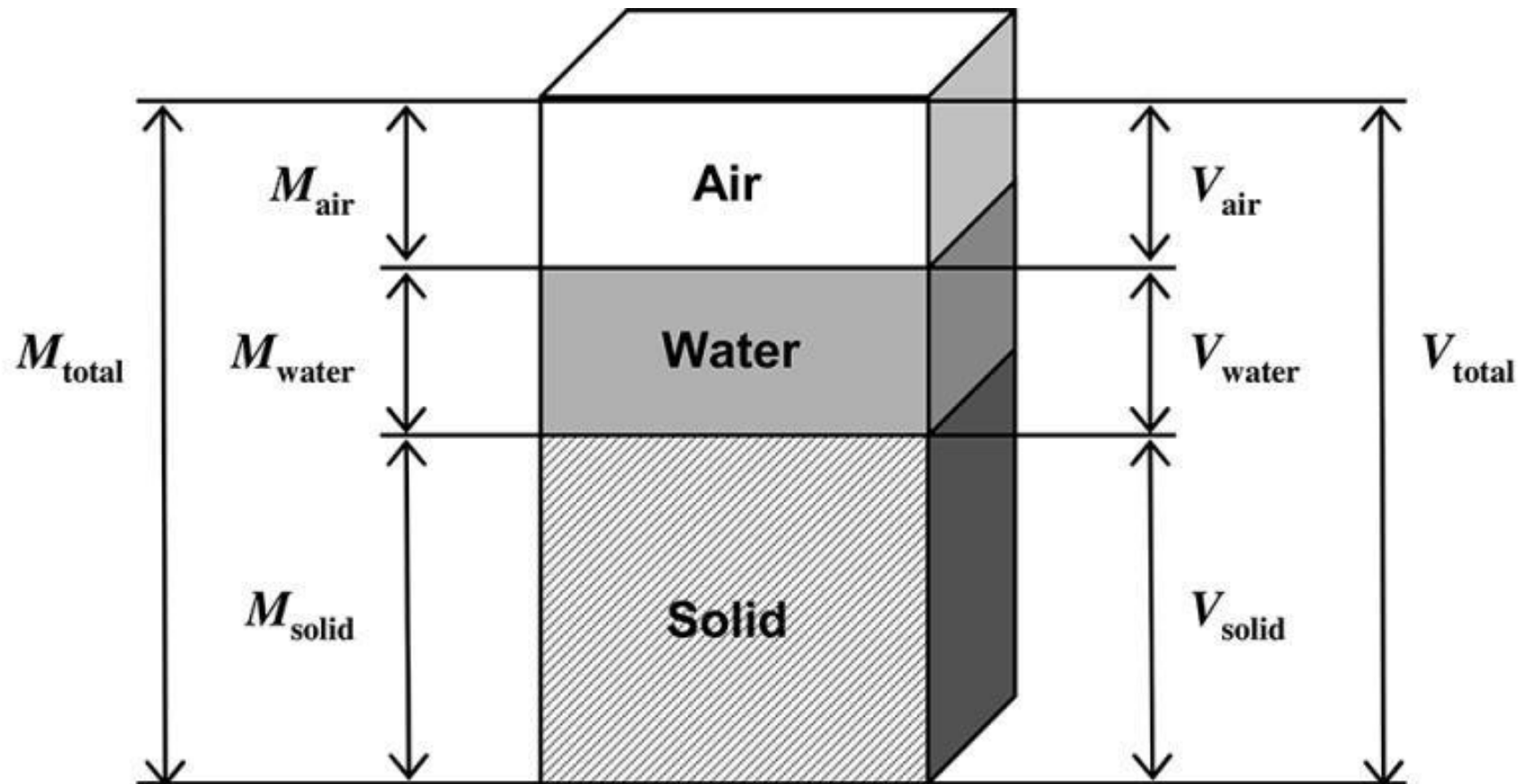
Soil Physical Properties Analysis
Focus on Soil and Water Relationship

Solid Phase

Parent Material
Compound
Soil Structure
Soil Texture

Liquid Phase

Water Quantity
Water-Soil Interactions
Porous Media Flow

Soil Physical Properties Analysis
Focus on Soil and Water Relationship

Lab

Field

Soil Physical Properties – Common Lab Analysis

Solid Phase
- Parent Material
  - Spectrum
  - Gravimetric
- Compound
  - Gravimetric
  - Mechanical/geotechnical tests
- Soil Structure
  - Aggregate size distribution
  - Aggregate stability
- Soil Texture
  - Particles

Soil Physical Properties – Common Lab Analysis

Liquid Phase
- Water Quantity
  - Gravimetric
  - Volumetric
- Water-Soil Interactions
  - Gravimetric
  - Inducing a gradient
- Porous Media Flow
  - Gravimetric
  - Inducing a gradient

Soil Physical Properties – Common Lab Analysis

Solid Phase

Soil Physical Properties – Common Lab Analysis – Solid Phase

Parent material

X-Ray fluorescence

- Rock powder
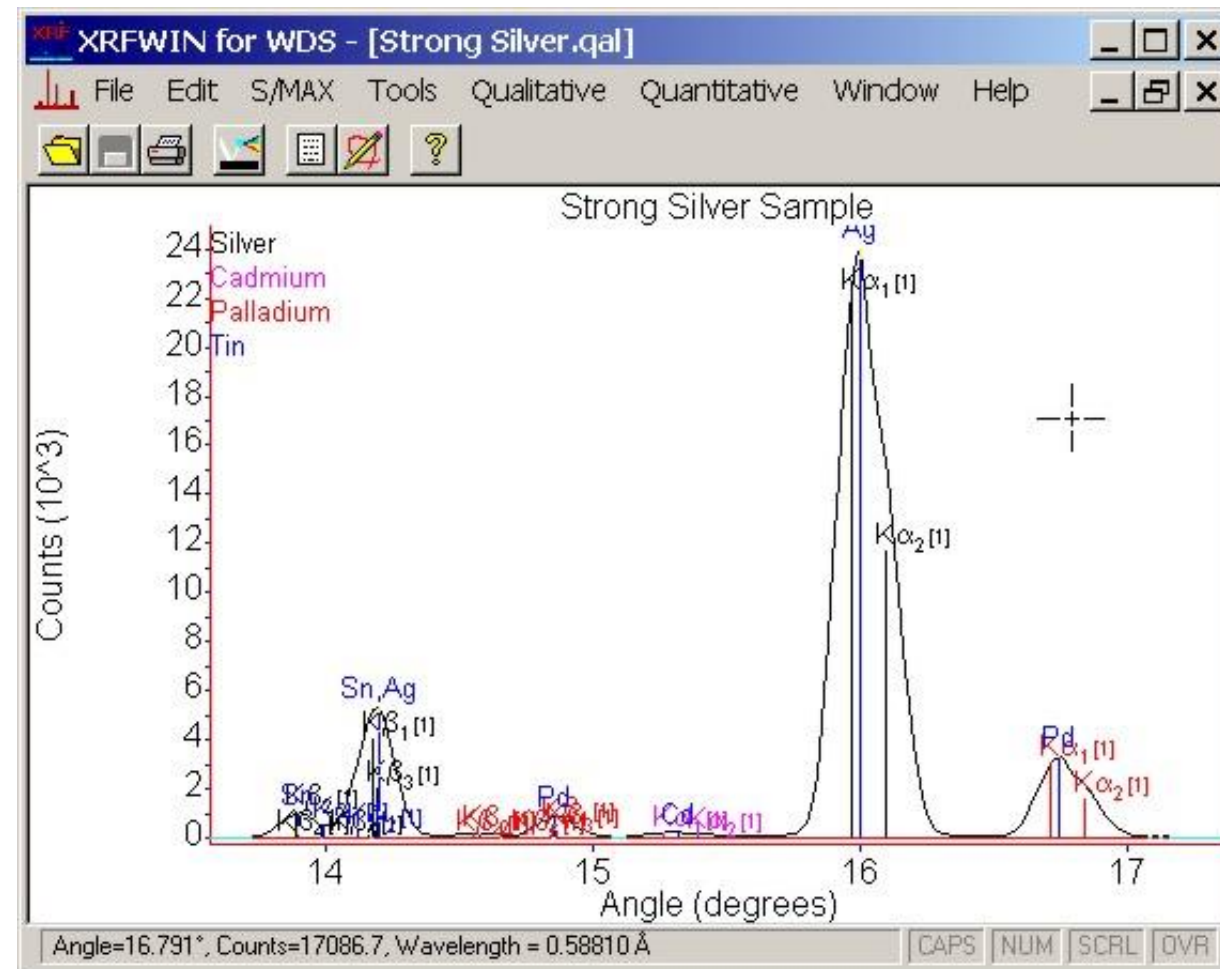- Wavelength dispersive spectrometer
- Typical peak of minerals

Soil Physical Properties – Common Lab Analysis – Solid Phase

Parent material

X-Ray fluorescence

Soil Physical Properties – Common Lab Analysis – Solid Phase

Parent material

Particle density (g cm^{-3})

$$\frac{m_{soild}}{V_{soild}}$$

Pycnometer

Soil Physical Properties – Common Lab Analysis – Solid Phase

Parent material

Pycnometer test

- Defined volume glassware
- Adding dry soil (mass known)
- Addind water – complete glassware fill
- Measuring mass (water + soil)
- Calculating water volume (temperature)
- Calculating soil volume

Soil Physical Properties – Common Lab Analysis – Solid Phase
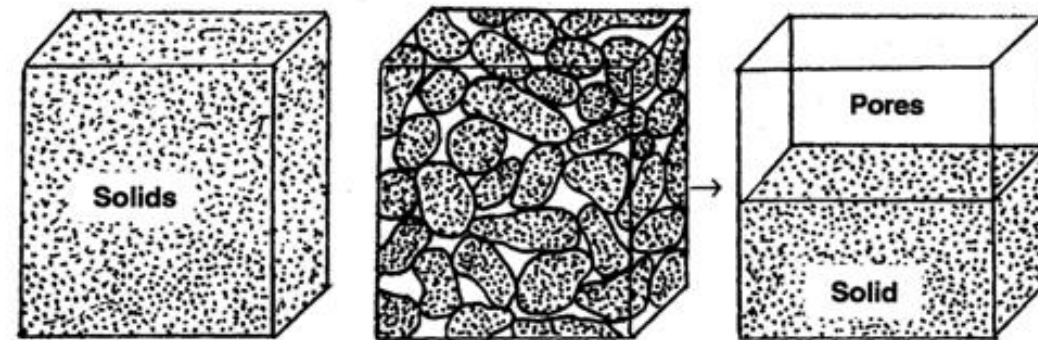
Parent material

Pycnometer test

DENSITY CHART

ALL DENSITIES ARE IN GRAMS PER CUBIC CENTIMETER

DENSITY	MINERAL
2 . 16	halite
2 . 32	gypsum
2 . 65	quartz
2 . 72	calcite
3 . 18	fluorite
3 . 4 to 3 . 6	topaz
4 . 1 to 4 . 3	chalcopyrite
4 . 58 to 4 . 65	pyrrhotite
5 . 02	pyrite

Soil Physical Properties – Common Lab Analysis – Solid Phase

Compound

Bulk density (g cm⁻³)

$$\frac{m_{soild}}{V_{sample}}$$

Particle Density

100% solid
Weight = 2.66 g
Volume = 1 cm³

Bulk Density

50% solid, 50% pore space
Weight = 1.33 g
Volume = 1 cm³

Soil Physical Properties – Common Lab Analysis – Solid Phase
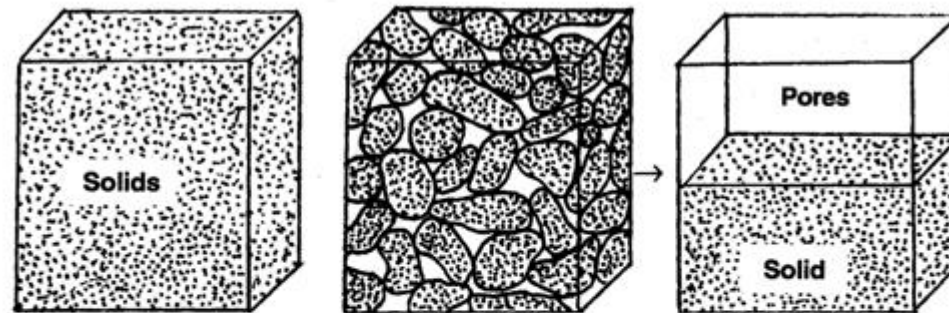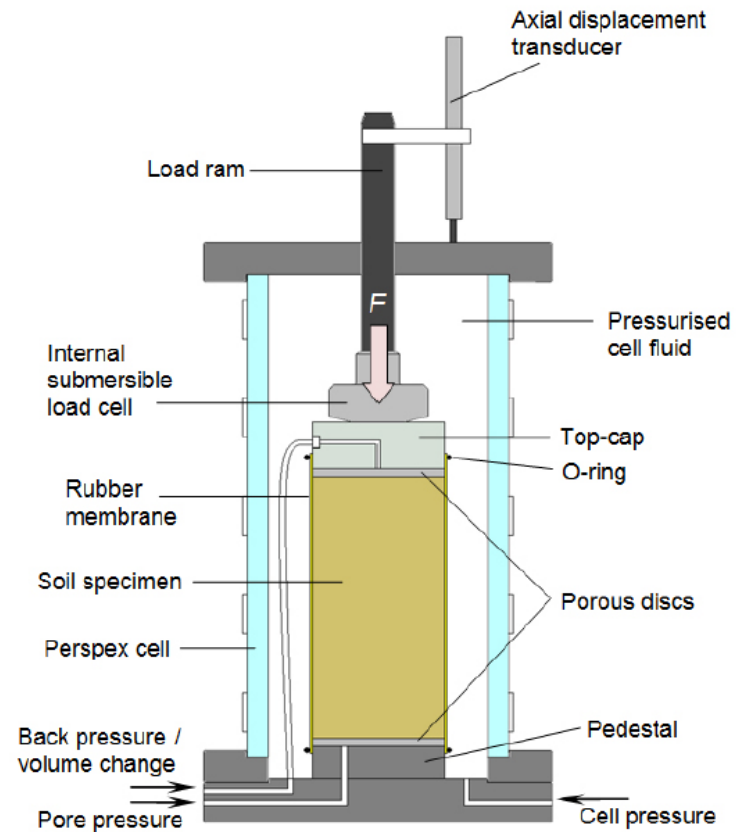
Compound
Bulk density (g cm⁻³)

Soil Physical Properties – Common Lab Analysis – Solid Phase

Compound

Porosity (%)

$$\frac{V_{Pores}}{V_{Sample}}$$

$$\phi = \left(1 - \frac{\rho_b}{\rho_p}\right)100\%$$

Particle Density

100% solid
Weight = 2.66 g
Volume = 1 cm³

Bulk Density

50% solid, 50% pore space
Weight = 1.33 g
Volume = 1 cm³

Soil Physical Properties – Common Lab Analysis – Solid Phase

Compound
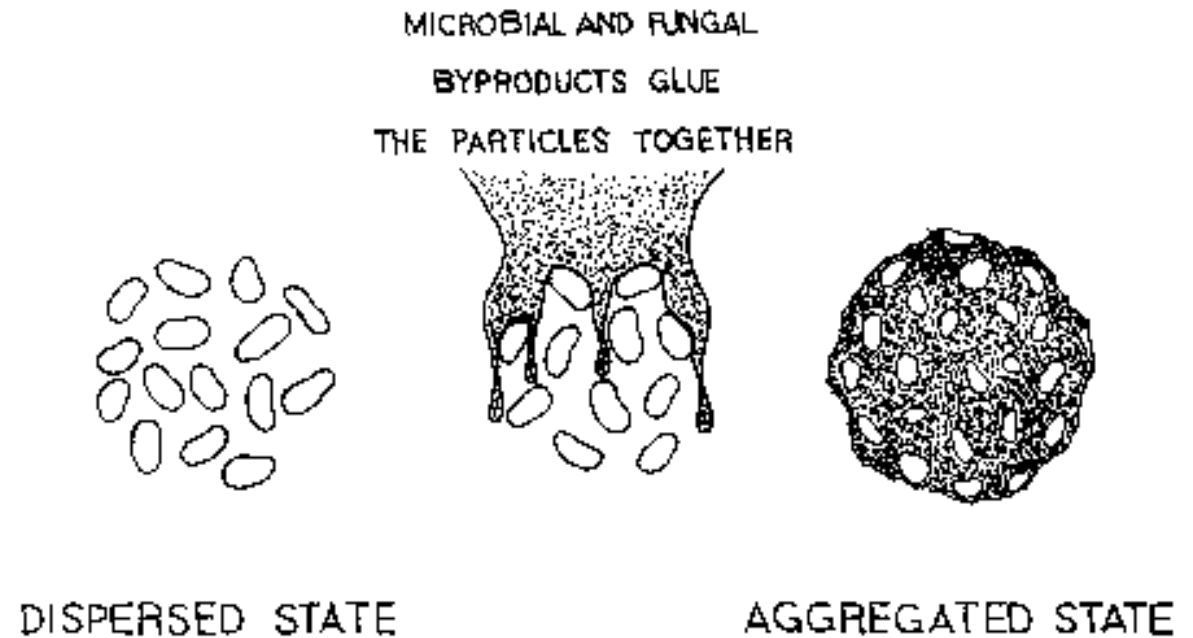*Elasticity and shear stress (N mm^2)*

Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil structure

Aggregate stability (%)

$$\frac{m_{stableAgg}}{m_{totSample}}$$

Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil structure
Aggregate stability (%)

$$\frac{m_{stableAgg}}{m_{totSample}}$$

MICROBIAL AND FUNGAL
BYPRODUCTS GLUE
THE PARTICLES TOGETHER

DISPERSED STATE

AGGREGATED STATE

Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil structure

Aggregate stability (%)

$$\frac{m_{stableAgg}}{m_{totSample}}$$

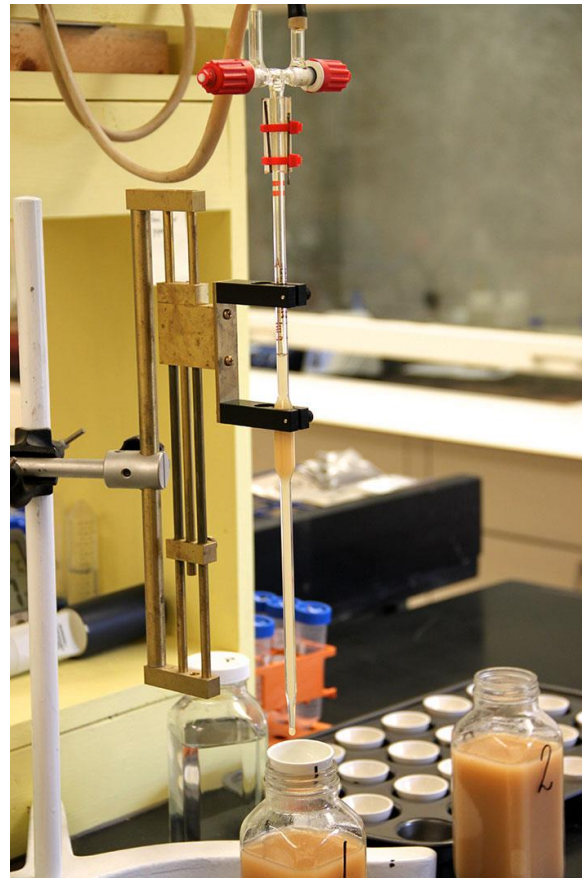$$AS\,(\%) = \frac{m_{A,S} - m_{S}}{m_{T} - m_{S}} * 100$$

Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil texture

Soil Physical Properties – Common Lab Analysis – Solid Phase
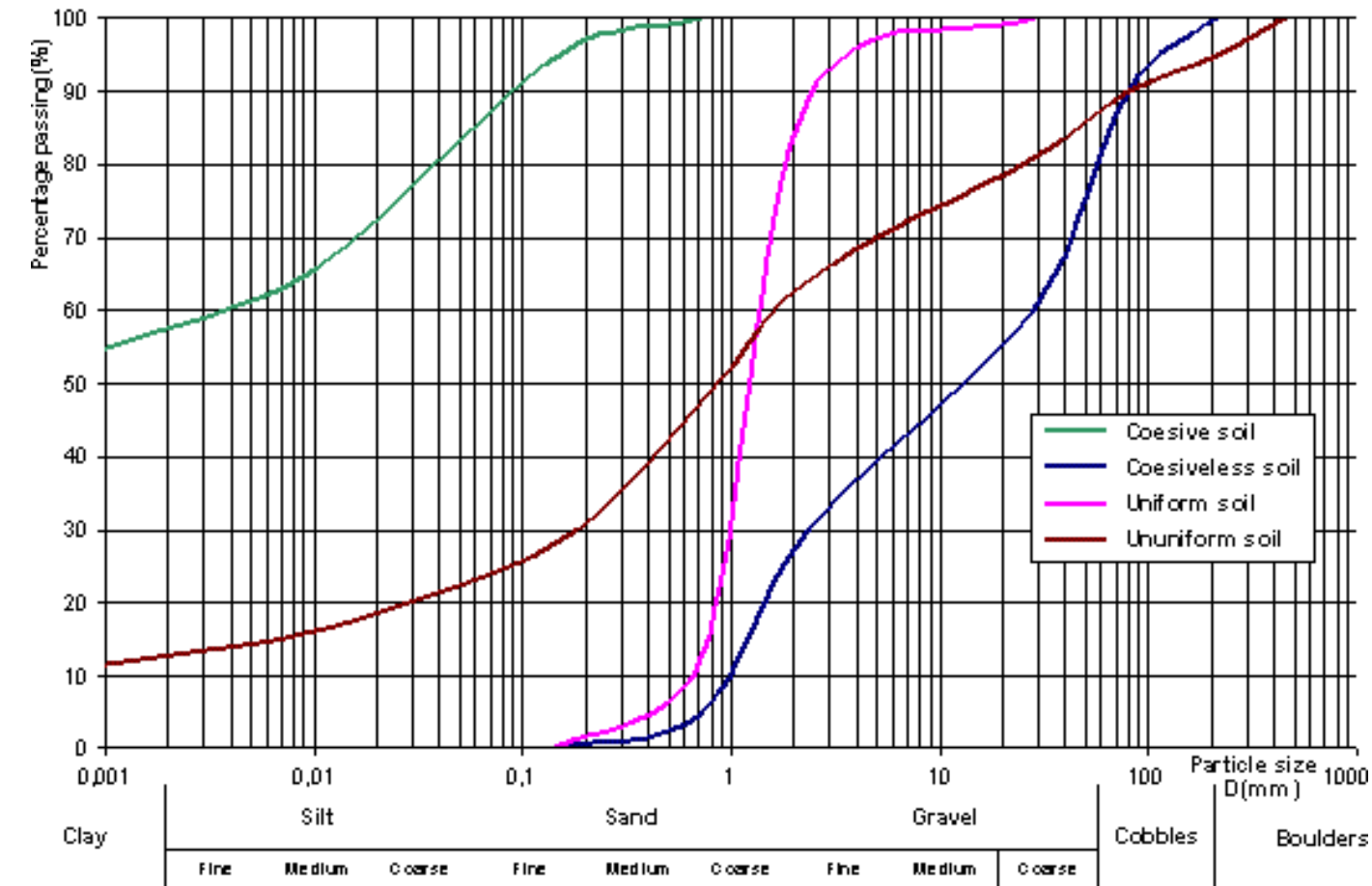
Soil texture

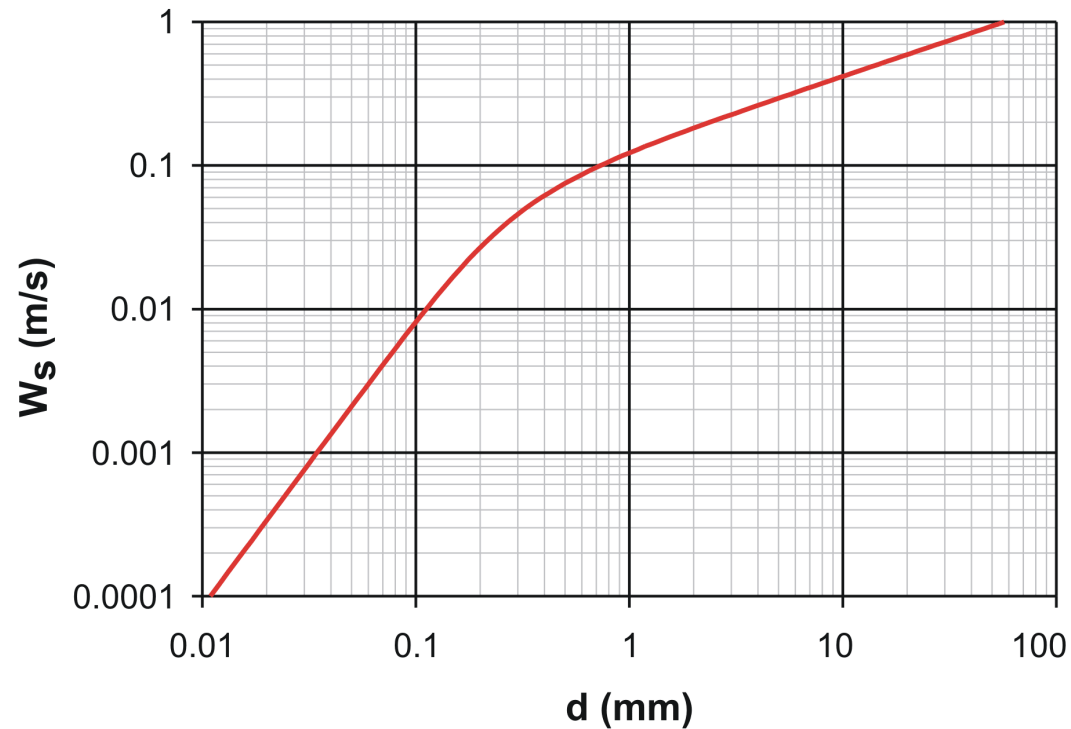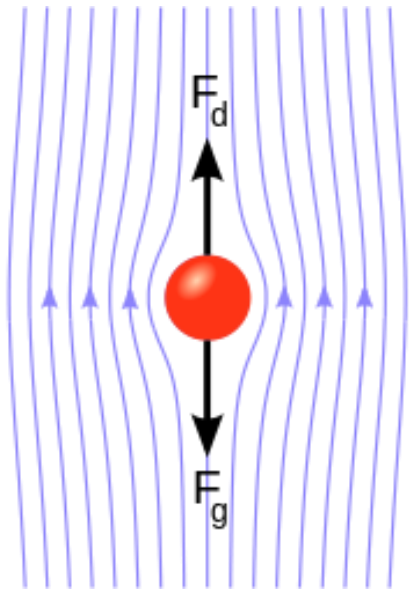# Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil texture

Soil Physical Properties – Common Lab Analysis – Solid Phase

Soil texture

$$V = \frac{2}{9}\frac{(\rho_P - \rho_f)}{\mu} g R^2$$

Soil Physical Properties – Common Lab Analysis

Liquid Phase

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity
Soil moisture content

Gravimetric (%)

$$\theta_m = \frac{M_{sample} - M_s}{M_s}$$

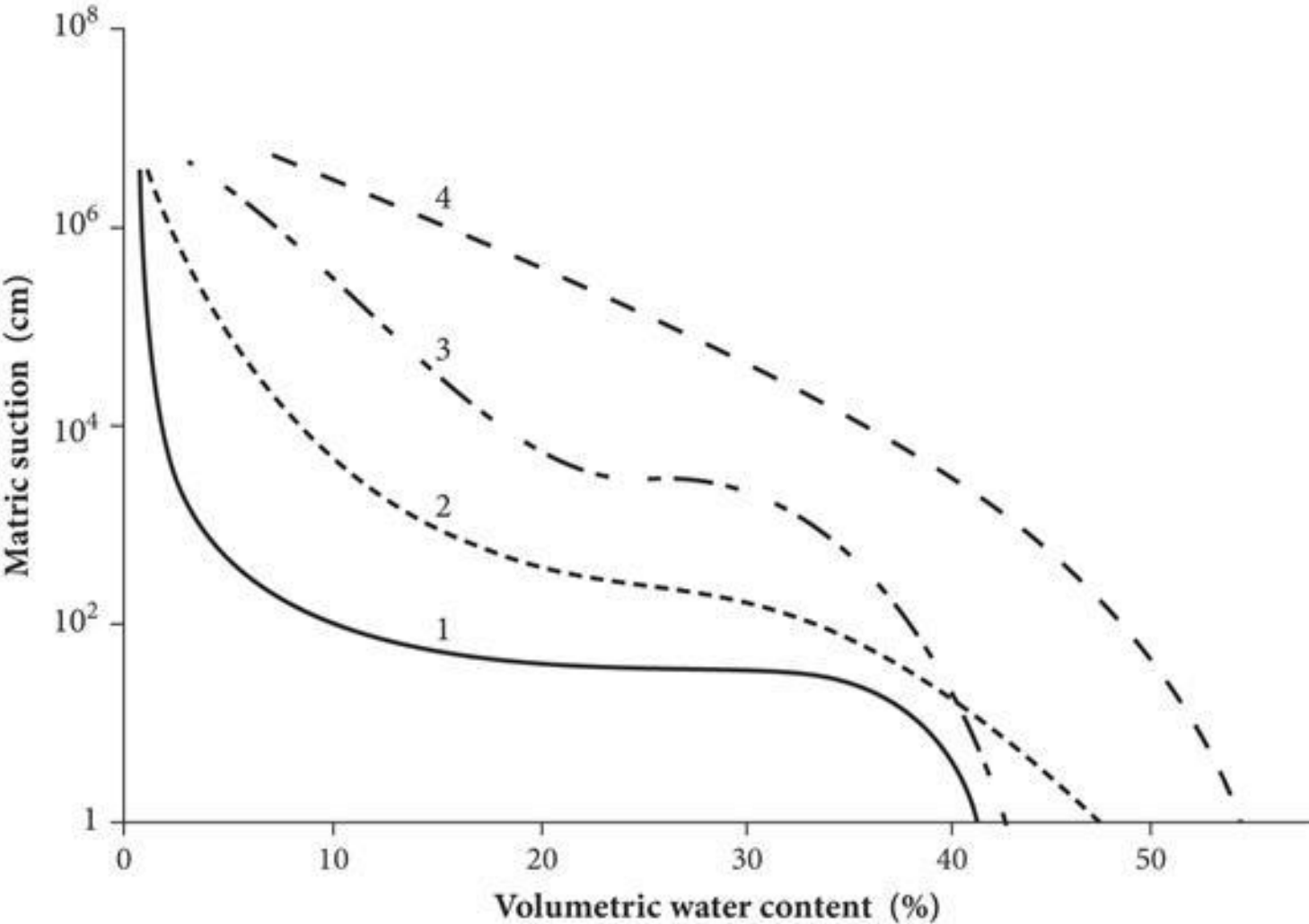*Volumetric (%) -> mm per soil ‚profile'*
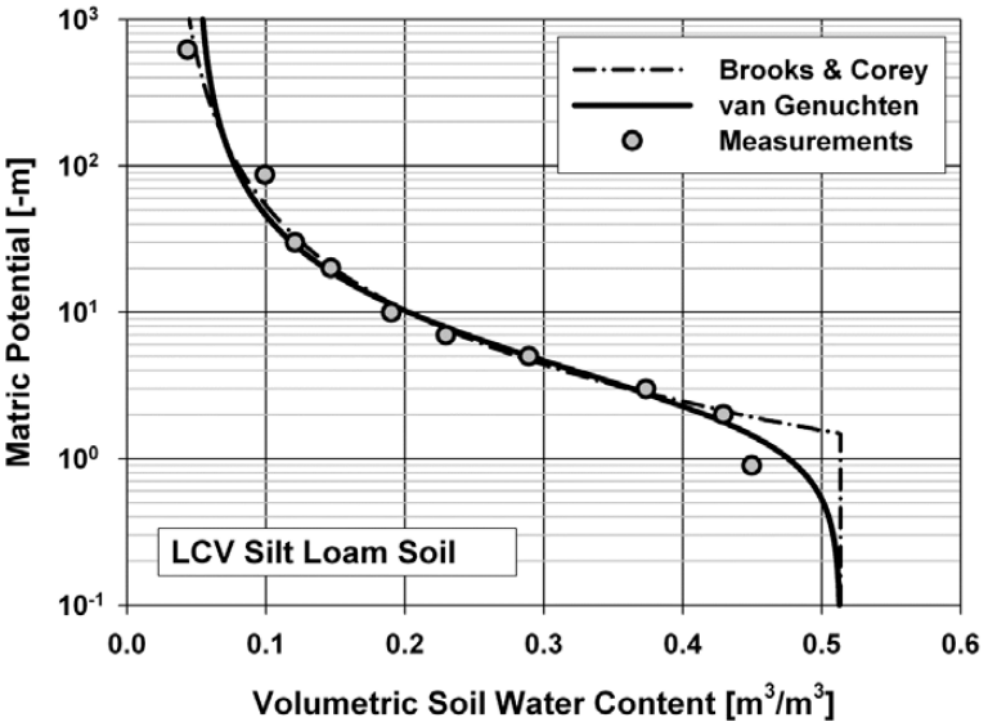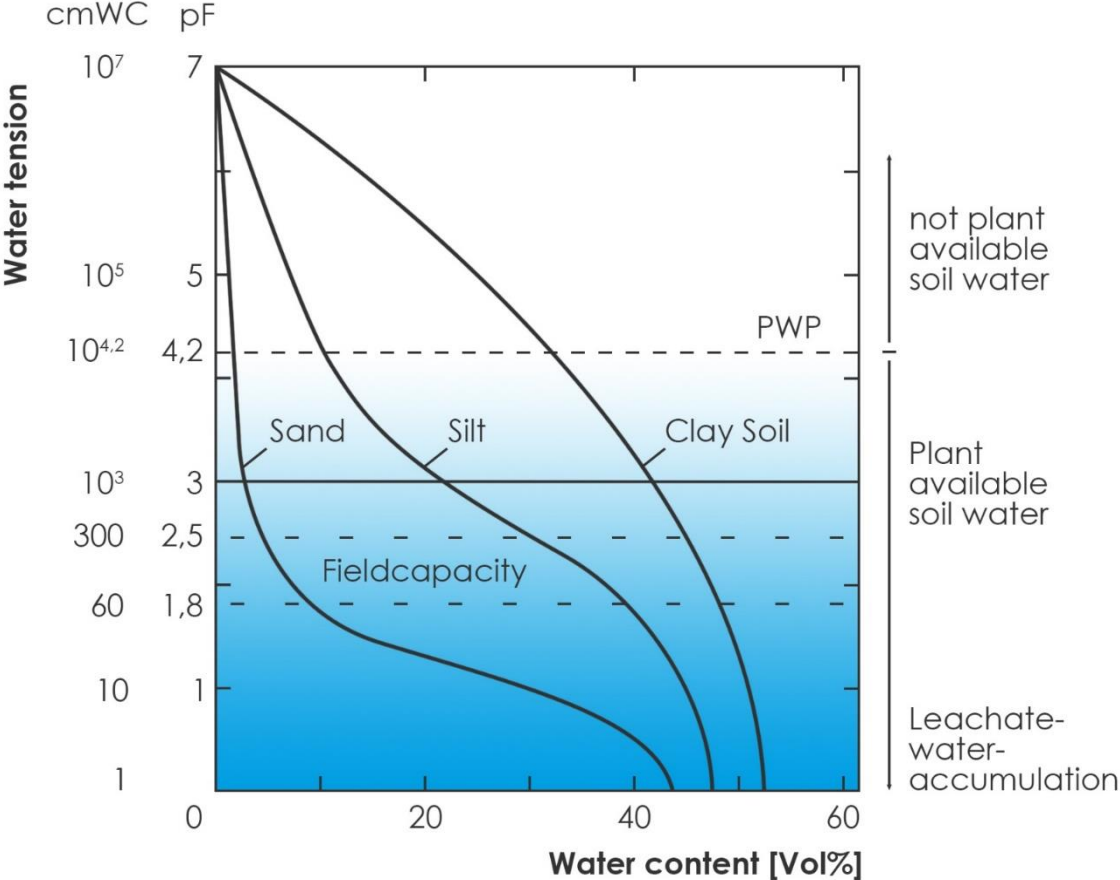
$$\theta_V = \frac{V_w}{V_{sample}}$$

