TEST:

http://education.jlab.org/reading/soil_01.html

The Hydrosphere:
Lecture 3: Water in Soils

Soil Moisture in the Hydrologic Cycle

Land Surface Water Balance

$P = E + R + \Delta S$

P = Precipitation

E = Evaporation

R = Runoff

S = Soil Moisture Storage

Soil Moisture in the Hydrologic Cycle

0.05% of fresh water (river flow = 0.006%)

infiltration capacity

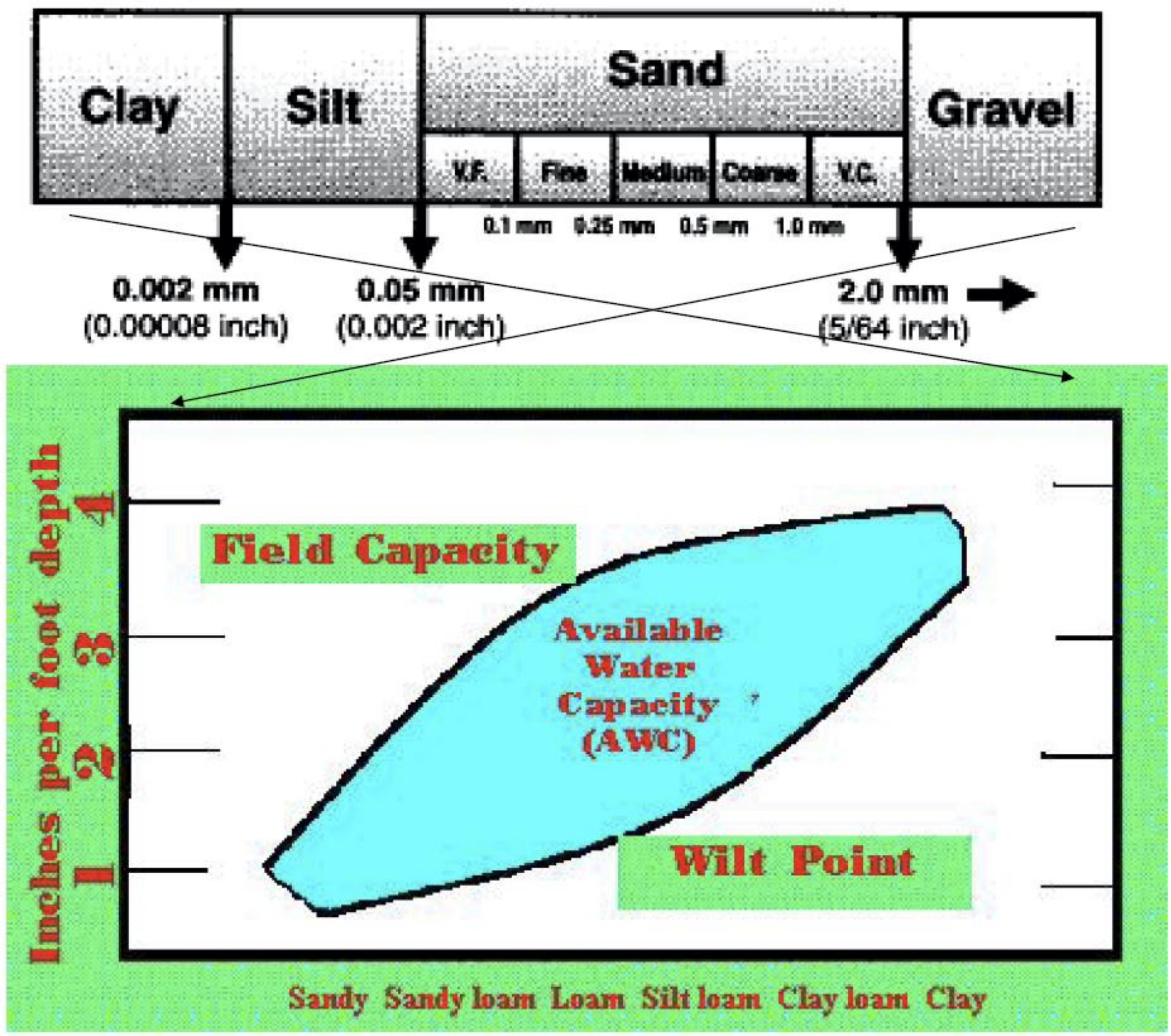
- High at outset but declines to a lower constant, depends on soil texture (sand, silt, clay) and structure: water infiltrates, is stored, moves horizontally & vertically, percolates to ground water, taken up by plants, ET to atmosphere
- the rates of exchange are governed by energy level of soil water
- **Capillary Mechanism**: **h = 0.15/r** (h = ht of capillary rise ; r = radius of the tube)
- Thicker the tube, the lower the capillary rise; plants get water through capillarity and root extension

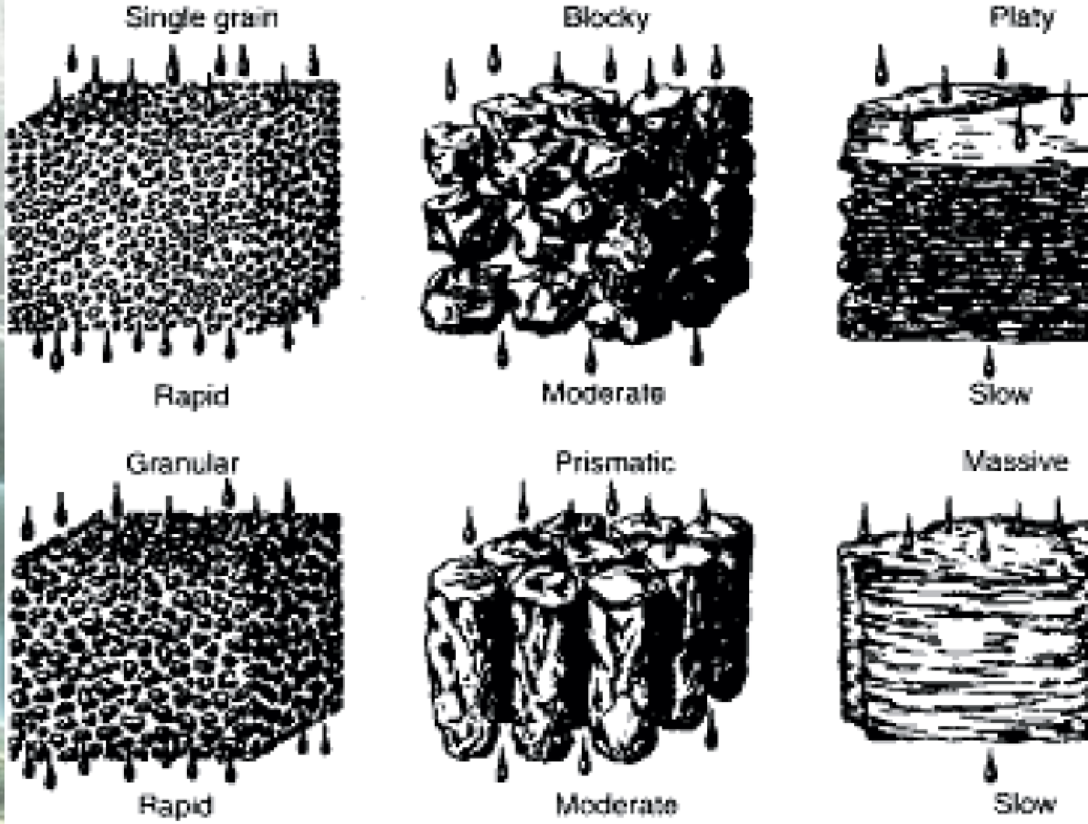
Soil water:

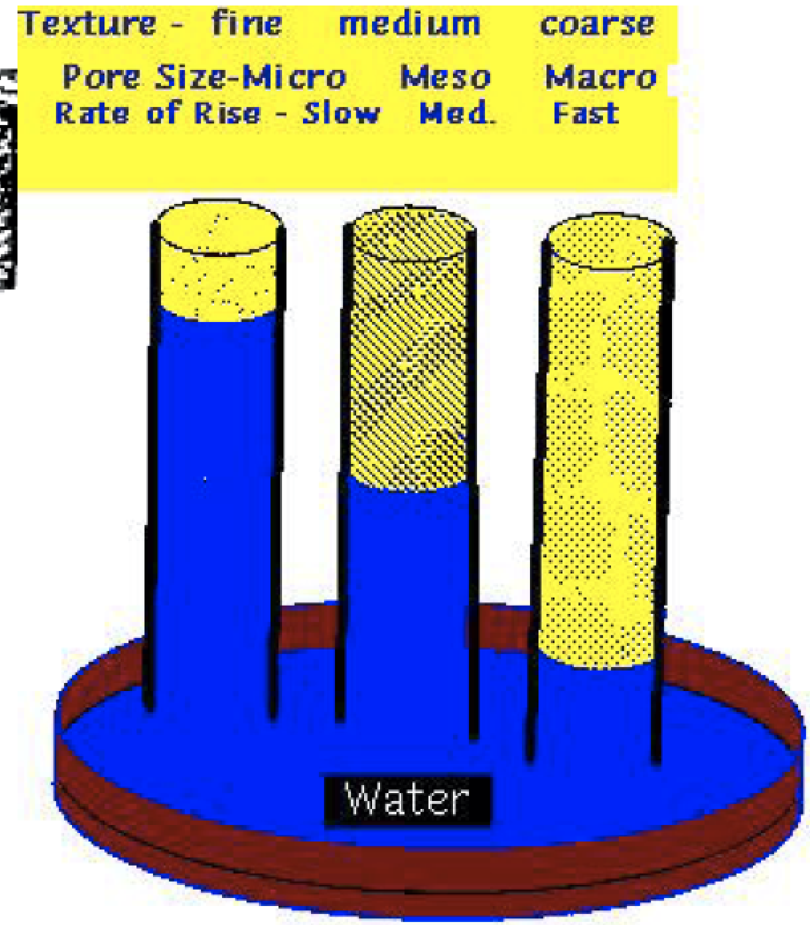
- **Adsorption**: hold of molecules to a surface, reduces m. motion, reduces water energy, releases heat of wetting due to tighter bond
- **Soil moisture tension**: electrostatic bond; distance decay
- **Structural water**: some minerals - Gypsum $CaSO_4 \cdot 2H_2O$ vs. anhydrite $CaSO_4$
- **Adhesion water:** electrostatic attraction between water molecule and soil surface; thin film of H_2O molecules (several molecules thick); tightly adsorbed and not usually available to plants.
- **Cohesion water**: beyond the zone of strong adhesion attraction, the force decreases to the attraction of water molecule to water molecule; this water is mobile: the main source of plant water
- **Gravitational water**: electrostatic hold is weaker than pull of gravity, **macropore** water