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water-Soil Interactions

Retention curve

Soil Physical Properties – Common Lab Analysis – Liquid Phase
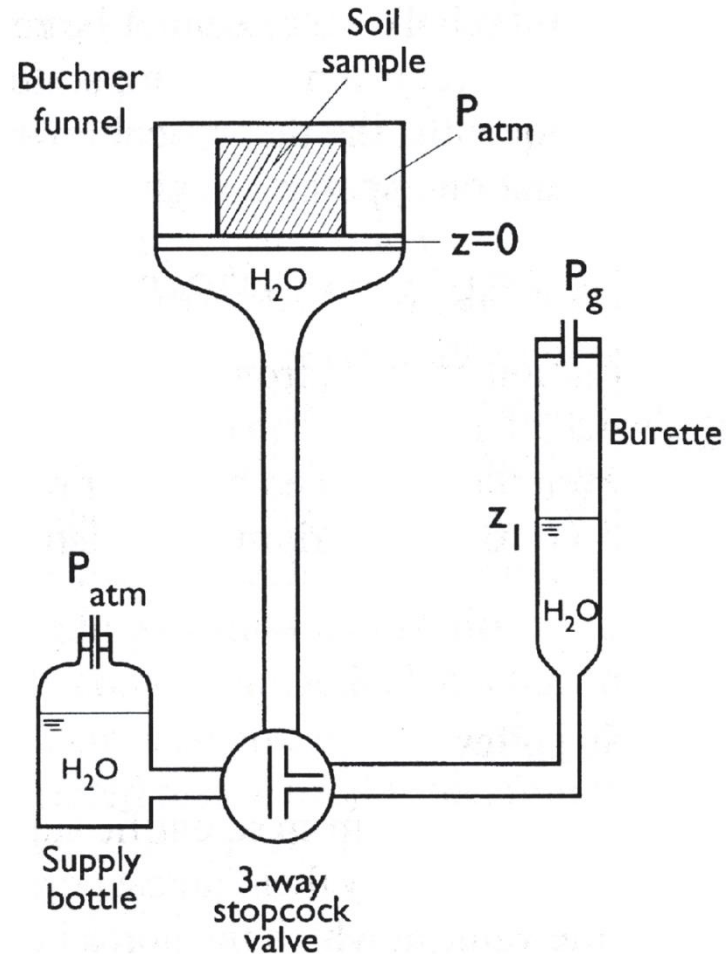
Water-Soil Interactions

Retention curve

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water-Soil Interactions
Retention curve

- Capillary meter   <- up to (theoretically 1 bar)
- Pressure chamber   <- larger 1 bar

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water-Soil Interactions
Capillary meter

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water-Soil Interactions
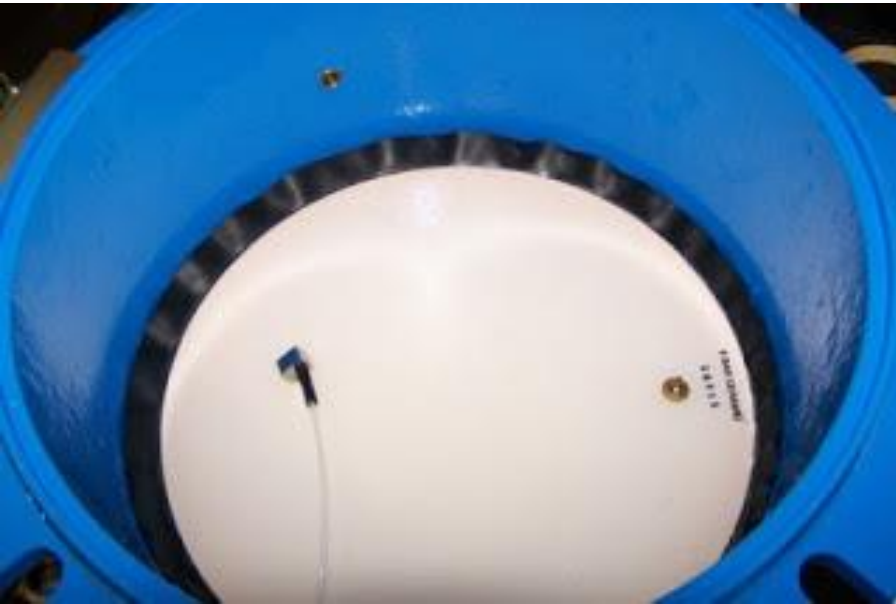*Pressure chamber*

Soil Physical Properties – Common Lab Analysis – Liquid Phase
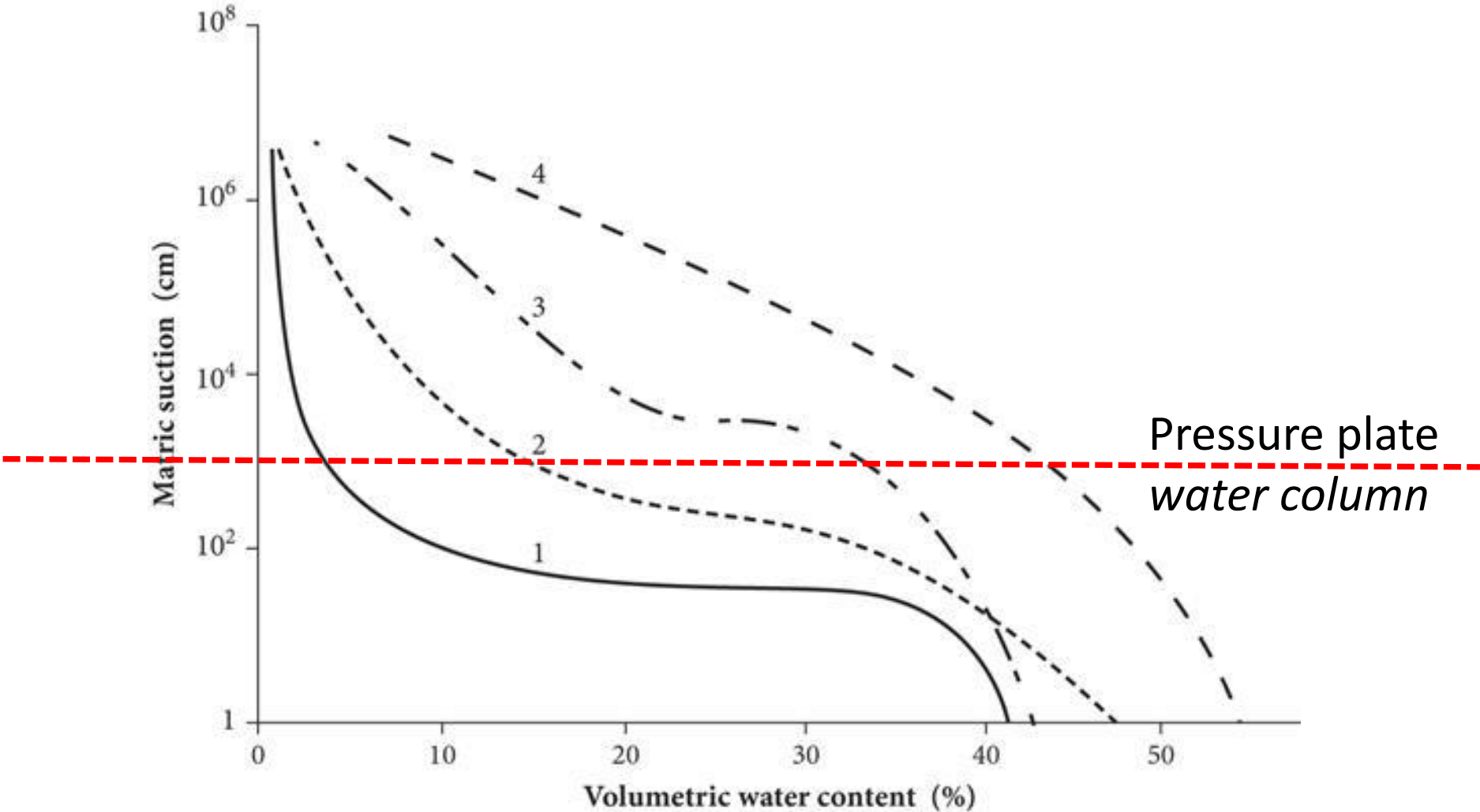
Water-Soil Interactions
Pressure chamber

Soil Physical Properties – Common Lab Analysis – Liquid Phase

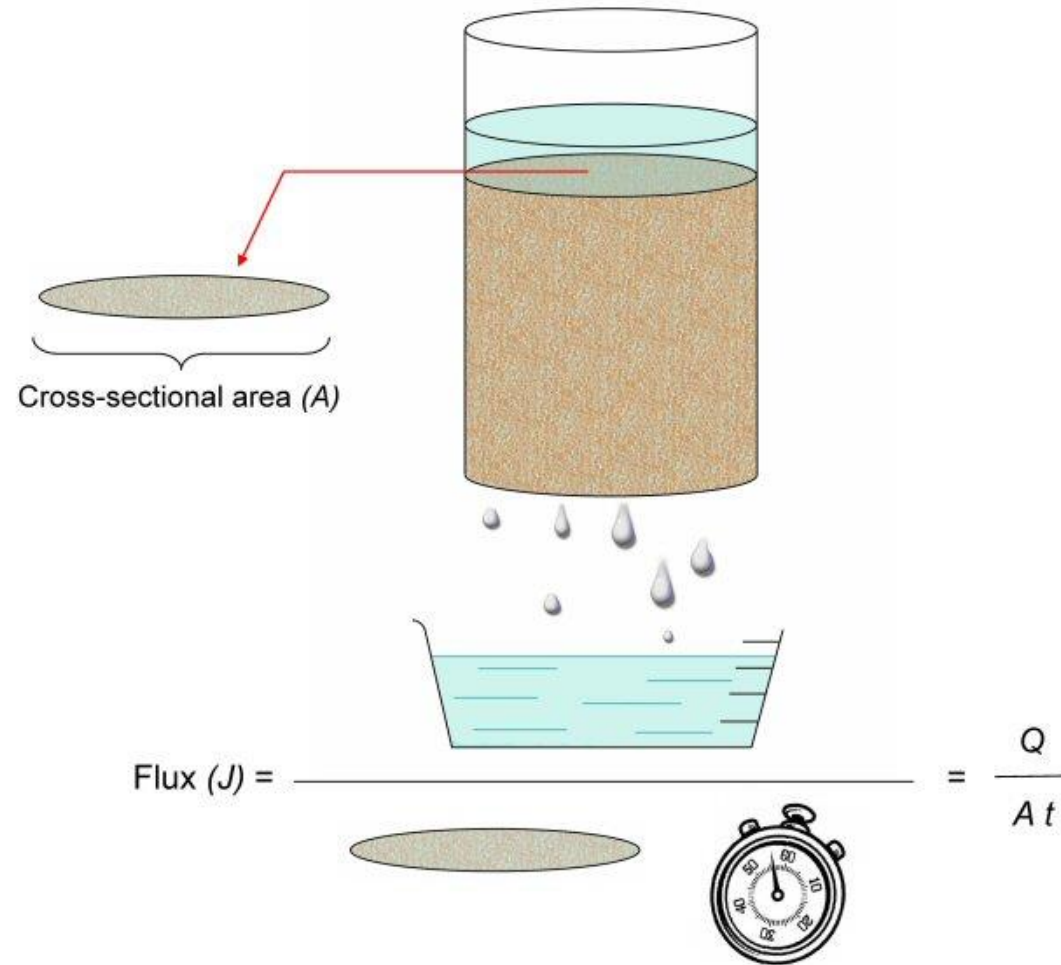**Water-Soil Interactions**

Retention curve

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Porous Media Flow Characteristics
Saturated hydraulic conductivity (m s^{-1})

$$q = K \, \nabla \, H$$

Cross-sectional area (A)