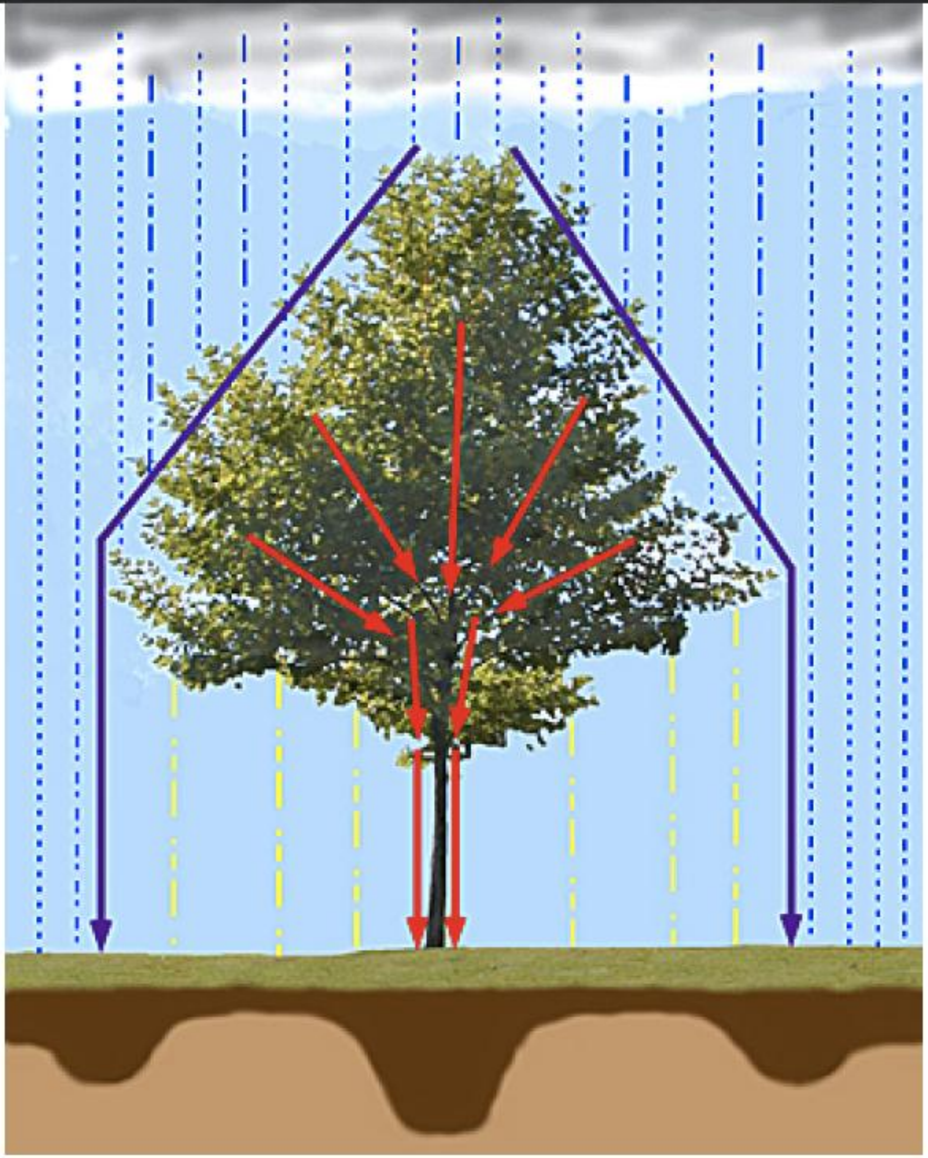
Soil water states

- **Saturation:** occurs during and up to a few days after a storm (100% air space occupied)
- **Field Capacity**: max. soil water after gravity removal, water in **micropores** (50% air space occupied)
- **Wilting Point**: transpiration > uptake (25% air space occupied)
- **Hygroscopic**: dry but at equilibrium with dry air (10% air space occupied)
- **Oven dry**: removes all but water hydration standard (1%)

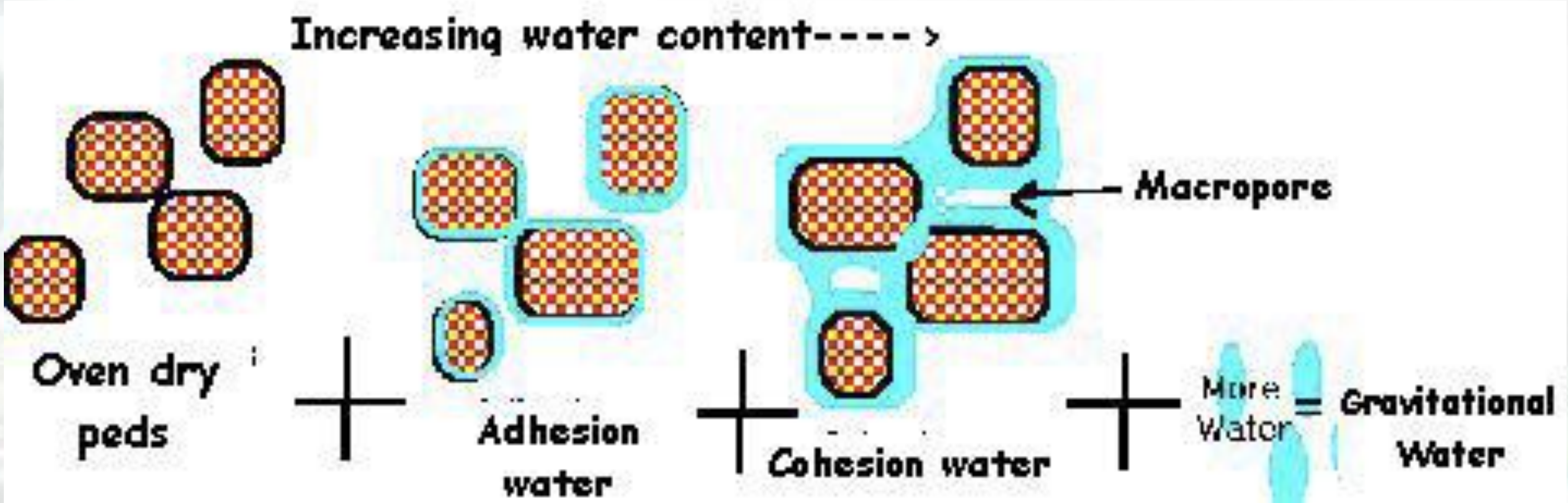

Clay
Silt
Sand
Gravel
V.F.
Fine
Medium
Coarse
V.C.
0.1 mm
0.25 mm
0.5 mm
1.0 mm
0.002 mm
(0.00008 inch)
0.05 mm
(0.002 inch)
2.0 mm
(5/64 inch)
Field Capacity
Available
Water
Capacity
(AWC)
Wilt Point
Inches per foot depth
1
2
3
4
Sandy
Sandy loam
Loam
Silt loam
Clay loam
Clay


Single grain
Blocky
Platy
Rapid
Moderate
Slow
Granular
Prismatic
Massive
Rapid
Moderate
Slow

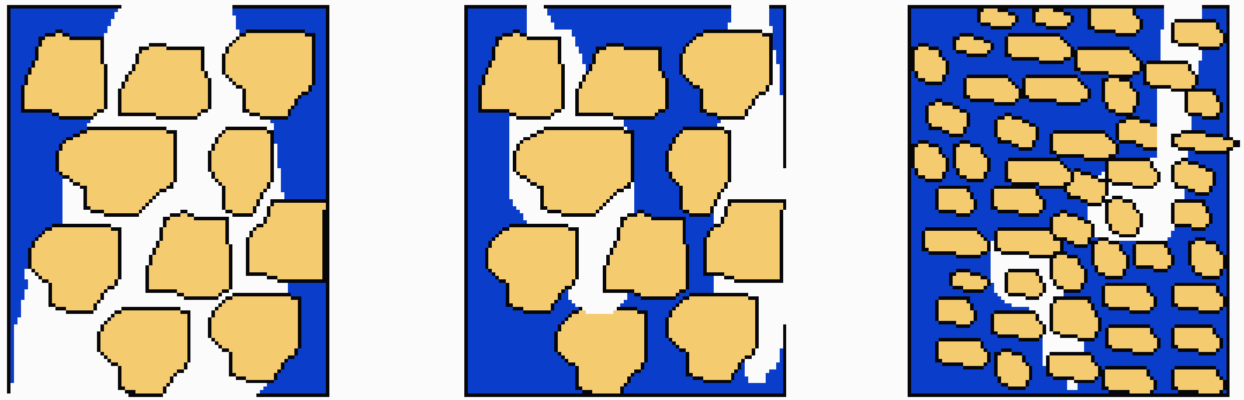

Texture - fine medium coarse
Pore Size-Micro Meso Macro
Rate of Rise - Slow Med. Fast
Water



Modification of falling precipitation by vegetation The relative quantity of precipitation entering the soil is indicated in dark brown.


Increasing water content---->
Macropore
Oven dry peds
Adhesion water
Cohesion water
More Water
Gravitational Water

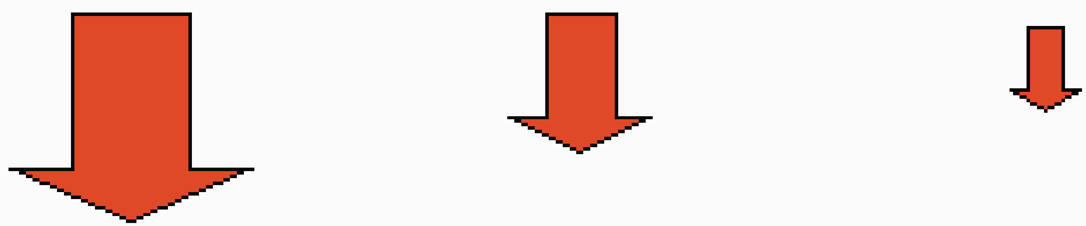
Soil texture:	Sand	Silt	Clay
Size [mm]:	0.05 - 2	0.002 - 0.05	< 0.002

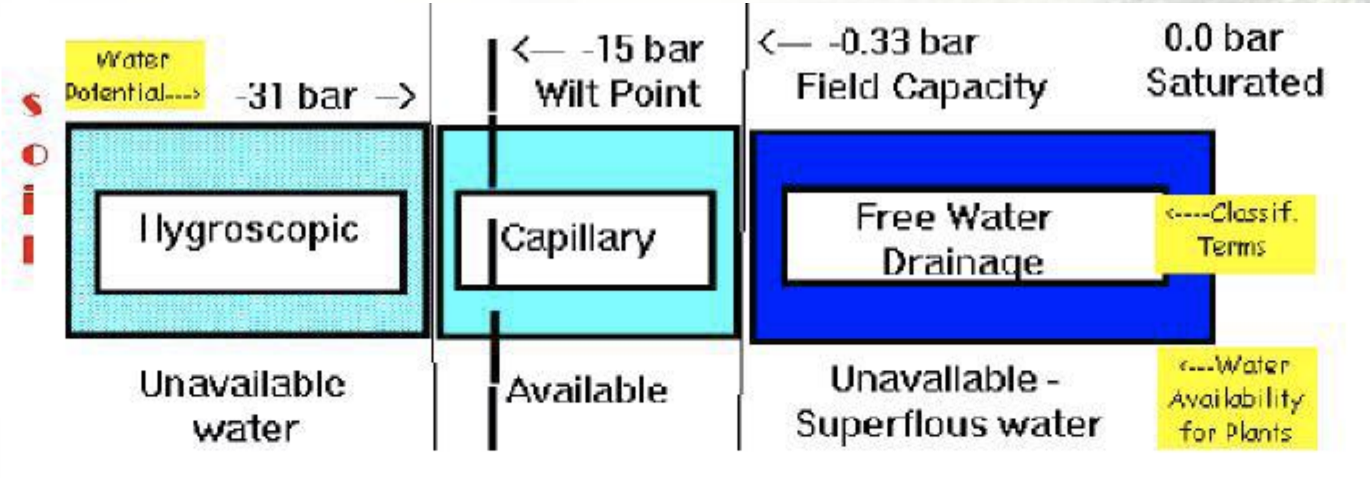


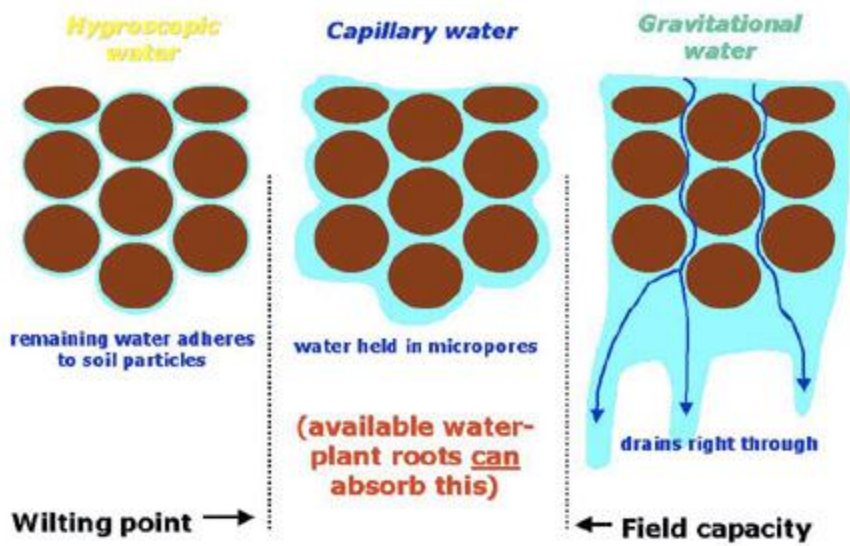
	Sand	Silt	Clay
Macropores	+++	++	(+)
Medium-sized p.	++	++	++
Micropores	(+)	++	+++

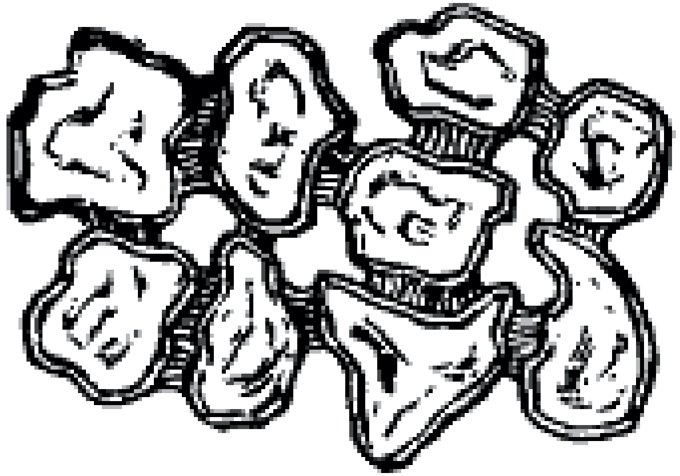
Percolation:

Leaching:



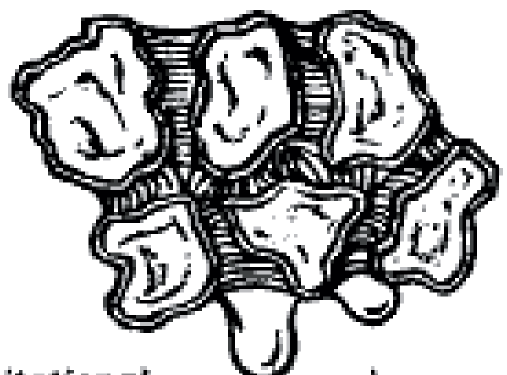

Water Potential--->
-31 bar ->
<-- -15 bar
Wilt Point
<-- -0.33 bar
Field Capacity
0.0 bar
Saturated
s
o
i
l
Hygroscopic
Capillary
Free Water
Drainage
<----Classif. Terms
Unavailable water
Available
Unavailable - Superflous water
<---Water Availability for Plants


Hygroscopic water
Capillary water
Gravitational water
remaining water adheres to soil particles
water held in micropores
drains right through
(available water- plant roots can absorb this)
Wilting point
Field capacity

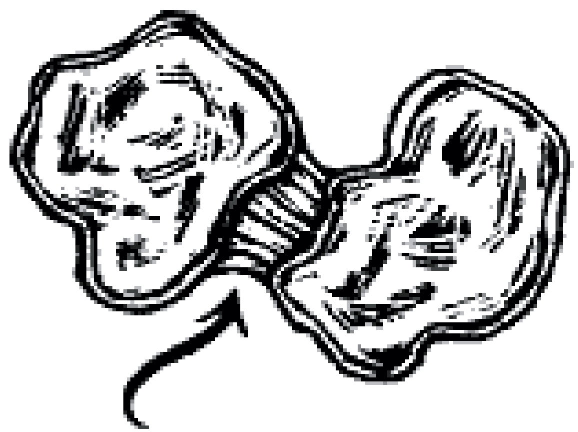


Field capacity. *The capillary pores are full and the remaining pore space is filled with air.*

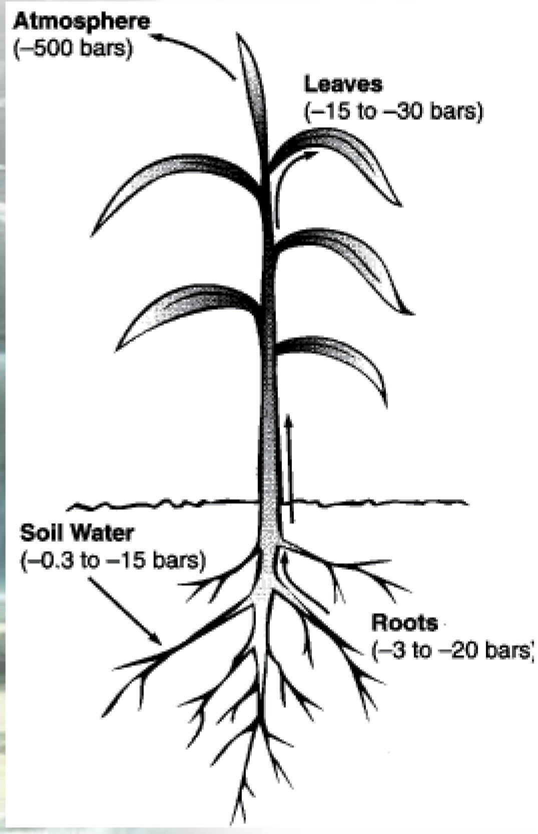
Wilting point. *The water available to plants is exhausted.*



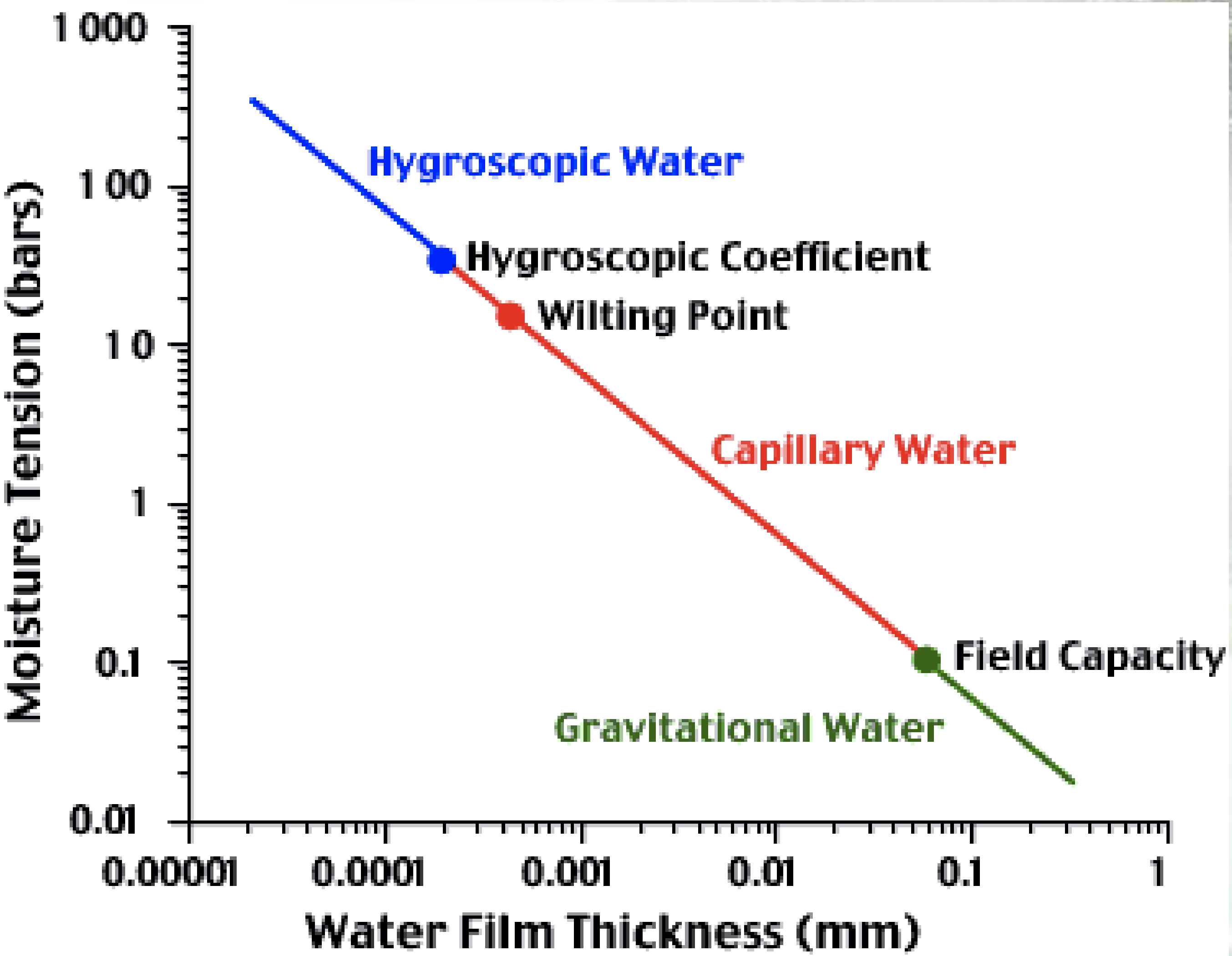
Gravitational water. *The pore spaces are filled with water in excess of their capillary capacity, and the excess, or gravitational water, drains downward.*