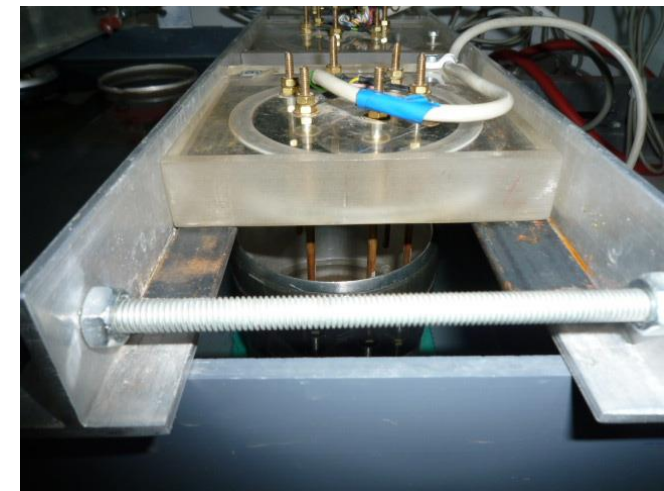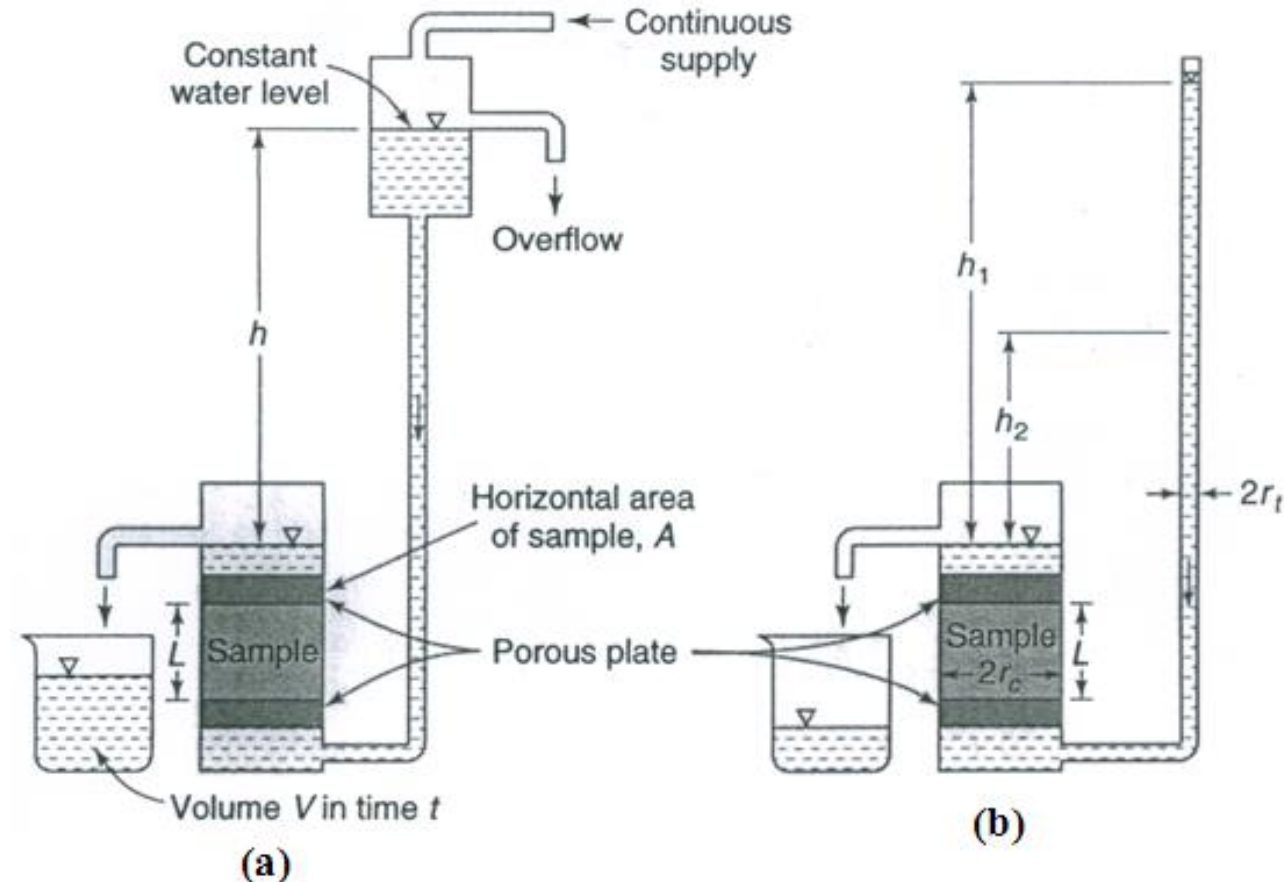Flux (J) = $\dfrac{}{}$ = $\dfrac{Q}{A\,t}$

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Porous Media Flow Characteristics
Saturated hydraulic conductivity (m s^{-1})

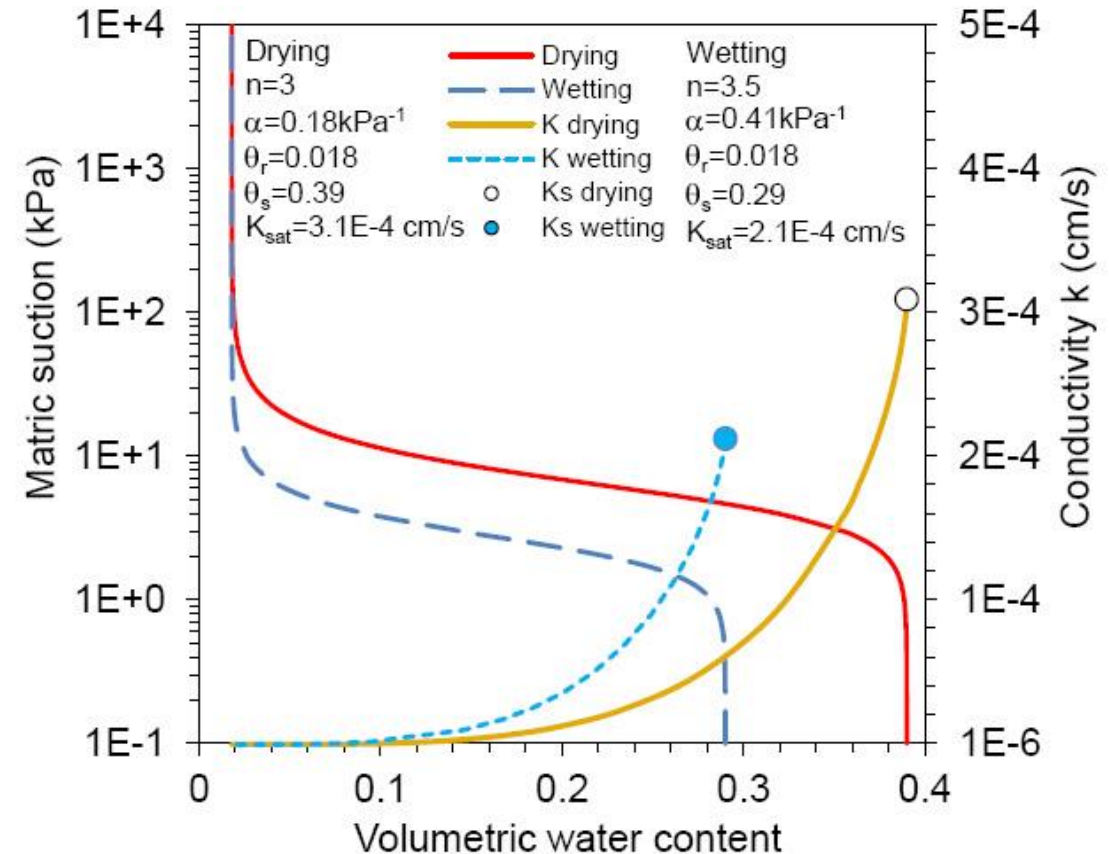$$q = K \, \nabla \, H$$

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Porous Media Flow Characteristics
Unsaturated hydraulic conductivity

Common Field Analysis

Soil Physical Properties – Common Field Analysis

Solid Phase
- Parent Material
    - Field survey
    - Mechanical/chemical tests
- Compound
    - Mechanical tests
    - Volume and mass
- Soil Structure
    - Visual
    - By hand
- Soil Texture
    - By hand

Soil Physical Properties – Common Field Analysis

Liquid Phase
- Water Quantity
    - Gravimetric (direct)
    - Indirect
- Water-Soil Interactions
    - Direct
    - Indirect
- Porous Media Flow Characteristics
    - Direct
    - Indirect

Soil Physical Properties – Common Field Analysis

Solid Phase

Soil Physical Properties – Common Lab Analysis – Soild Phase

Parent Material

Soil and geological maps and field survey

- Available information: soil and geological maps
- Online sources (e.g. FAO soil map)
- Construction sites and boreholes

- Landscape unsteadiness – bank breaks
- Landscape pattern (glacial, alluvial, …)
- Vegetation cover

Soil Physical Properties – Common Lab Analysis – Soild Phase

Parent Material

Soil and geological maps and field survey

VIII/I - North and Central Asia
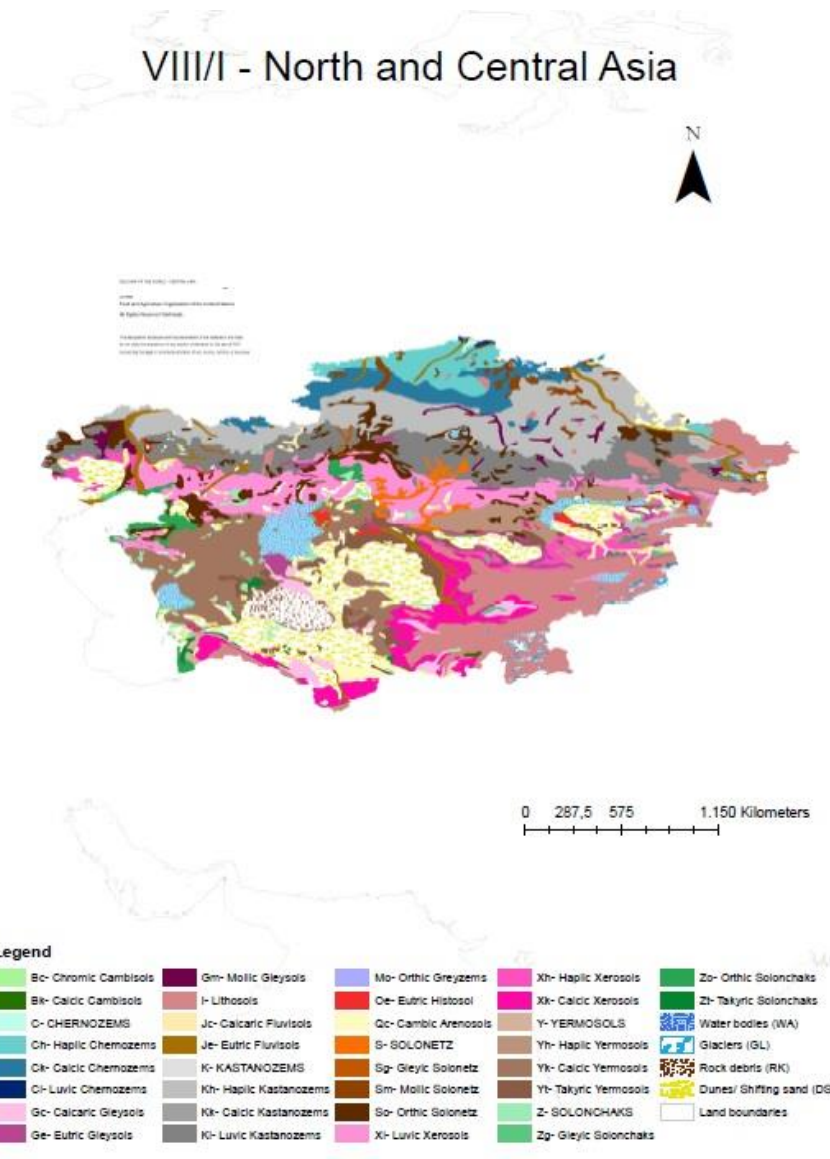
Soil Physical Properties – Common Lab Analysis – Soild Phase

Parent Material

Mechanical tests

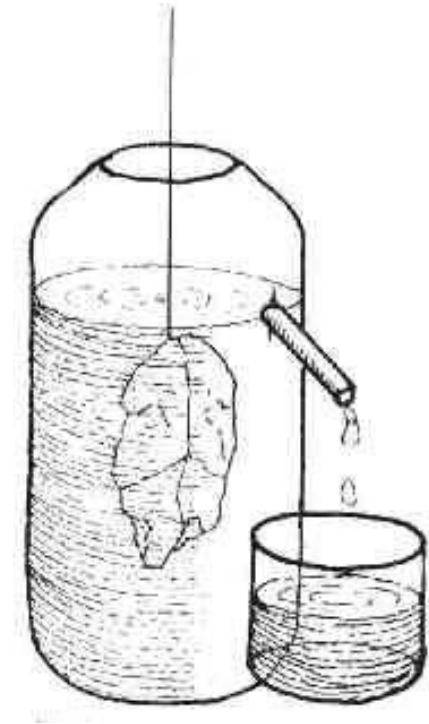# Soil Physical Properties – Common Lab Analysis – Soild Phase

Parent Material
Chemical tests

Soil Physical Properties – Common Lab Analysis – Soild Phase

Parent Material
Rock density

Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound mechanical tests
Shear stress and pressure

Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound mechanical tests

Shear stress and pressure

Torvane Shear Test

Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound mechanical tests
Shear stress and pressure

Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound
Mechanical tests
Shear stress and pressure

| Material	Unit weight (kN/m^3)	Cohesion (kN/ m^2)	Frictional angle (°)
Silty sand, many fines (SM-ML)	20.00	0.00	34
Silty to clayey sand (SM-SC)	21.00	5.00	31
Clayey sand, many fines (SC-CL)	20.50	5.00	28
Clayey sand, with high plastic fines (SC-CH)	18.50	10.00	27
Silt (ML)	19.00	0.00	33
Silt to clayey soil (CL-ML)	21.00	30.00	15
Clayey silt (CL)	20.00	20.00	27
Clay (CH)	17.50	25.00	22

Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound

Volume and mass

Cohesive soil
- Clod of soil
- Cover with Saran (thin plastic surface)
- Weight the clod
- Volume through water dipping
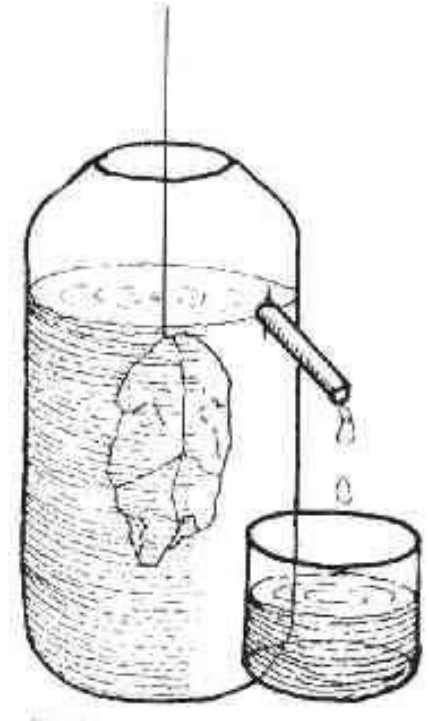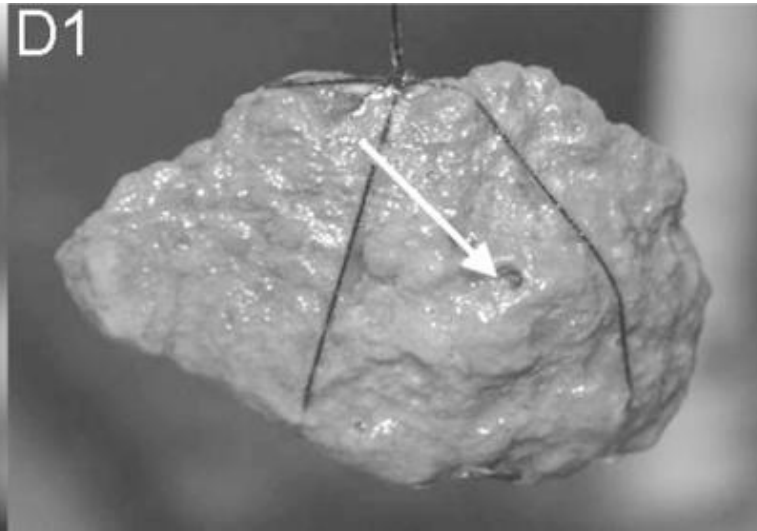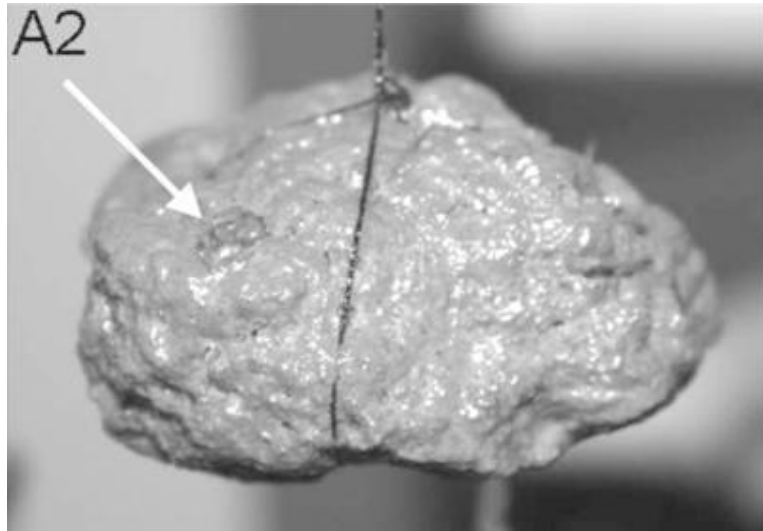
Soil Physical Properties – Common Lab Analysis – Soild Phase