Capillary water *is held in the pore space against the force of gravity.*



Atmosphere
(–500 bars)
Leaves
(–15 to –30 bars)
Soil Water
(–0.3 to –15 bars)
Roots
(–3 to –20 bars)



Moisture Tension (bars)
1 000
1 00
1 0
1
0.1
0.01
Hygroscopic Water
Hygroscopic Coefficient
Wilting Point
Capillary Water
Field Capacity
Gravitational Water
0.00001
0.0001
0.001
0.01
0.1
1
Water Film Thickness (mm)

Measuring Soil Moisture

- Laboratory
- Satellites: Microwave
  - SMMR and SSM/I passive microwave satellites
  - Canadian RADARSAT
- Mathematical
  - Thornthwaite ET = P- (R-dS)
- Sensors for soil moisture tension
- Lysimeter
  - Excavate soil monolith, scale under monolith to weigh mass and measuring infiltration and percolation to arrive at ET and soil moisture
    - ET = P-(R-Perc-SM measured by scale)
    - SM=P-(R-Perc-ET)

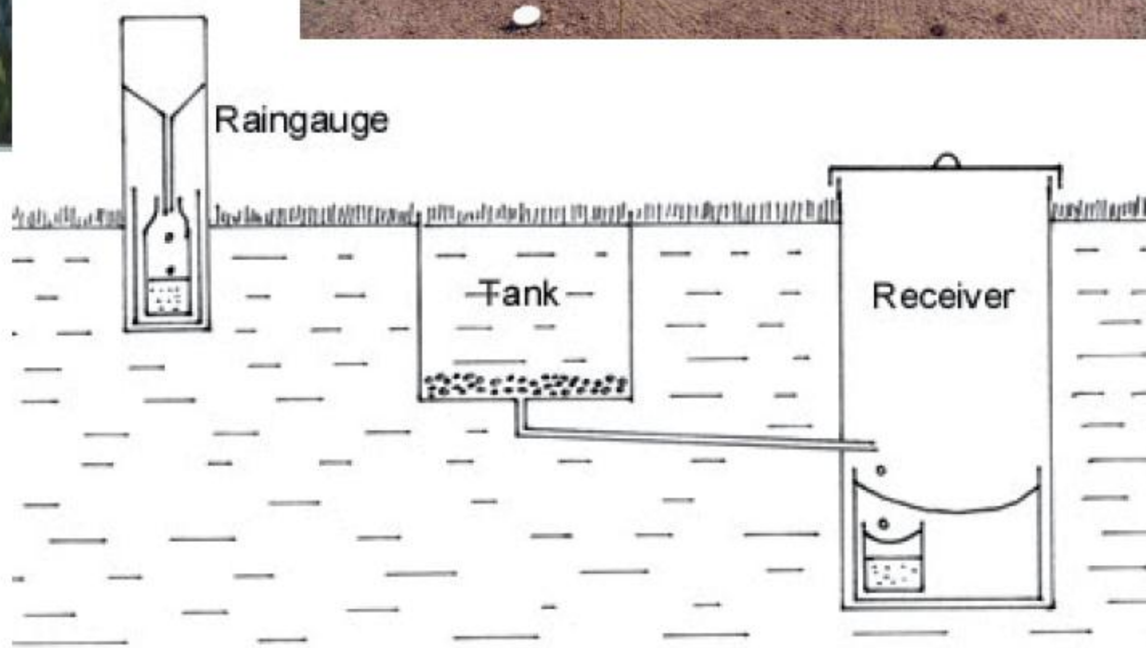
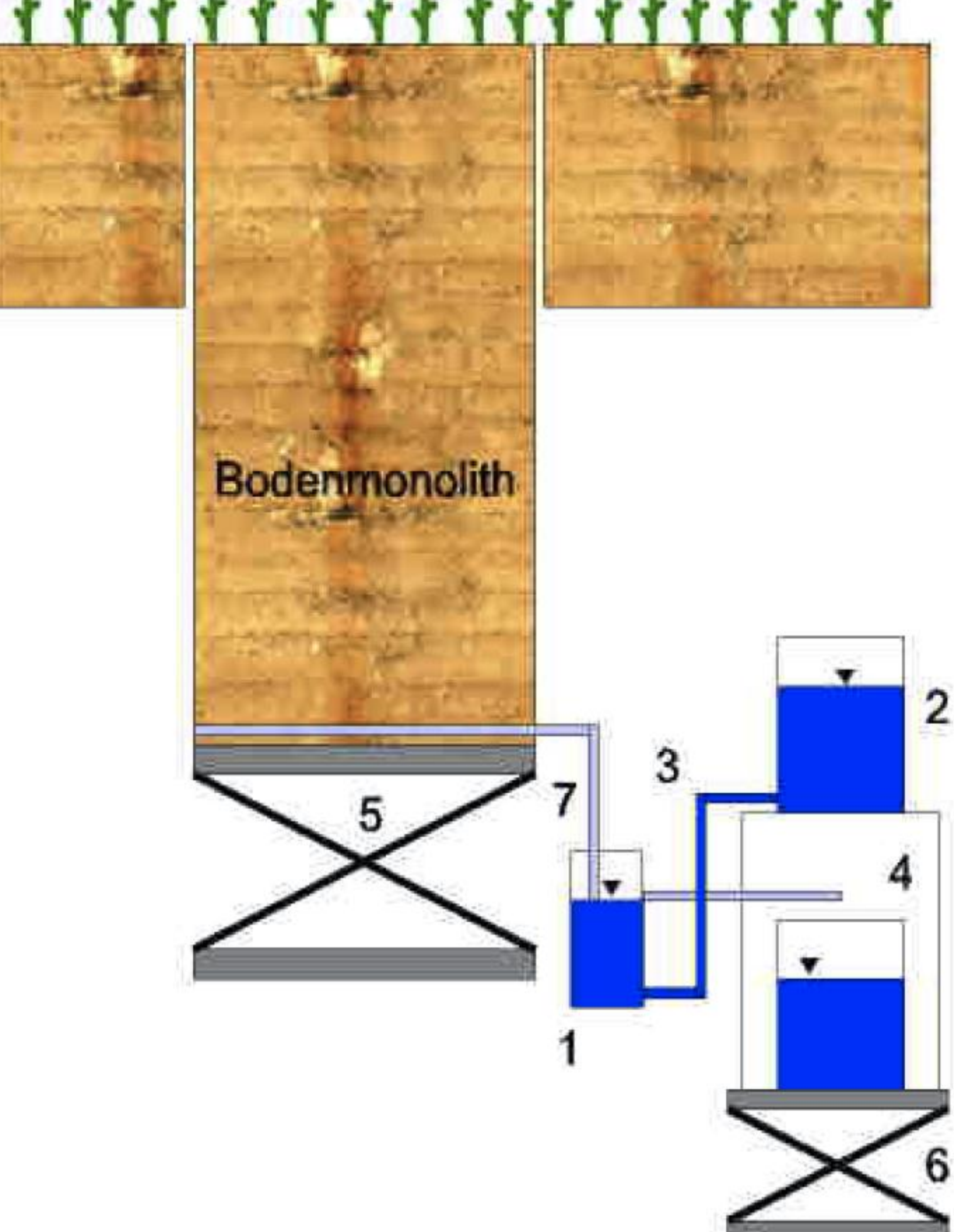


Fig 2. Lysimeter apparatus for measuring evapotranspiration



Principle sketch of a negative pressure lysimeter

1 leveling vessel
2 store of water containers
3 single solenoid valve
4 receptacles for the percolated water
5 balance for the weight difference of the lysimeter
6 balance for the wieght difference of the percolated water/capillary ascent
7 hanging water gauge (63 cm, pF 1.8)

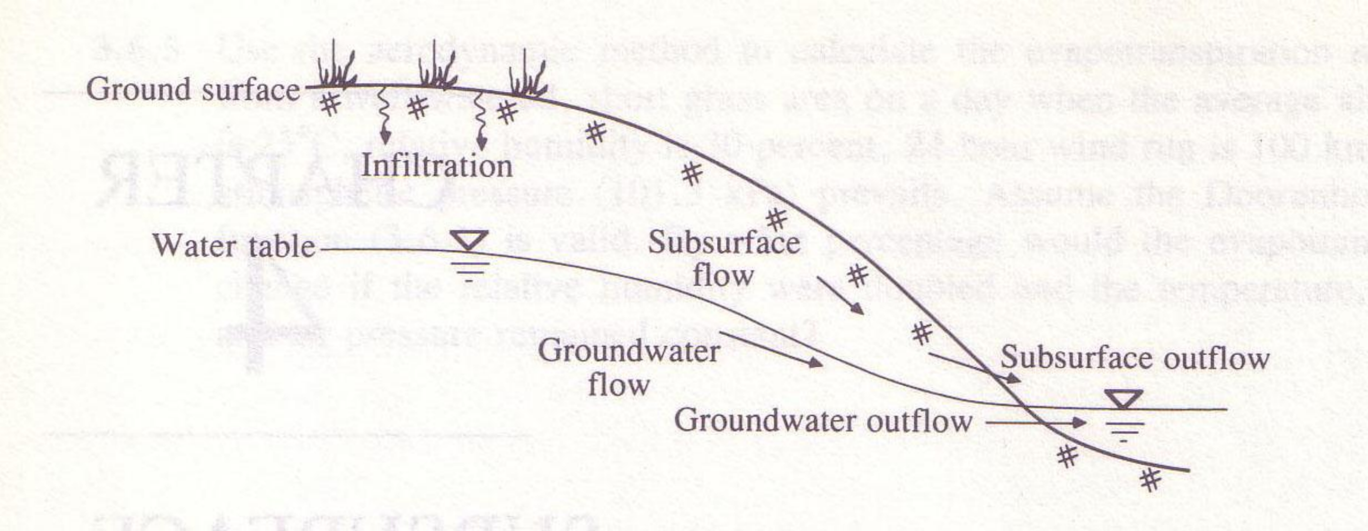
http://kids.msfc.nasa.gov/News/2001/News-Soil.asp

http://www.rsi.ca/resources/satellites/cl_land.htm

Unsaturated Flow

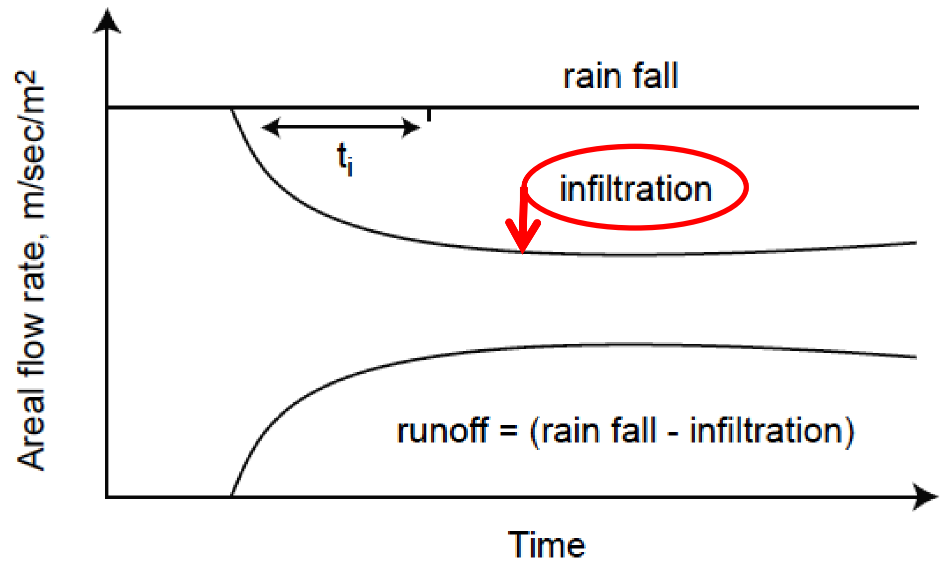
Subsurface water flows beneath the land surface.

Subsurface flow processes and the zones in which they occur are shown in the figure.

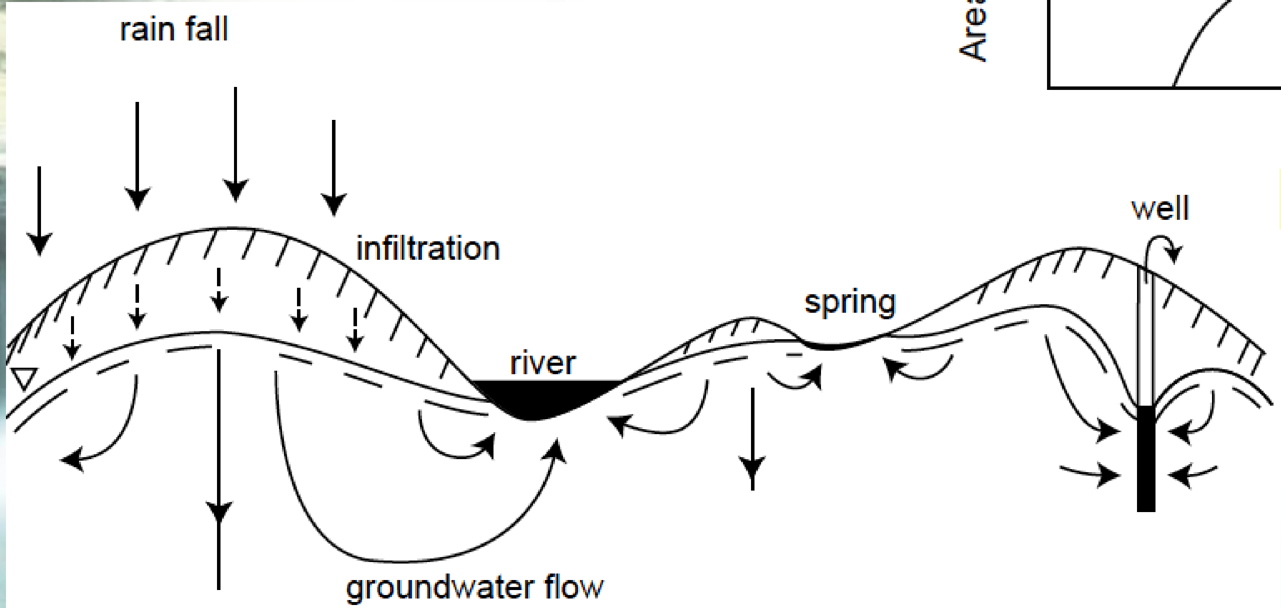


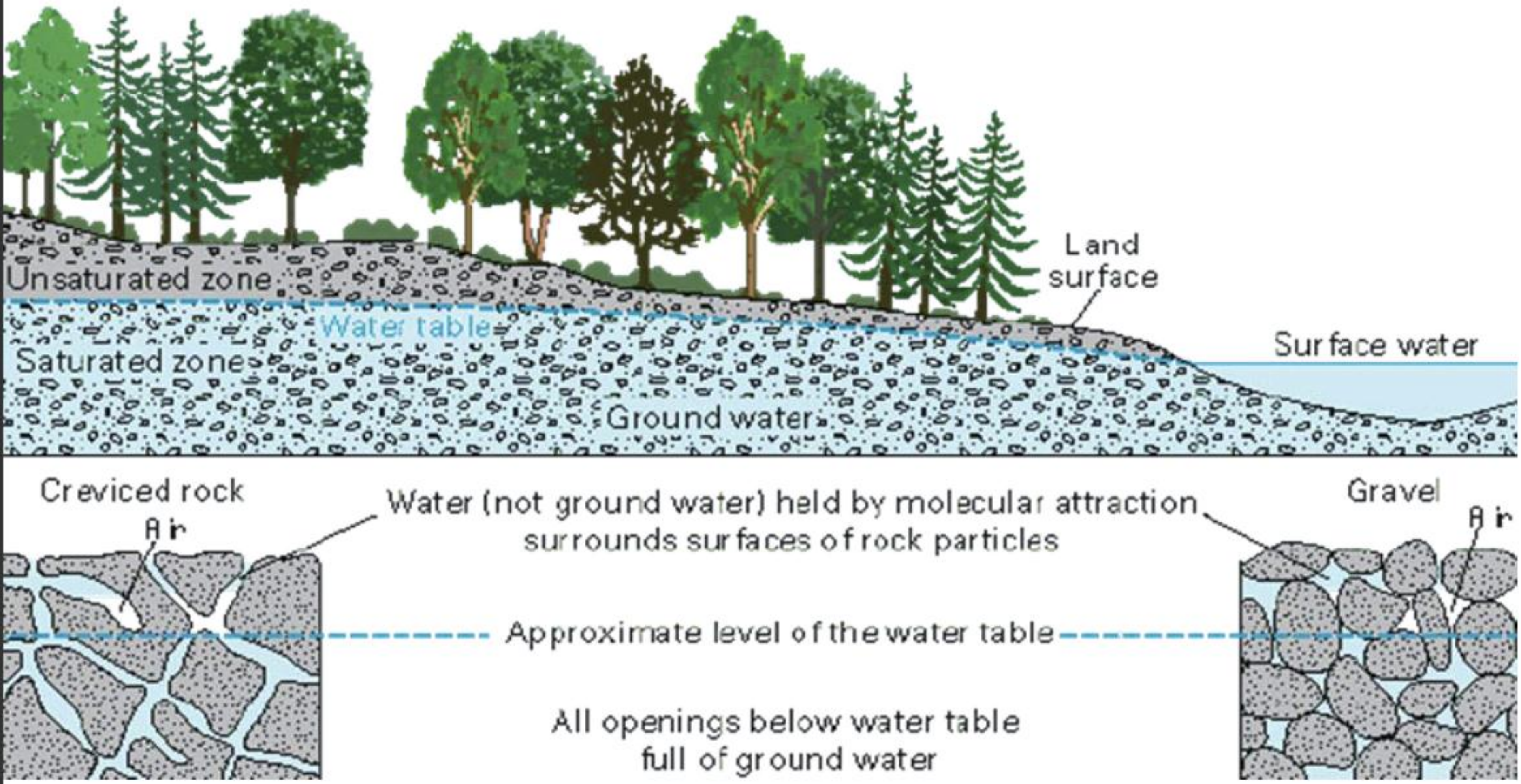
Subsurface water zone and processes.

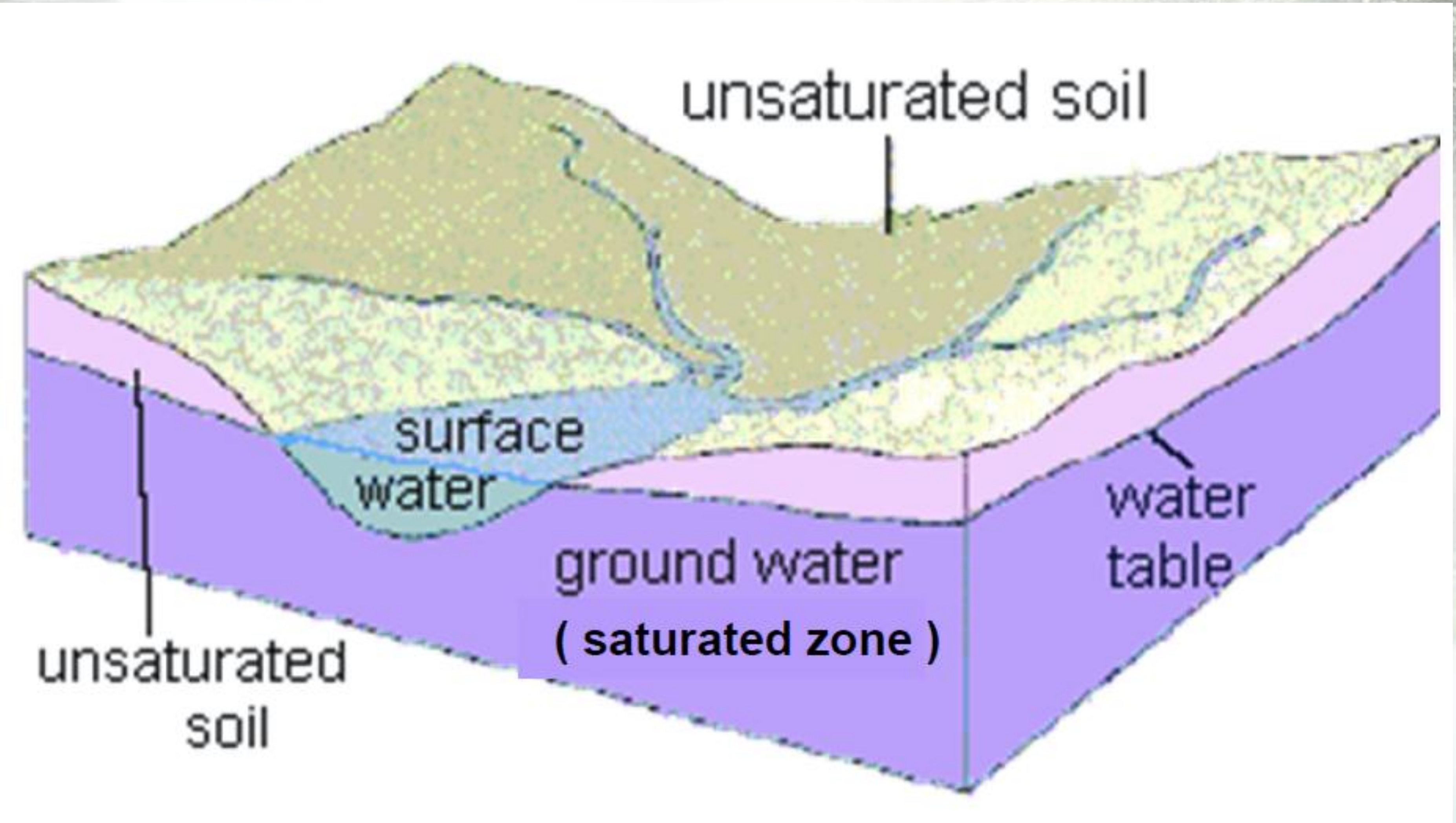
- Fluid mostly infiltrates surface
  - Infiltration rate fast at first until near-surface pores are filled, constant rate thereafter set by permeability
  - Fluid that doesn’t infiltrate the subsurface can runoff
    - Causes erosion
  - Surface with high infiltration rates are very resistant to erosion