Compound
Volume and mass

<u>Non-cohesive soil</u>
- Level soil surface and place a frame
- Excavate certain (undefined) volume of soil within the frame
- Weigh the excavated soil
- Cover the excavated ditch with a plastic foil
- Fill the plastic soil to the frame (measure the water volume)

Soil Physical Properties – Common Lab Analysis – Soild Phase
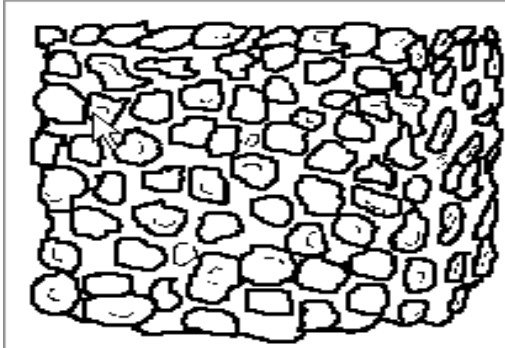
Soil structure *Visual / by hand*

Soil Physical Properties – Common Lab Analysis – Soild Phase

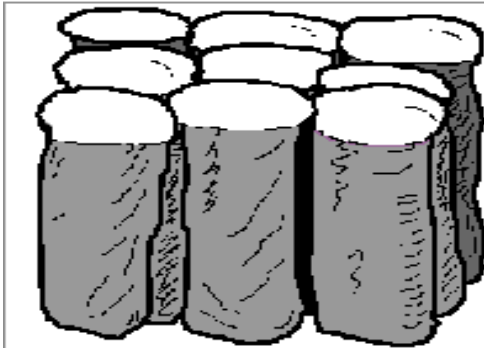## Soil structure
Visual / by hand

Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.
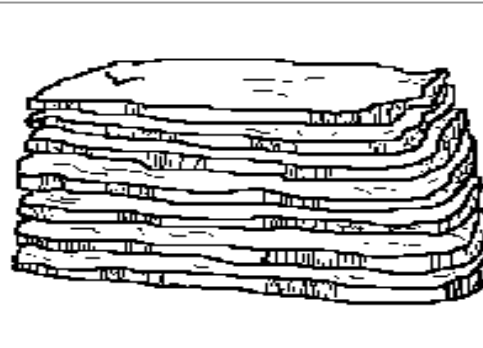
Blocky: Irregular blocks that are usually 1.5 - 5.0 cm in diameter.

Prismatic: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.

Columnar: Vertical columns of soil that have a salt "cap" at the top. Found in soils of arid climates.

Platy: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.

Single Grained: Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.
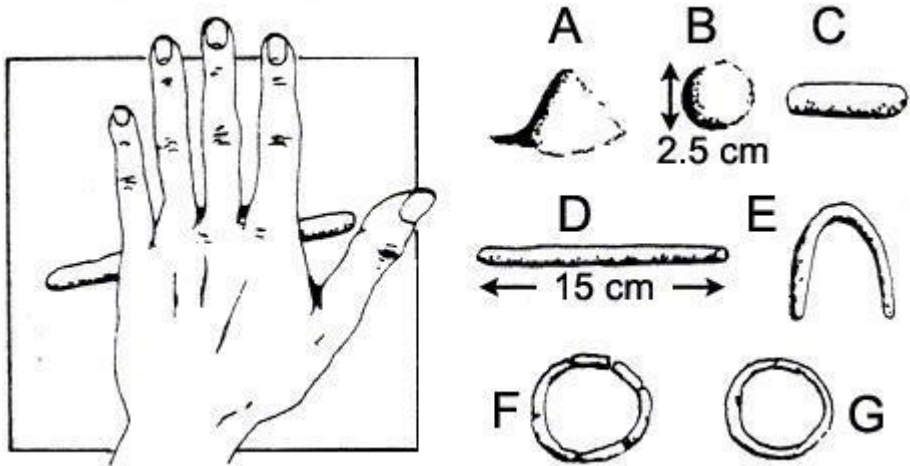
Soil Physical Properties – Common Lab Analysis – Soild Phase

Soil texture
Visual / by hand

Soil textural group	Soil textural class	Feel by hand texturing
Coarse to very coarse	Sand, loamy sand	Gritty -- does not ribbon or leave a stained smear on hand.
Moderately coarse	Sandy loam	Gritty -- leaves smear on hand, does not ribbon -- breaks into small pieces.
Medium	Loam, silt loam, silt	Smooth and flour-like, does not ribbon, breaks into pieces about 1/2 inch long or less
Moderately fine	Sandy clay, sandy clay loam, clay loam, silty sandy clay loam, silty clay, clay	Forms ribbon; clays form longer ribbons than clay loams. Clay loam feels gritty.

Soil Physical Properties – Common Field Analysis

Liquid Phase

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity
Gravimetric (direct)

- Roasting/burning the soil
- Spiritus
- Burns also organic matter and high adhesive water fraction!

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity

Carbid method (indirect)

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity
Indirect - electric signal / neutrons

TDR
Time Domain Reflectrometry – measures the time delay of electric wave signal
Two or three parallel waveguides where pulse travels along

FDR
Frequency Domain Reflectrometry – measures dielectric permittivity
Send the signal through the soil

Neutronprobe
Contains Americium-241 and Berryllium – measures the colliosion of fast neutrons
Fast neutrons collide with hydrogen

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity

Indirect - electric signal / neutrons

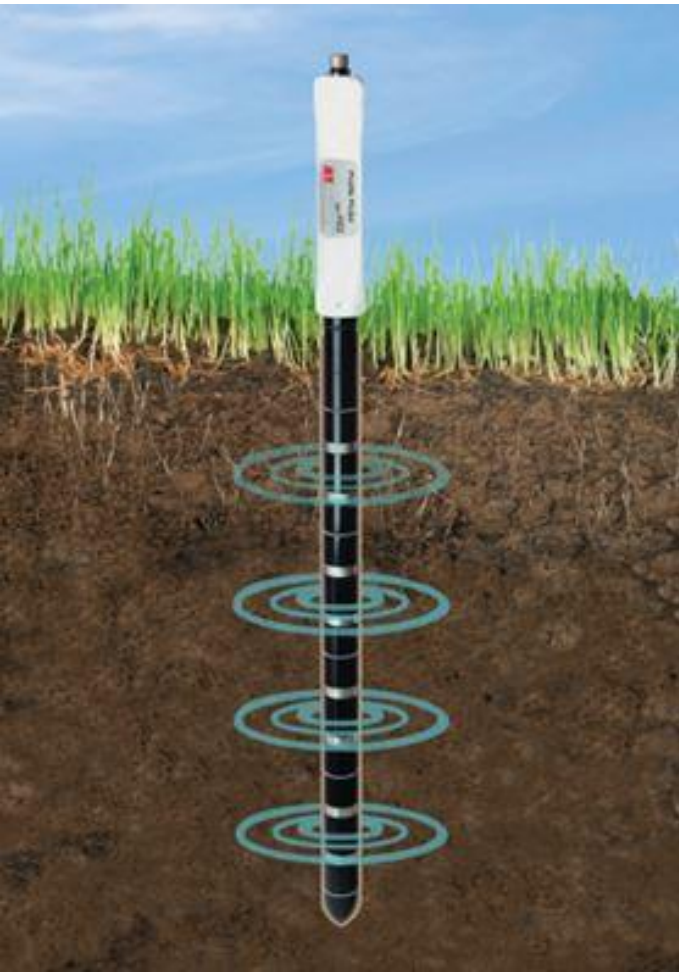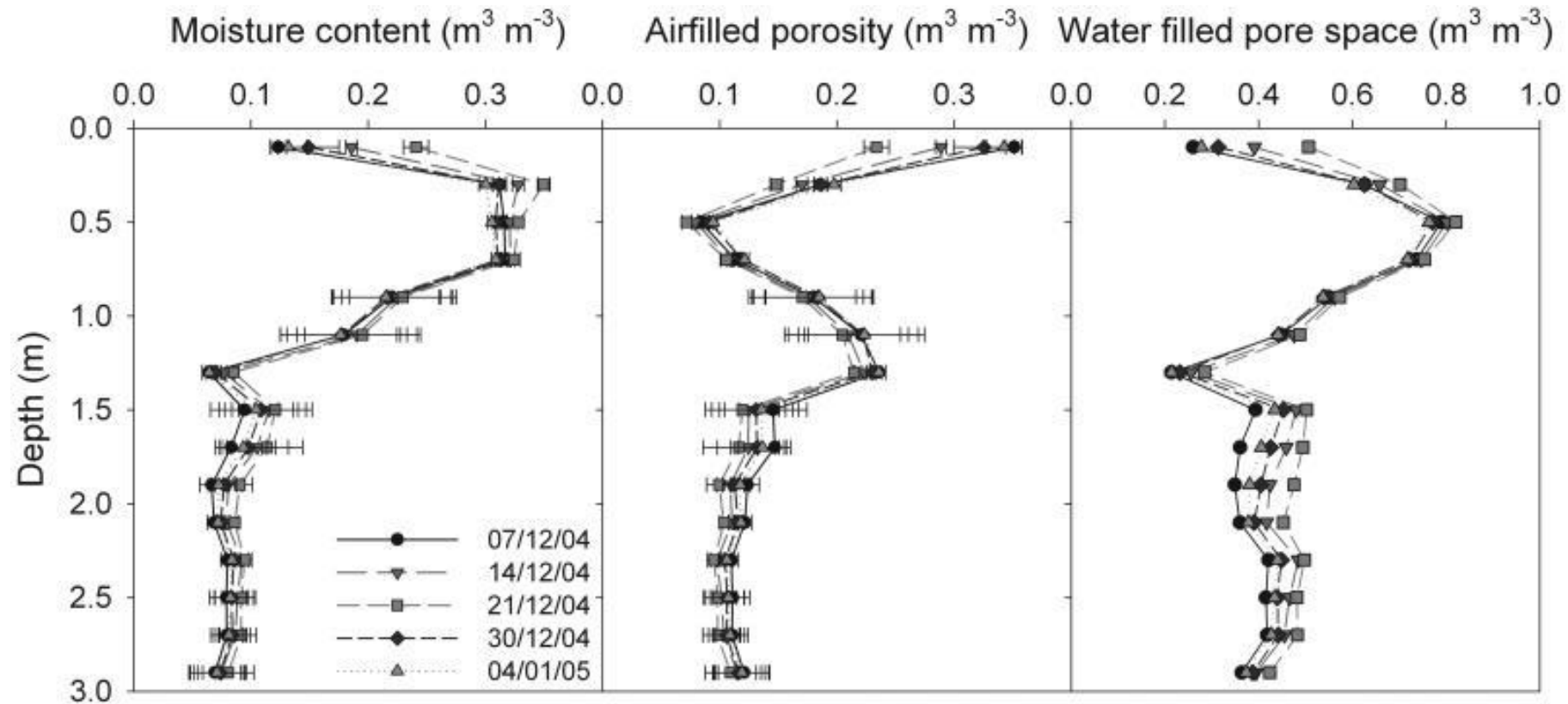*TDR*   *FDR*   *Neutron Probe*

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity

Indirect - electric signal

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water quantity

Indirect - electric signal

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water soil interaction

Soil matric potential

Tensiometer

Up to 1 bar (practically appr. 0.7 bar)!

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water soil interaction

Soil matric potential

Tensiometer

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Water soil interaction
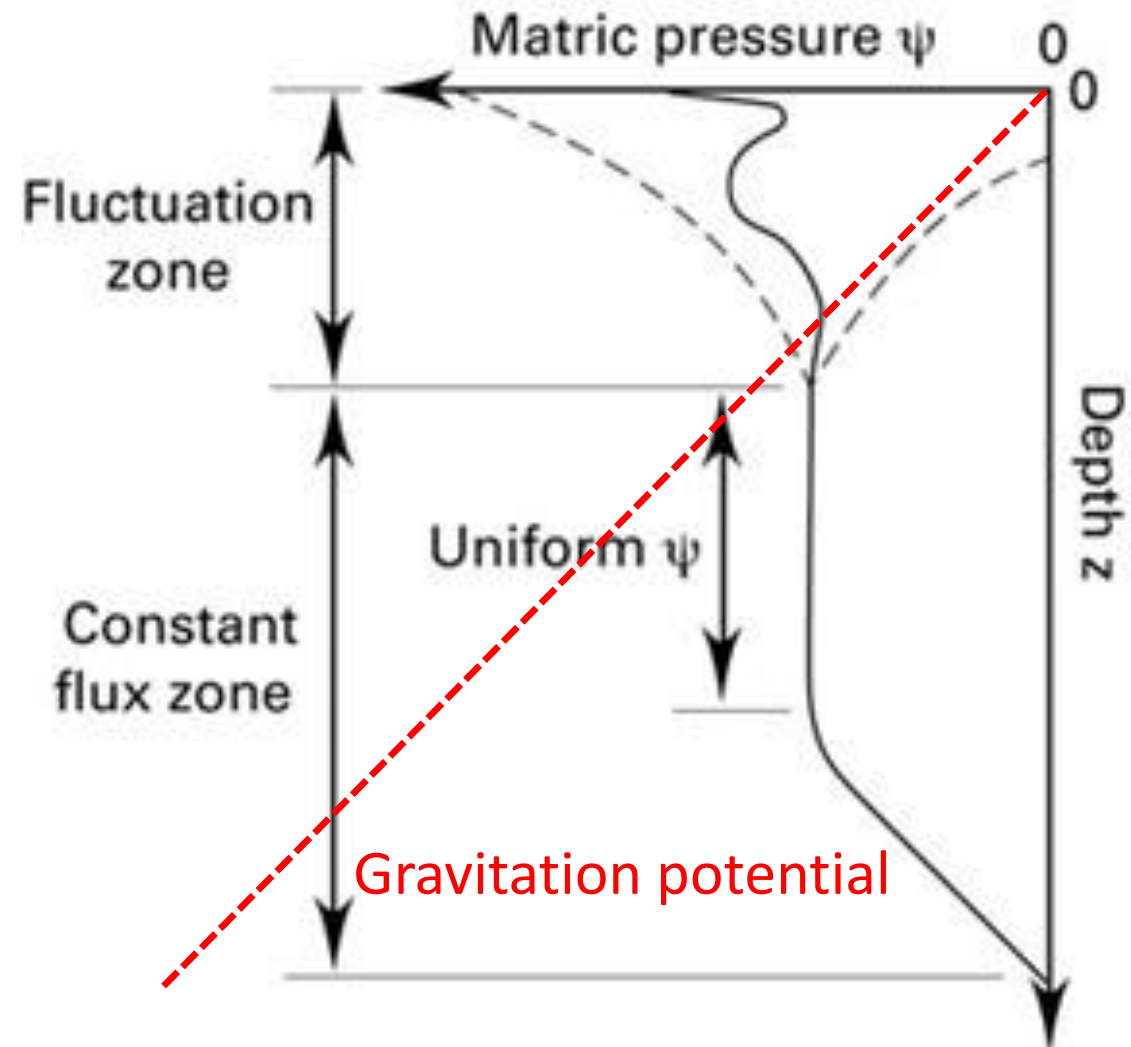
Soil matric potential