Melosh 2011

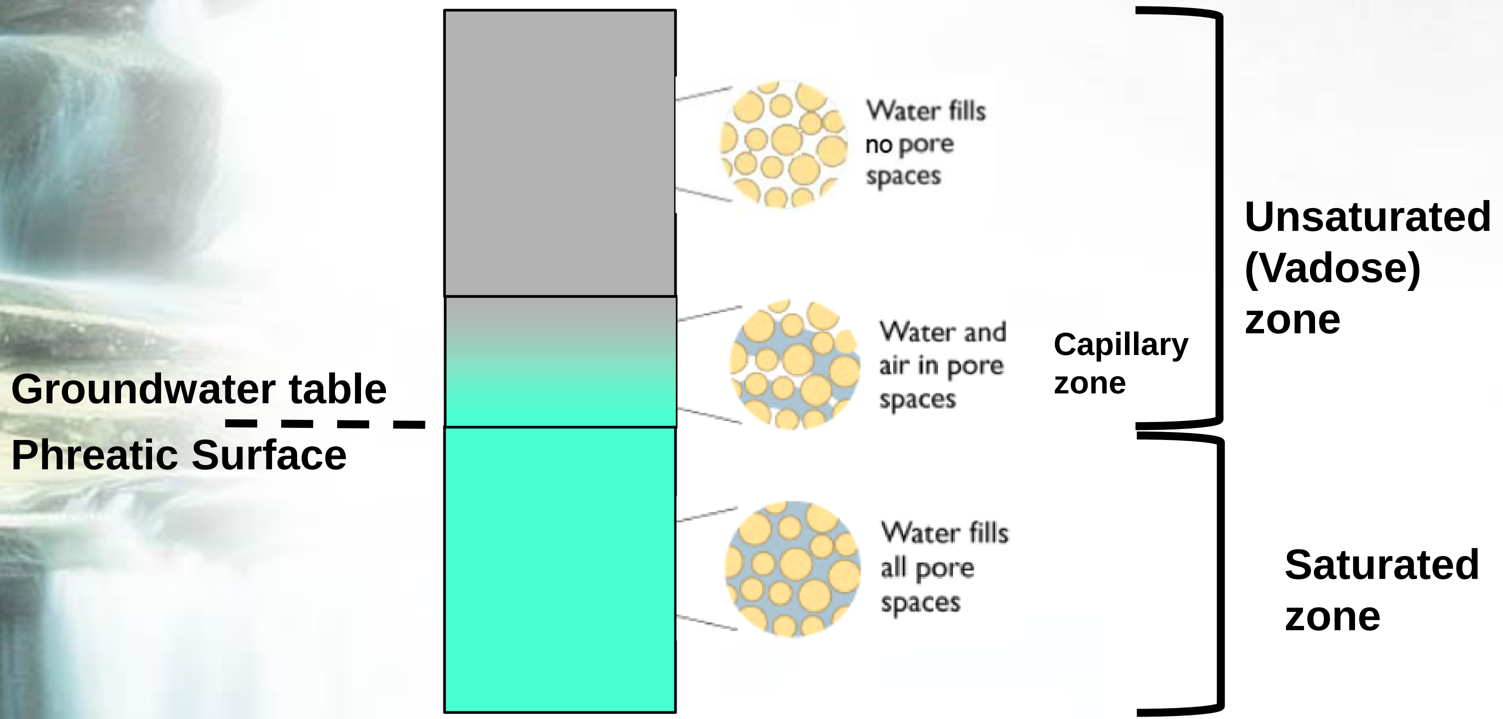



Land surface
Unsaturated zone
Water table
Saturated zone
Surface water
Ground water
Creviced rock
Air
Water (not ground water) held by molecular attraction surrounds surfaces of rock particles
Gravel
Air
Approximate level of the water table
All openings below water table full of ground water

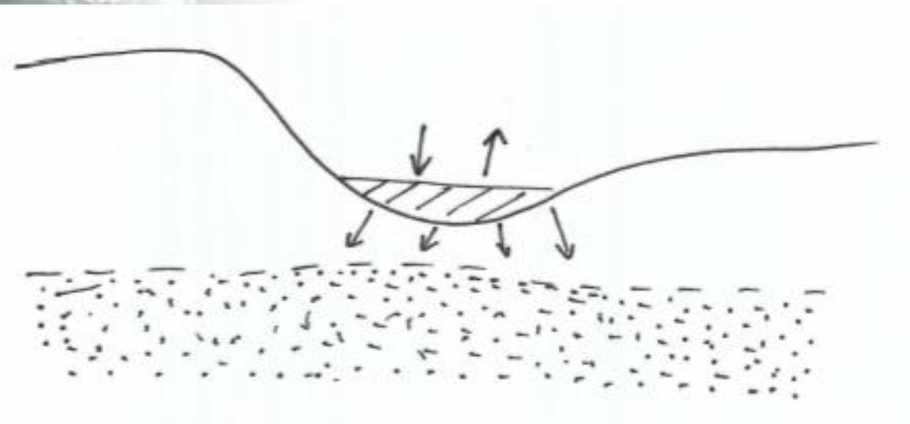


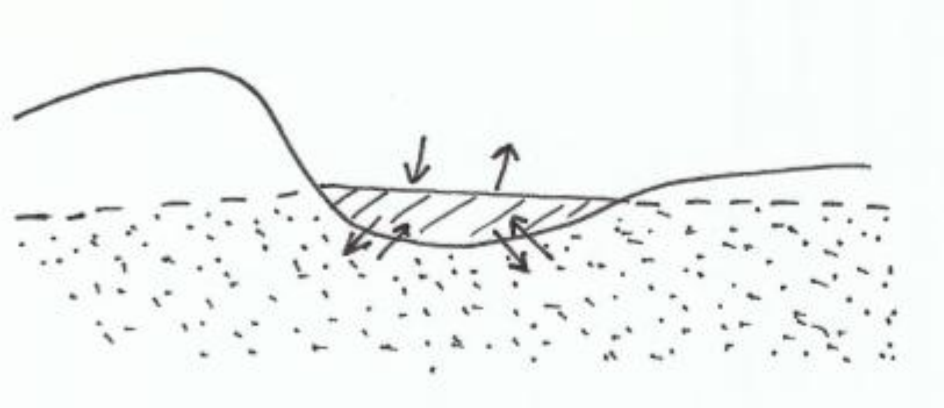
unsaturated soil
surface water
water table
ground water
(saturated zone)
unsaturated soil

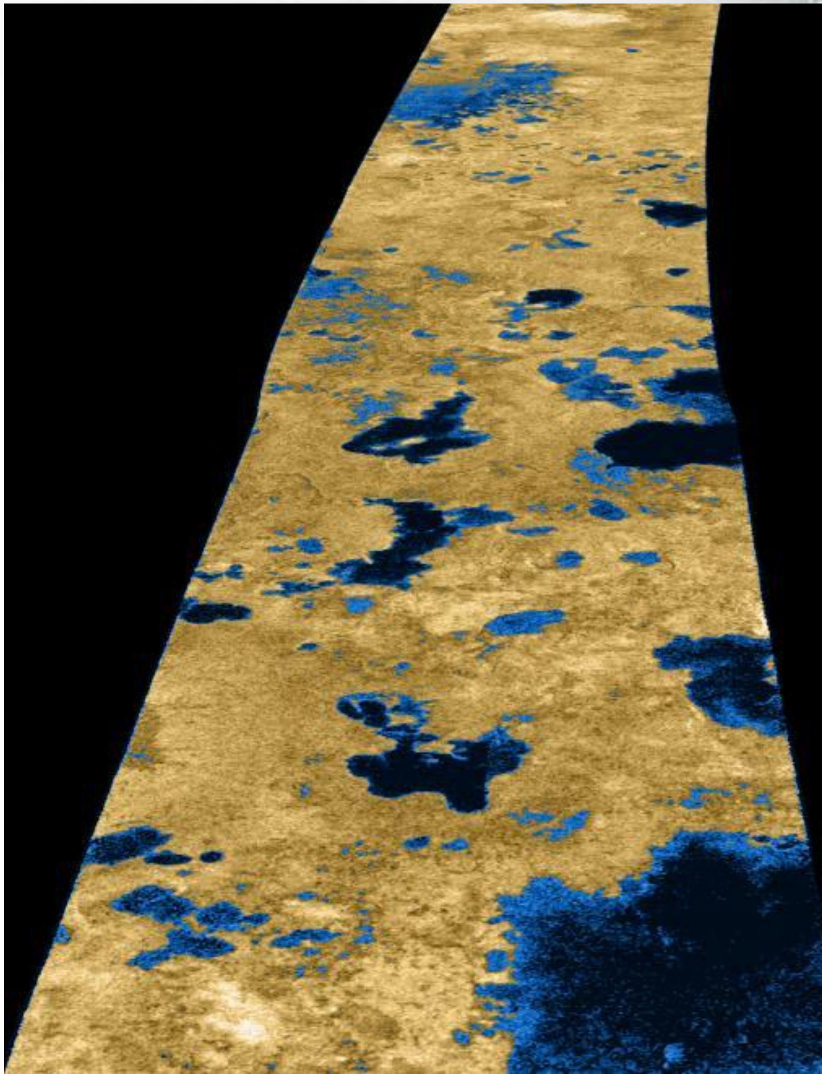
Nomenclature



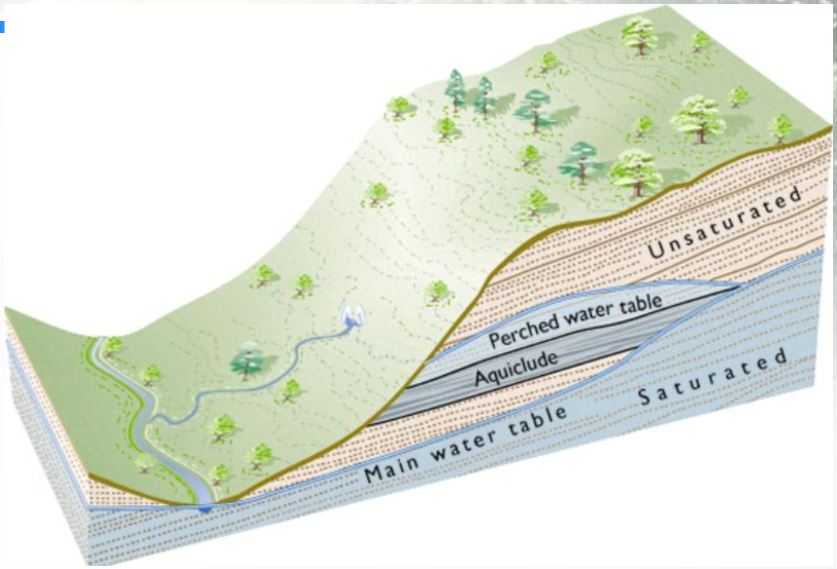
- **Ponded liquids**
  - (Precipitation – evaporation) vs. transport into the groundwater table

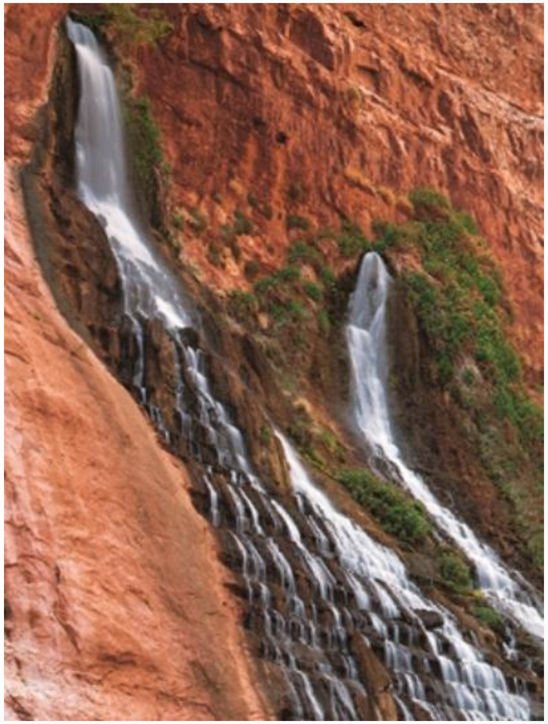






- Mix of permeable and impermeable layers can lead to perched aquifers and spring discharge
- Especially true on the Colorado Plateau where permeable sandstone overlies impermeable slitstones
- Seeps weaken rock by transporting cementing agents to the surface
- Discharge transports sediment away





Unsaturated Flow

Three important processes are

- **Infiltration** of surface water into the soil to become soil moisture.
- **Subsurface flow** (Unsaturated flow through the soil).
- **Groundwater flow** (Saturated flow through the soil/rock strata).

Unsaturated Flow

Soil and rock strata which permit water flow are called "**Porous Media**".

Flow is unsaturated when the porous medium still has some of its voids occupied by air, and saturated when the voids are filled with water.

The water table is the surface where the water in a saturated porous medium is at atmospheric pressure.

Unsaturated Flow

Below the water table, the porous medium is saturated and at greater pressure than atmosphere.

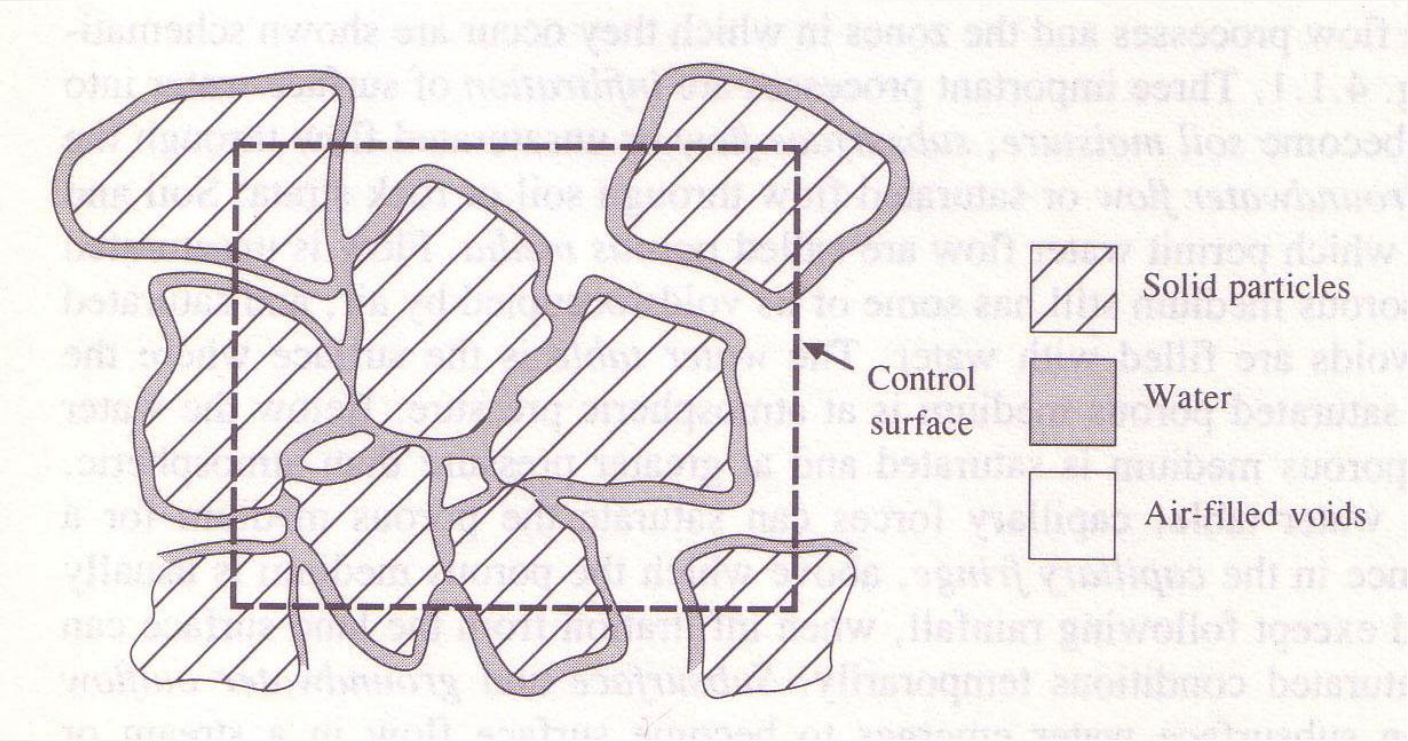
Above the water table, the porous medium is usually unsaturated except following rainfall, when infiltration from the land surface can produce saturated conditions temporarily.

Subsurface and groundwater outflow occur when subsurface water emerges to become surface flow in a stream.

Soil moisture is extracted by ET as the soil dries out.

Unsaturated Flow

Cross section through unsaturated porous medium.



A portion of cross section is occupied by soil particles and voids (air & water)

Unsaturated Flow

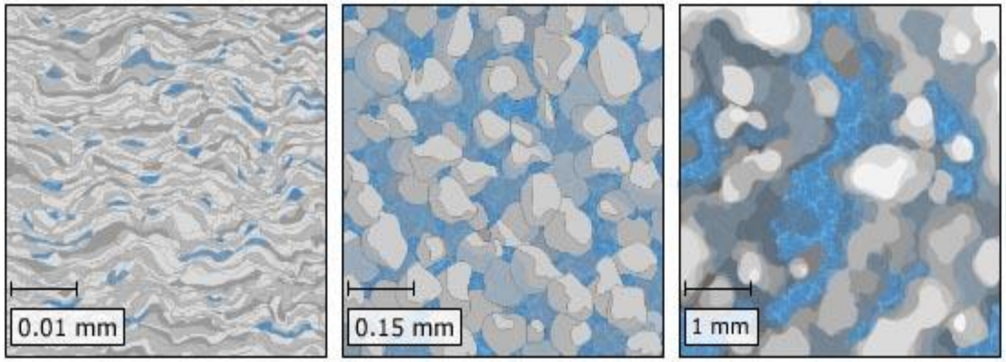
Porosity

The Porosity (η) is defined as

$$\eta = \frac{\text{Volume of Voids}}{\text{Total Volume}}$$

The range of η is approximately $0.25<\eta<0.75$ for soils, the value depending on the soil texture.

Porosity is a measure of how much of a rock/soil is open space. This space can be between grains or within cracks or cavities of the rock.



Unsaturated Flow

Soil Moisture Content

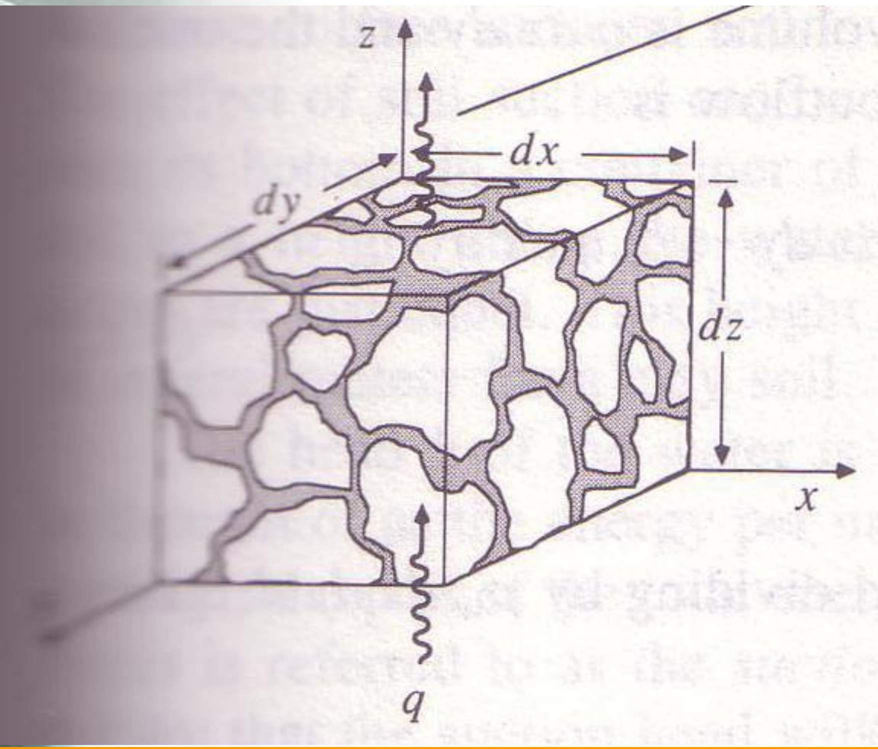
A part of the voids is occupied by water and the remainder by air, the volume occupied by water being measured by the Soil Moisture Content (θ)

$$\theta = \frac{\text{Volume of Water}}{\text{Total Volume}}$$

$0.25 < \theta < \eta$; **the soil moisture content is equal to the porosity when the soil is saturated**.