Gypsum block
Ceramic block

Indirect measurement!
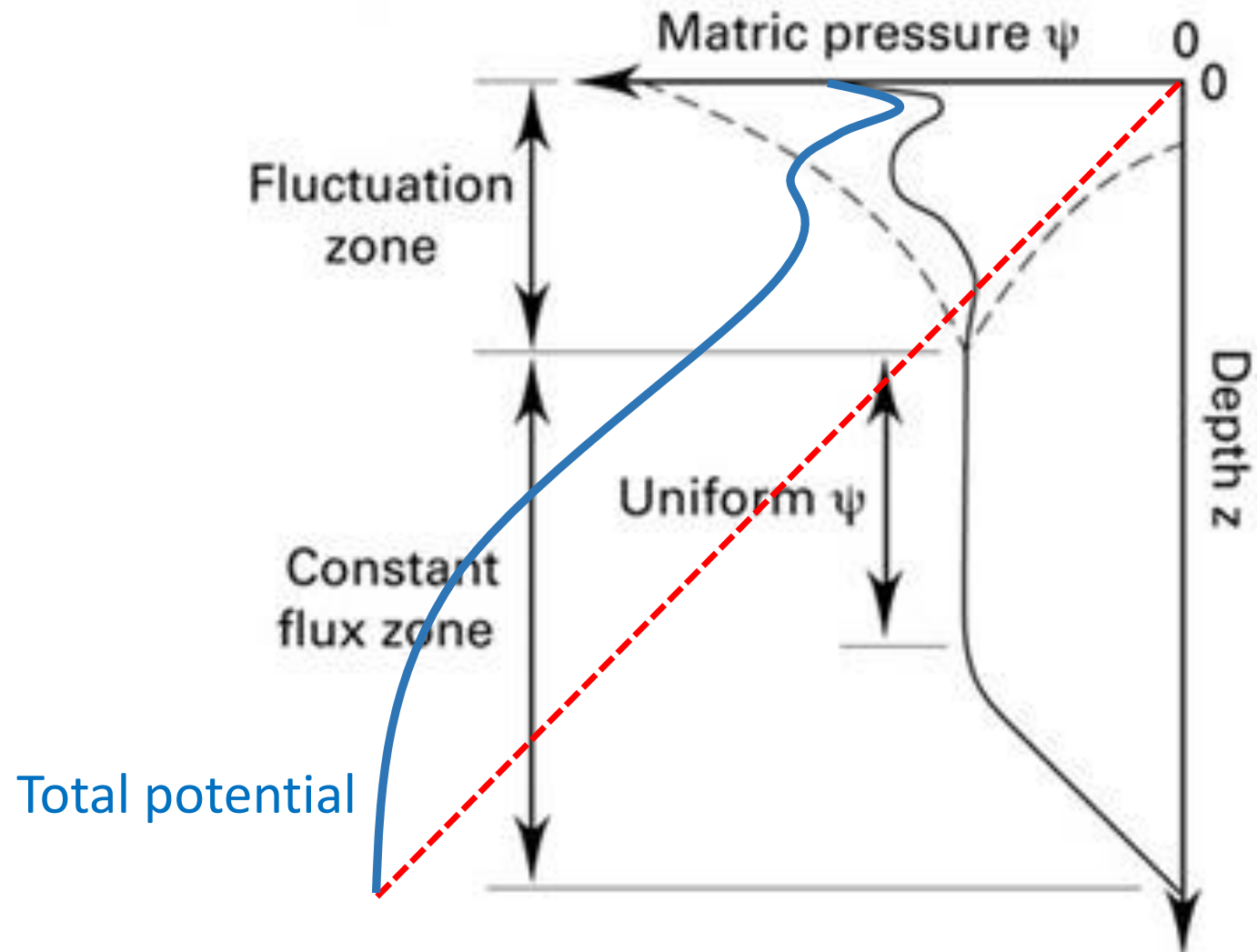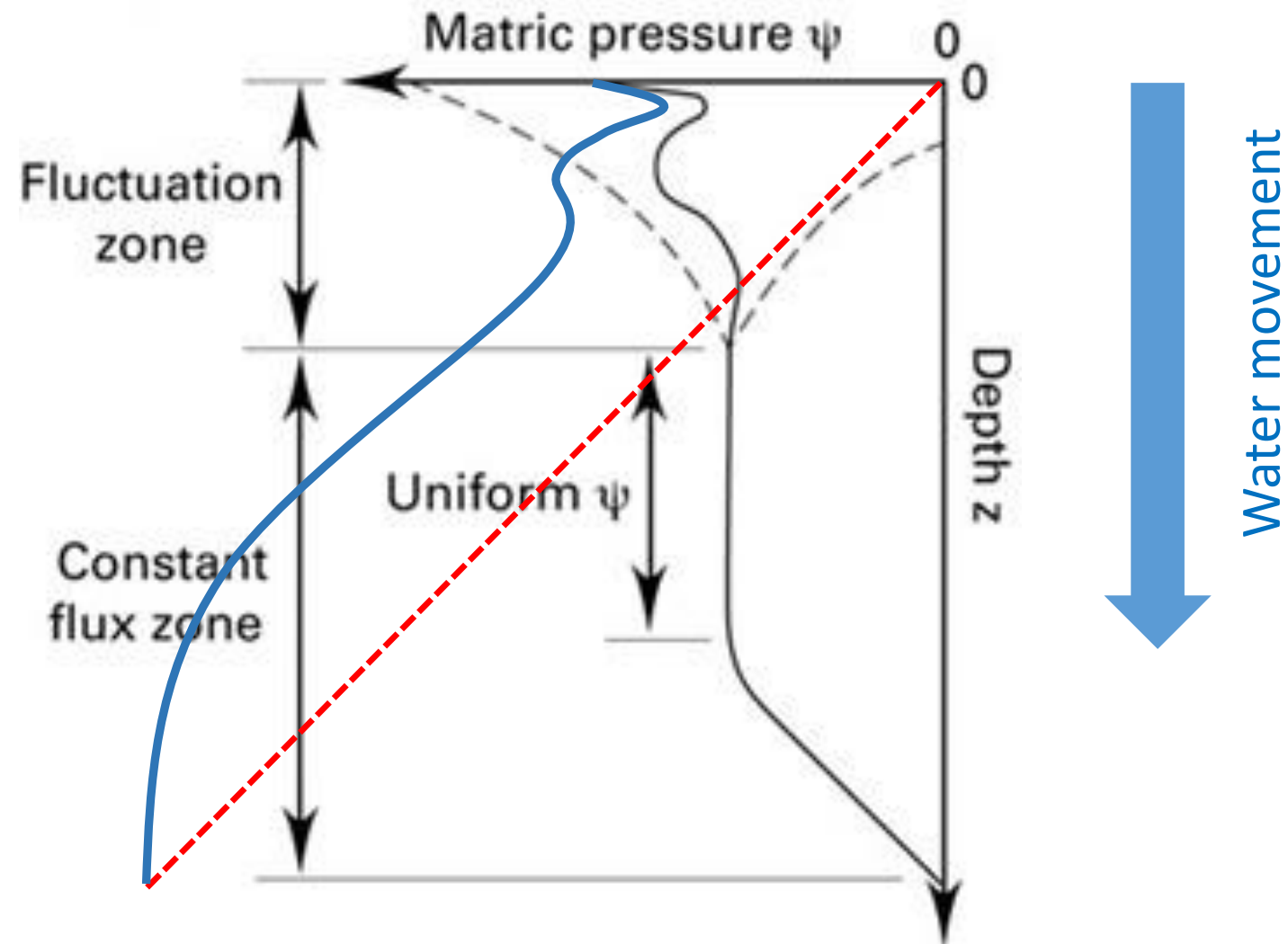
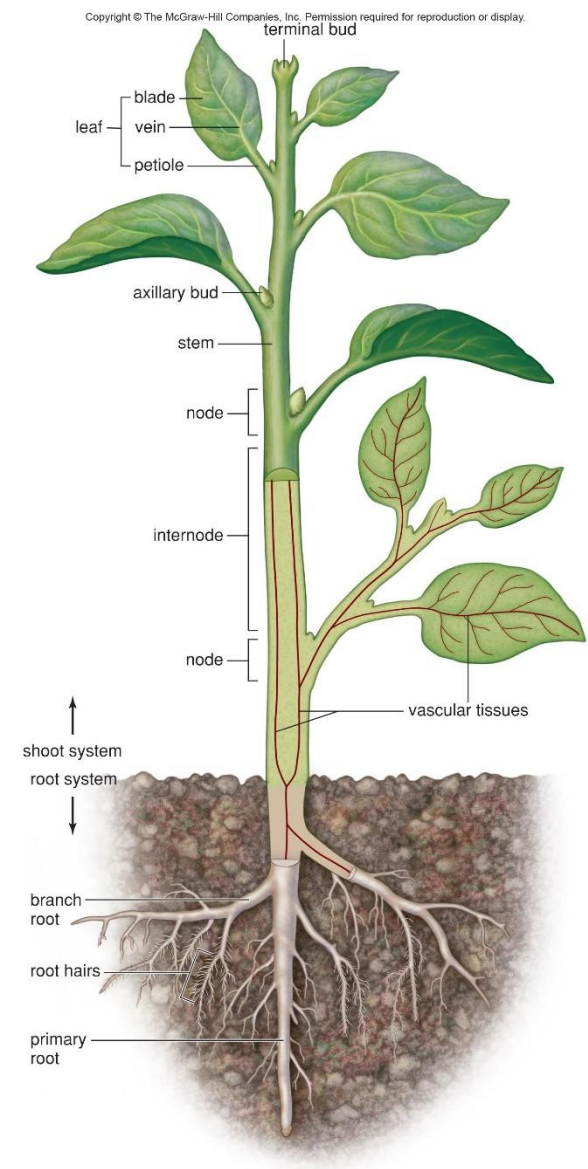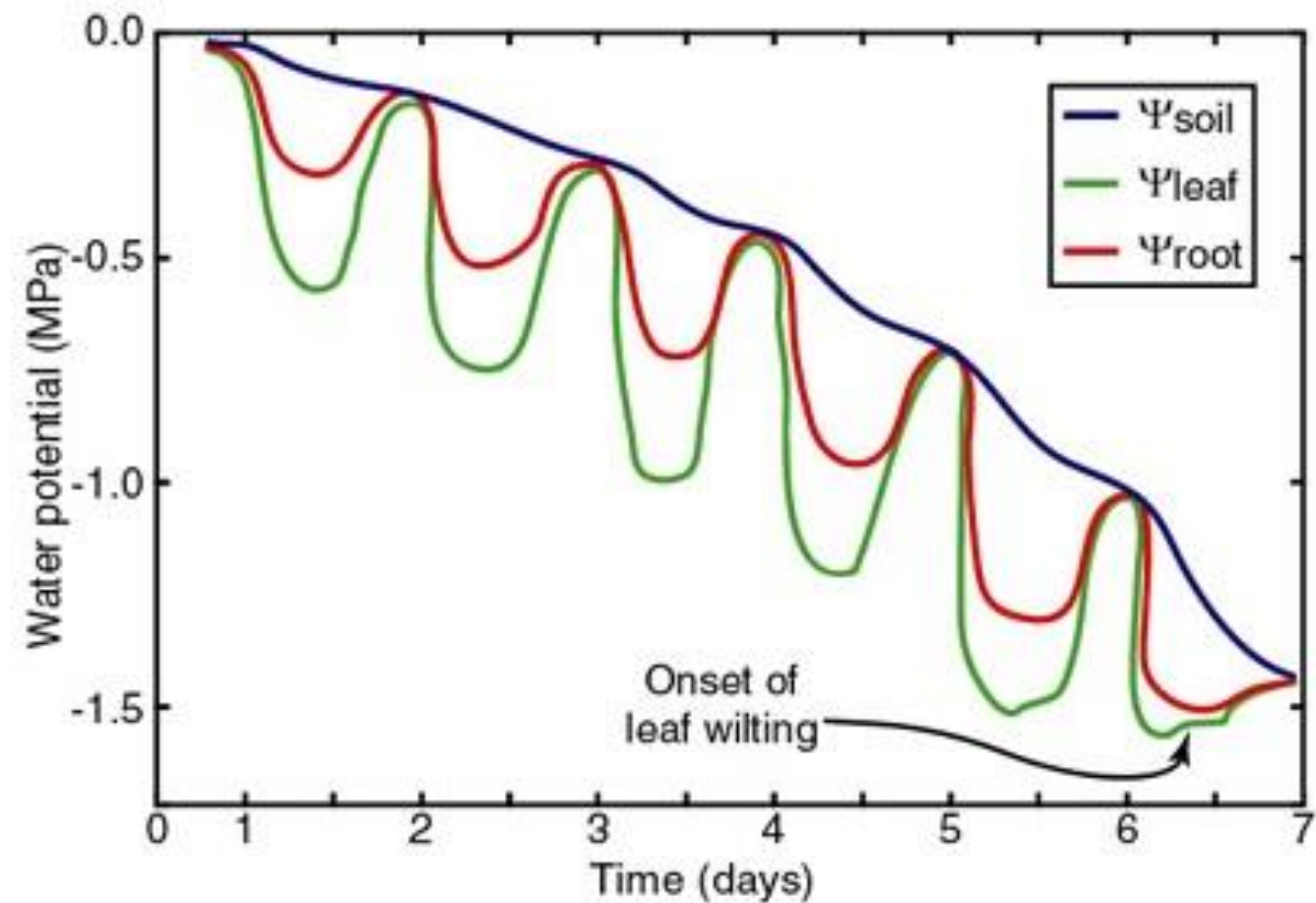# Soil Water Movement
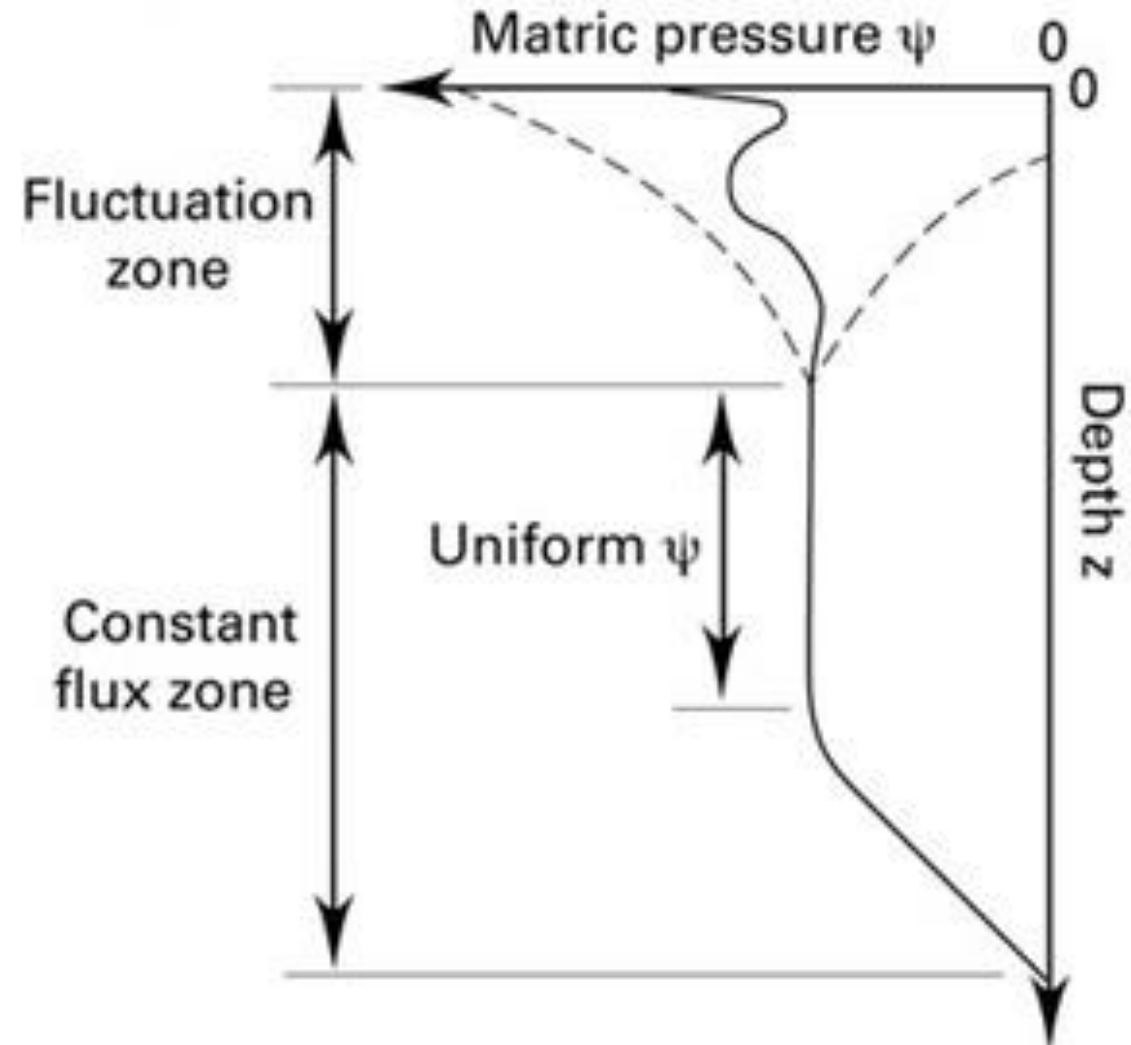
Soil Water Movement

Soil Water Movement

Soil Water Movement

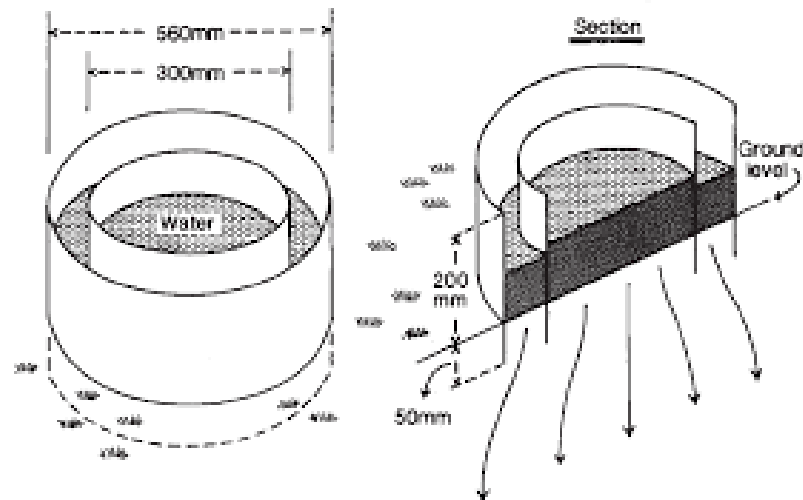# Soil Water Availability – Process over time

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow

Saturated conditions

Double ring method

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow
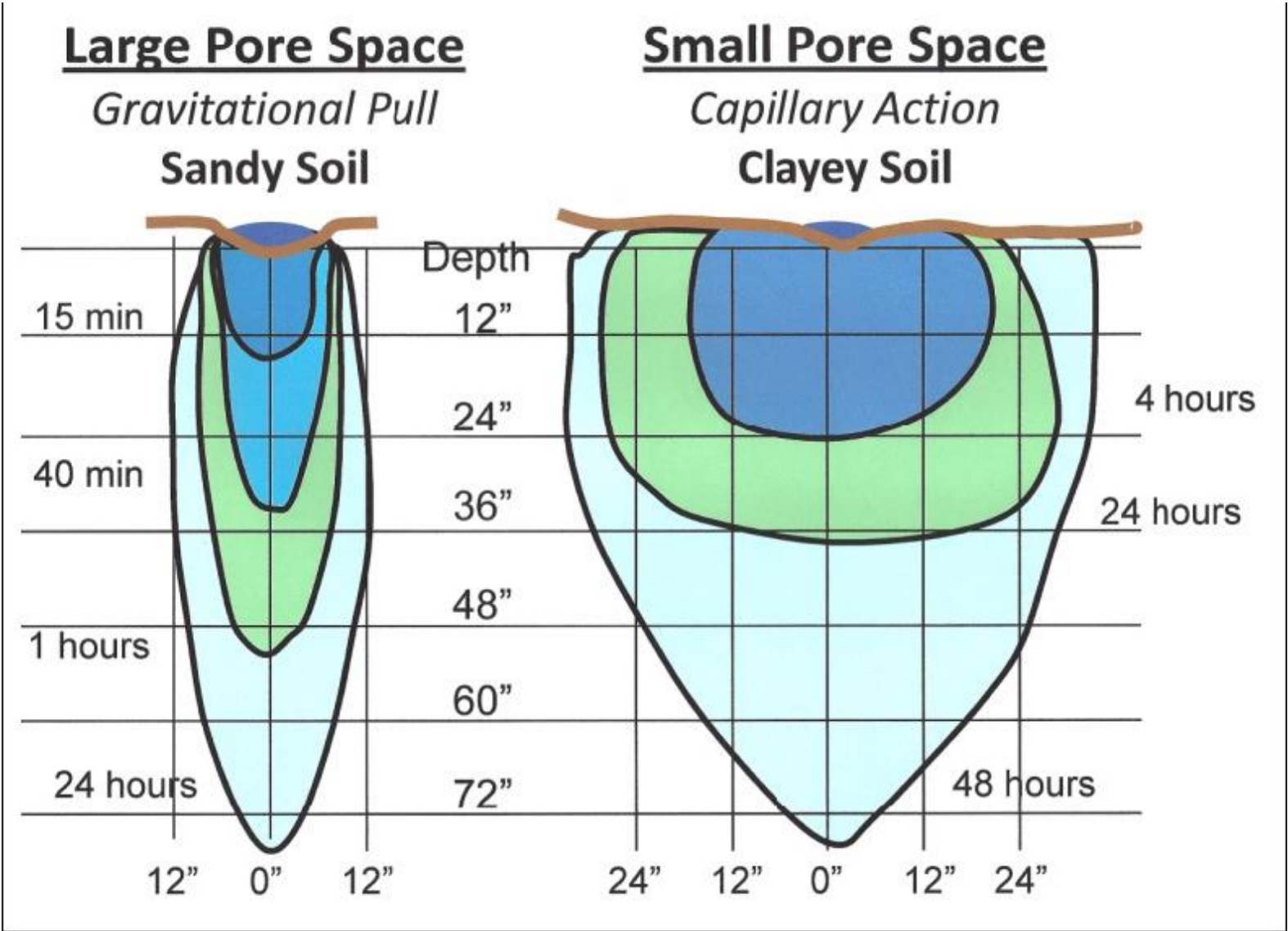
Saturated conditions

Double ring method

Site location: EXAMPLE   Soil type: Loam   Test date: 5 DEC 1987

1. Reading on the clock (hr min sec)	2. Time difference (min)	3. Cumulative time (min)	4. Water level readings before filling (mm)	4. after filling (mm)	5. Infiltration (mm)	6. Infiltration rate (mm/min)	7. Infiltration rate (mm/hour)	8. Cumulative infiltration (mm)
14 05 0	start = 0	start = 0		100				start = 0
	2				(100-92) 8	(8/2) 4.00	240	
14 07 0		(0+2) 2	92	100				(0+8) 8
	3				(100-93) 7	(7/3) 2.33	140	
14 10 0		(2+3) 5	93	99				(8+7) 15
	5				(99-89) 10	(10/5) 2.00	120	
14 15 0		(5+5) 10	89	101				(15+10) 25
	10				(101-84) 17	(17/10) 1.70	102	
14 25 0		(10+10) 20	84	100				(25+17) 42
	10				(100-89) 11	(11/10) 1.10	66	
14 35 0		(20+10) 30	89	102				(42+11) 53
	10				(102-95) 7	(7/10) 0.70	42	
14 45 0		(30+10) 40	95	101				(53+7) 60
	20				(101-92) 9	(9/20) 0.45	27 *	
15 05 0		(40+20) 60	92	100				(60+9) 69
	20				(100-91) 9	(9/20) 0.45	27 *	
15 25 0		(60+20) 80	91					(69+9) 78

*basic infiltration rate

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow
Saturated conditions

Double ring method

Large Pore Space
Gravitational Pull
Sandy Soil

Small Pore Space
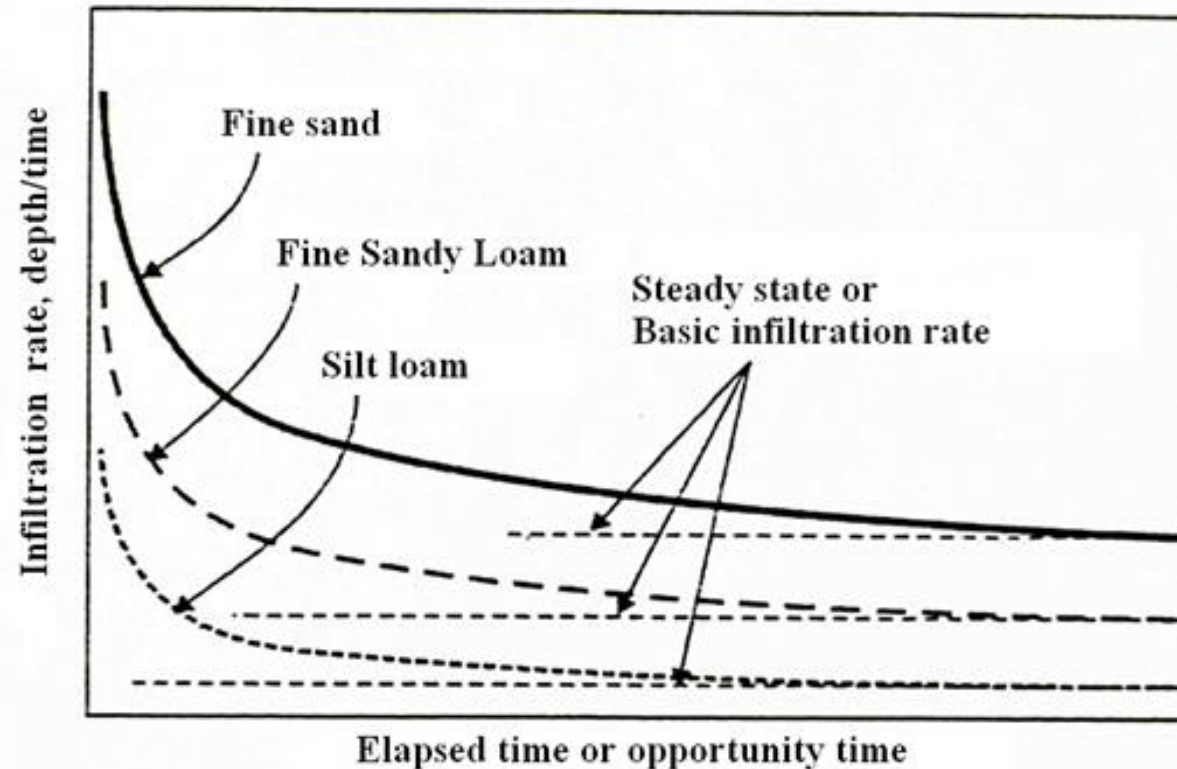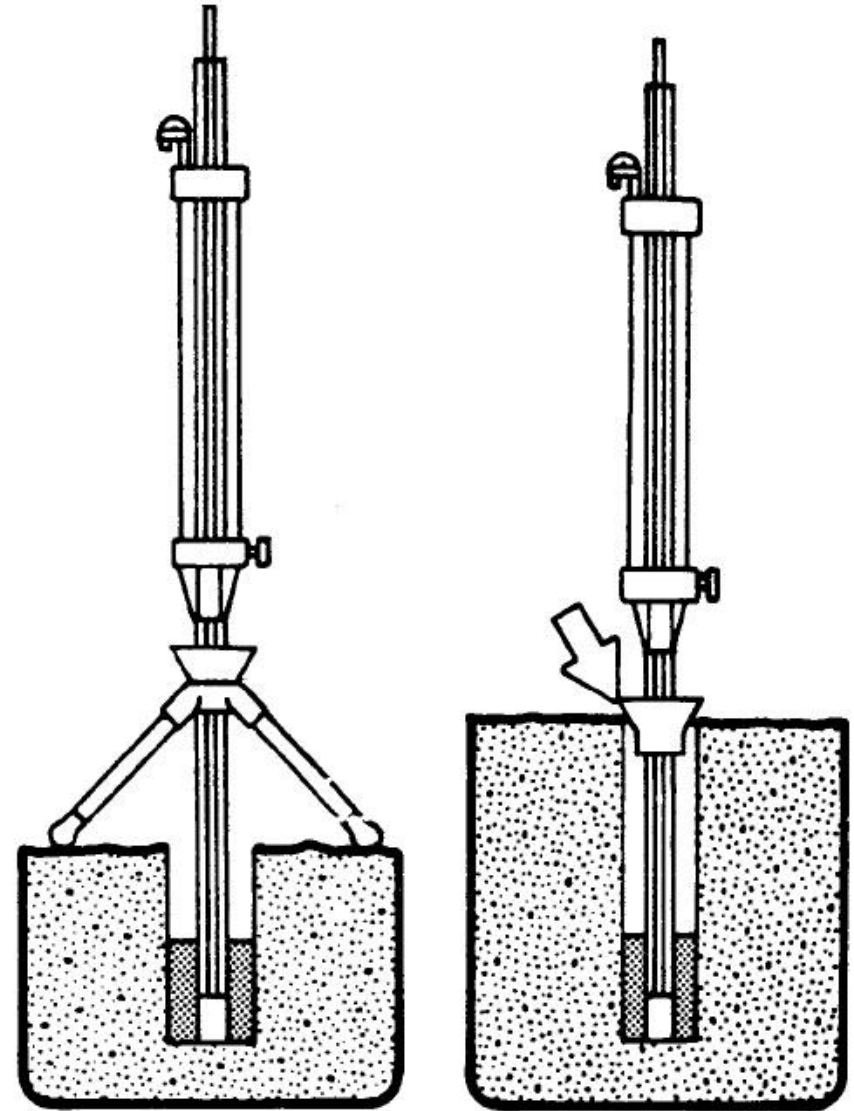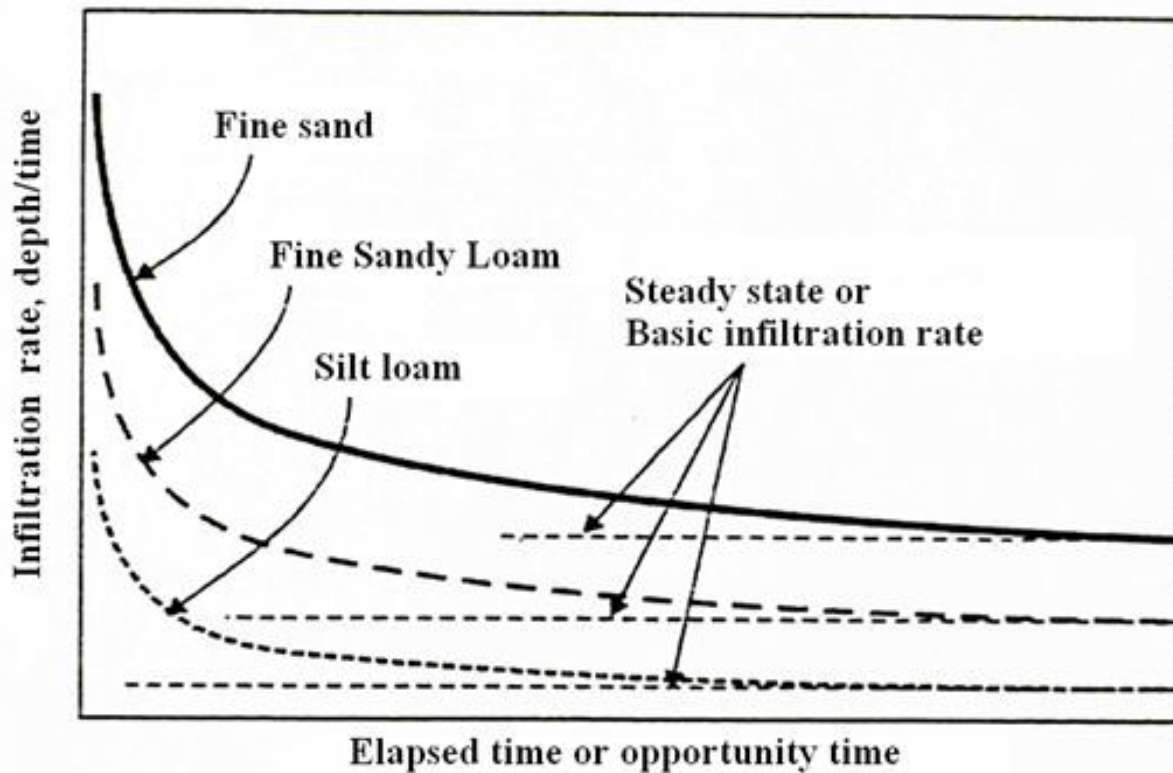Capillary Action
Clayey Soil

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow
Saturated conditions

Double ring method

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow

Saturated conditions

Borehole technique / Guelph permeameter

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow
Saturated conditions

Borehole technique / Guelph permeameter

+ ,Matric potential flux'

Soil Physical Properties – Common Lab Analysis – Liquid Phase

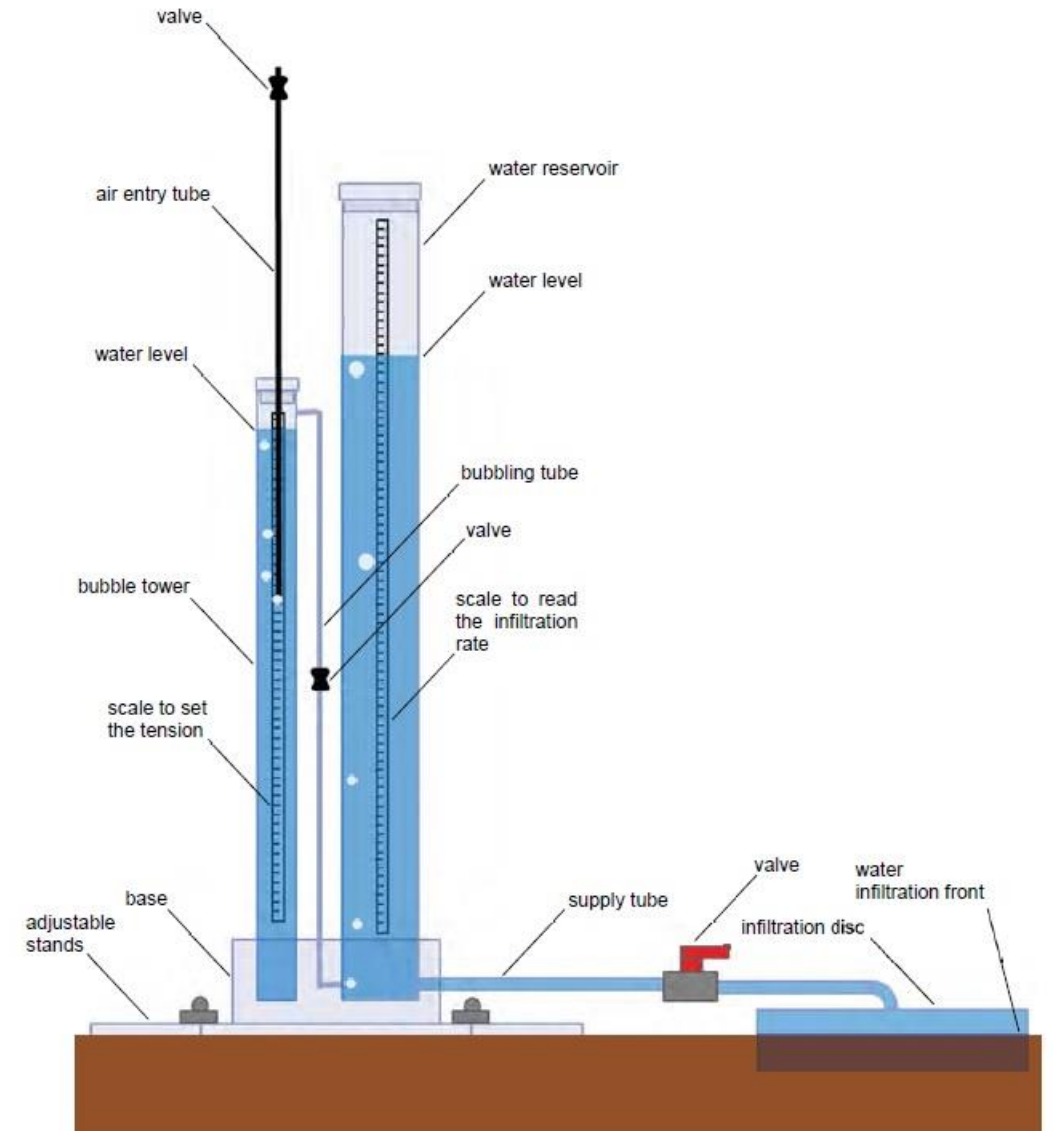**Prorous media flow**
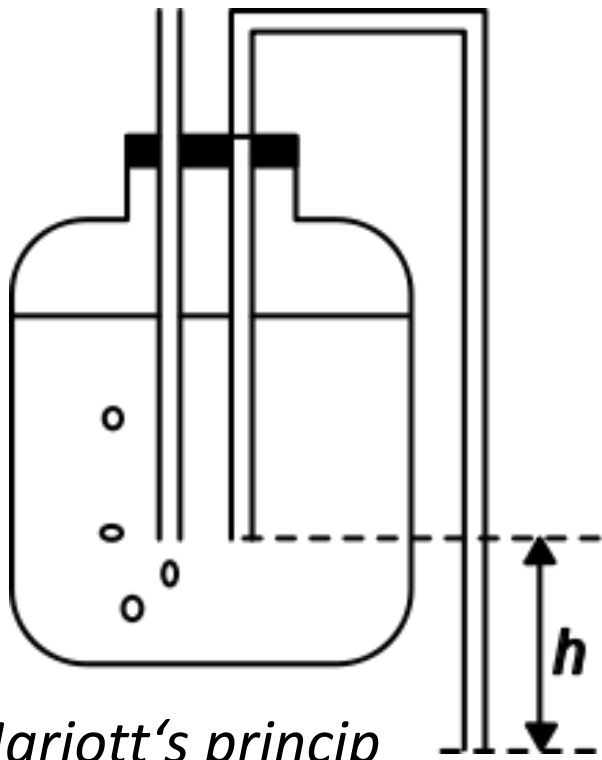*Unsaturated conditions*

Tension - Infiltrometer

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow

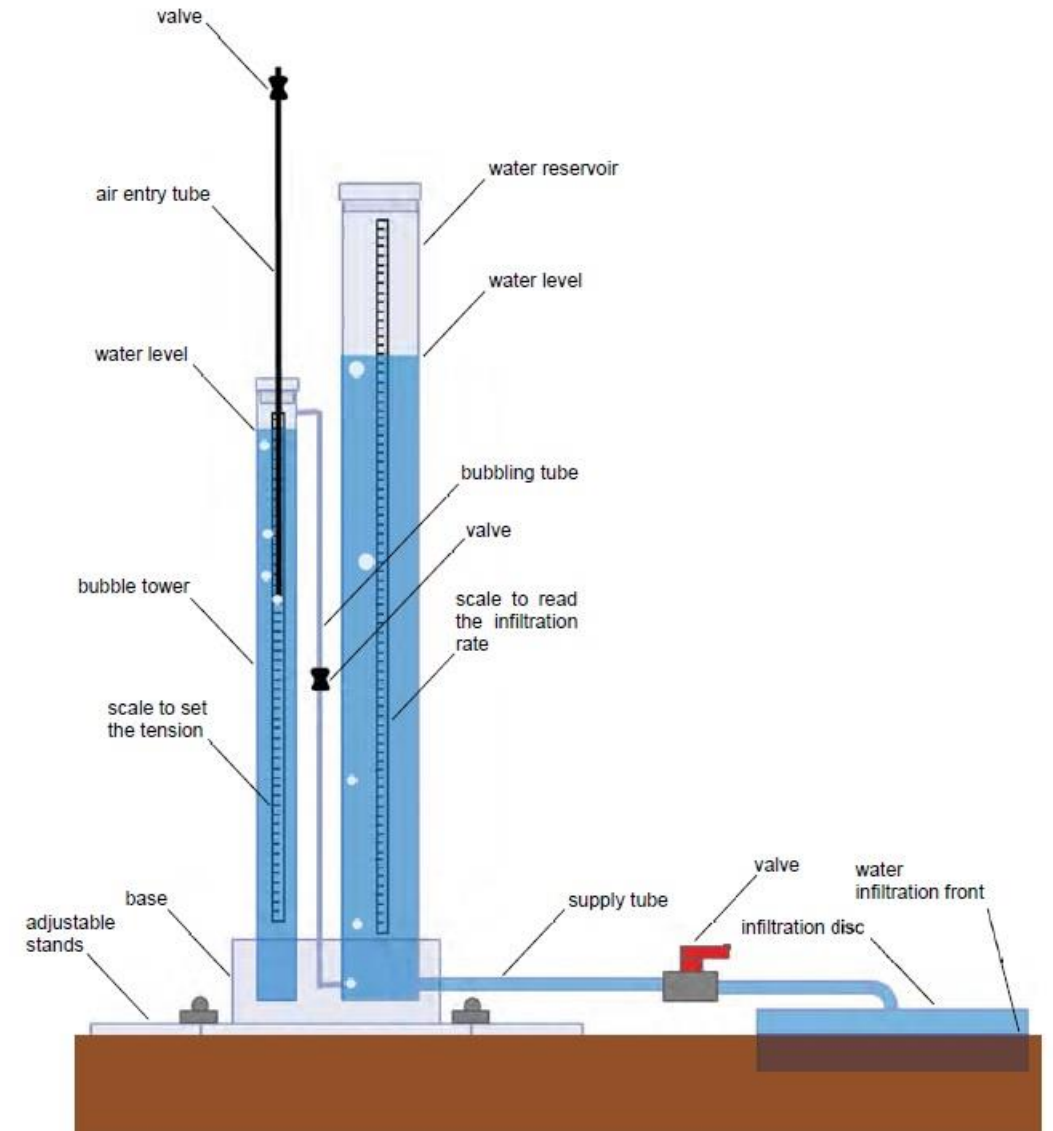*Unsaturated conditions*
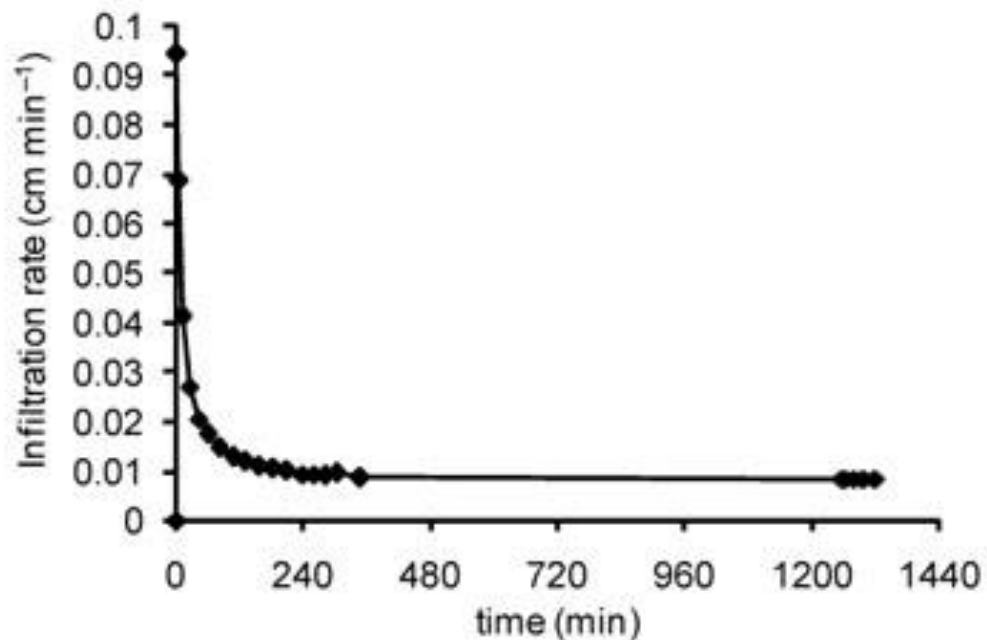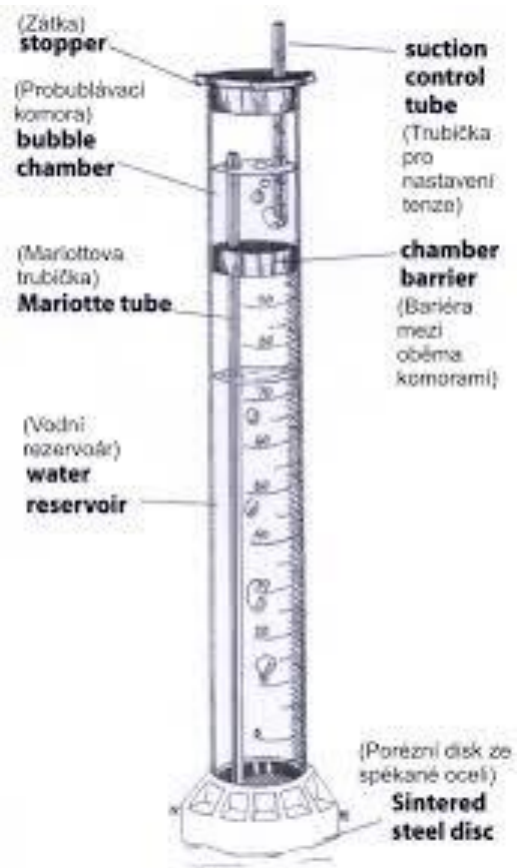
Tension – Infiltrometer

Boyle-Mariott's princip
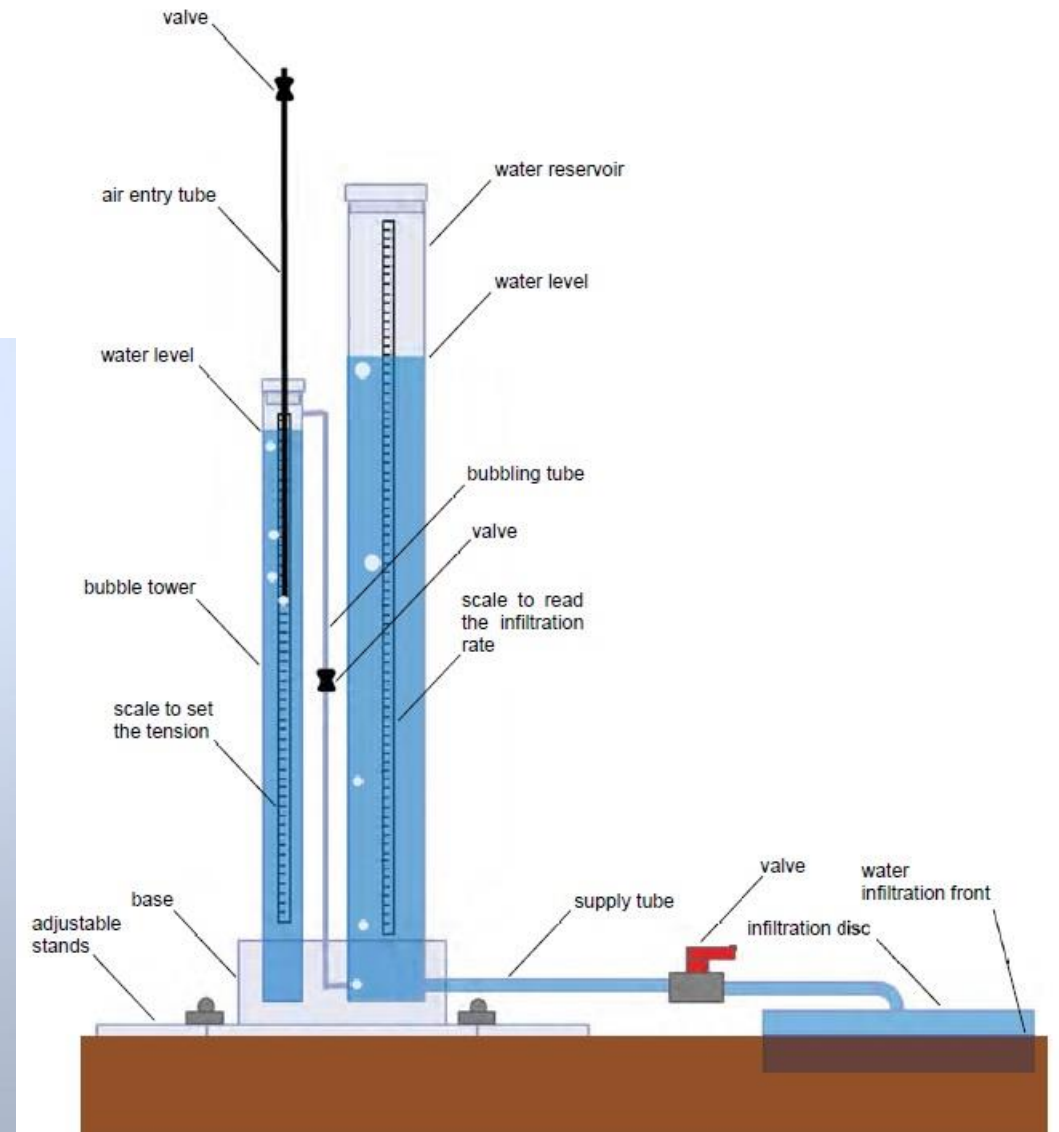
Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow

Unsaturated conditions

Tension - Infiltrometer

Soil Physical Properties – Common Lab Analysis – Liquid Phase

Prorous media flow
Unsaturated conditions

Mini-Disc

Thank you for your attention