Unsaturated Flow

Darcy Flux



Control volume containing unsaturated soil

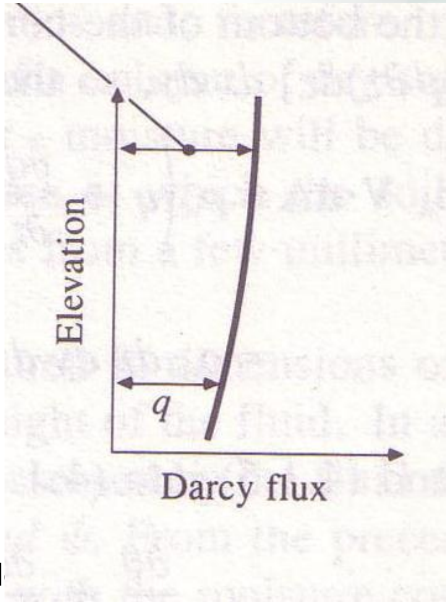
Its sides have length **dx**, **dy**, **dz** in the coordinate directions.

Volume = **dx.dy.dz**

The volume of water contained in the control volume = **θ.dx.dy.dz**

The flow of water through the soil is measured by the "**Darcy Flux**" (q)

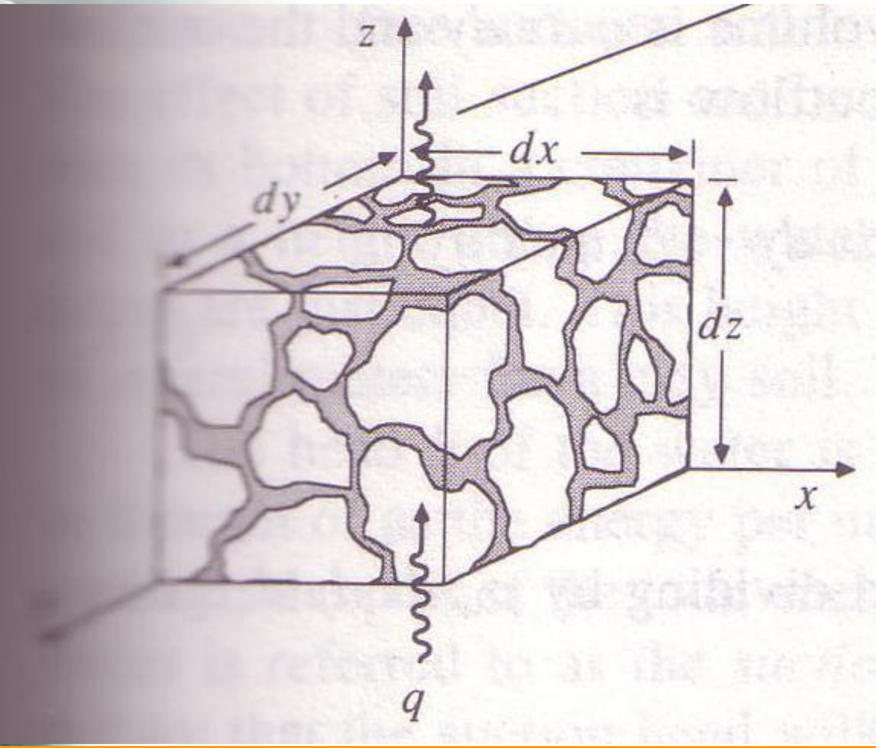
$$q = \frac{Q}{A}$$



Paul R. H

Unsaturated Flow

Darcy's Law



Control volume containing unsaturated soil

Darcy's Law was developed to relate the Darcy flux, **q** to the rate of head loss per unit length of medium, Sf

$$q = KS_f$$

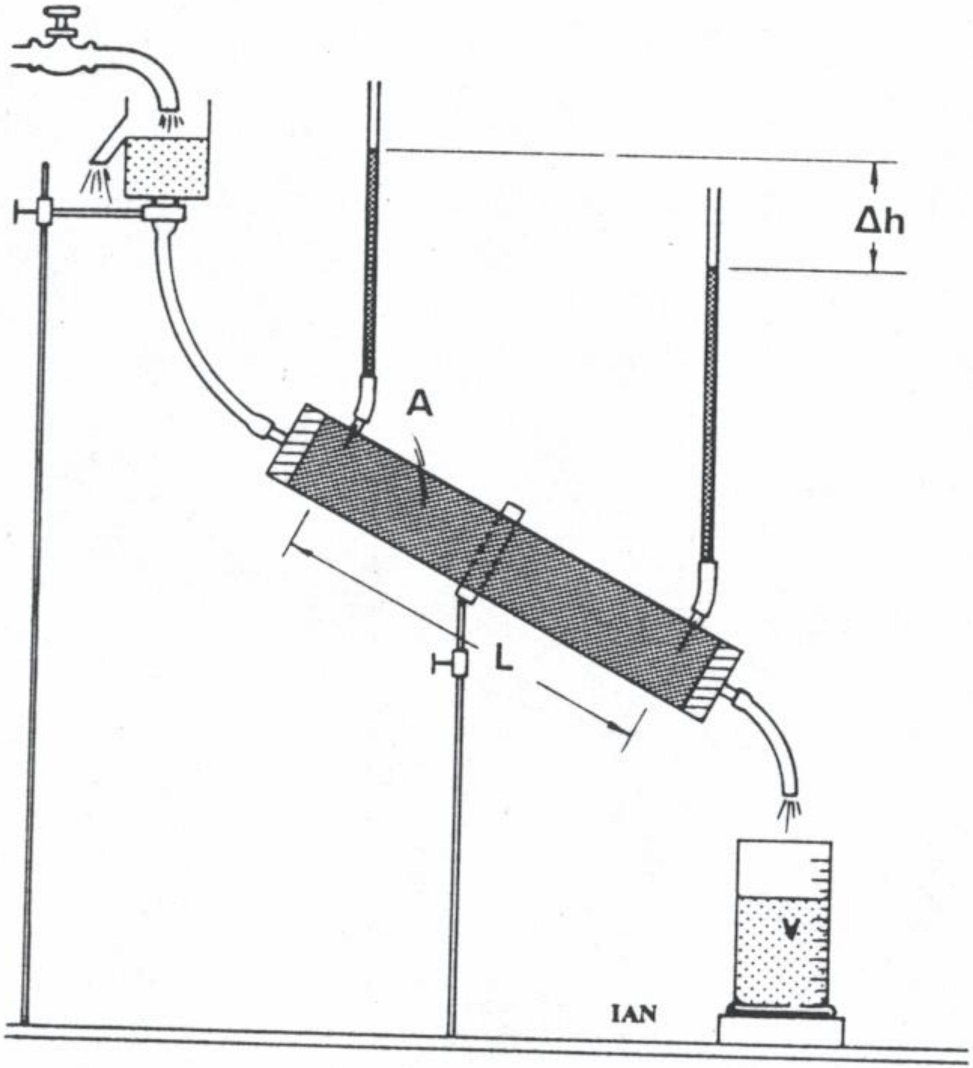
Consider flow in the vertical direction and denote the total head of the flow by **h**

$$Sf = -\frac{\partial h}{\partial z}$$

$$q = -K\frac{\partial h}{\partial z}$$

Darcy's Equation

The negative sign indicates that the total head is decreasing in the direction of flow because of friction,



Darcy's Law

- V = Ki = K (Δh/ΔL)

  where:

  V = velocity,

  i = hydraulic gradient,

  K= constant for sediment and liquid types
  =hydraulic conductivity

Infiltration

Infiltration is a process of water penetrating from the ground surface into the soil.

The factor influences the infiltration rate

1) condition of soil surface and its vegetative cover
2) the properties of the soil: porosity and hydraulic conductivity
3) the current moisture content of the soil.

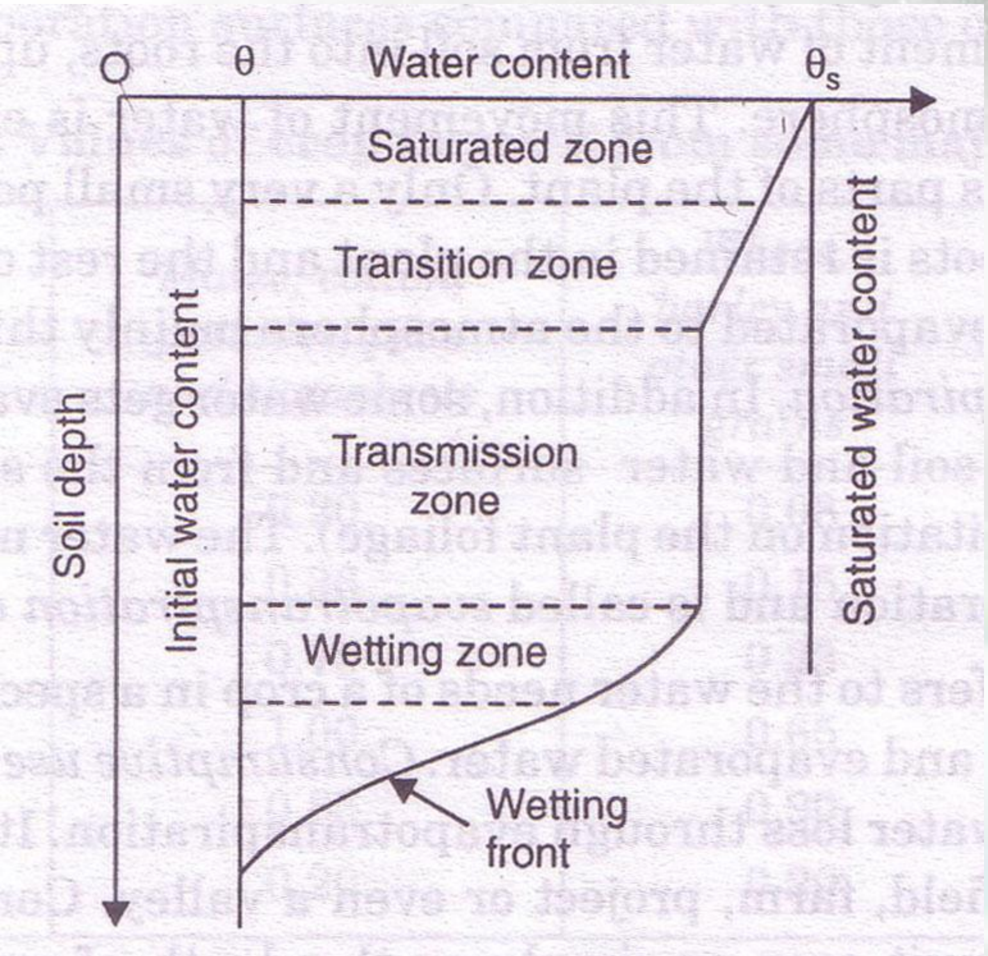
Hydraulic Conductivity/Permeability is a measure of the ease with which a fluid (water in this case) can move through a porous media.

Infiltration

The distribution of soil moisture within the soil profile during the downward movement of water is illustrated in the figure.

There are 5 moisture zones

1) **Saturated zone**
2) **Transition Zone**
3) **Transmission zone**
4) **Wetting zone**
5) **Wetting front**



Moisture zones during infiltration.

Infiltration

1) Saturated Zone :

near the surface, extending up to about 1.5 cm below the surface and having a saturated water content.

2) Transition Zone :

which is about 5 cm thick and is located below the saturated zone. In this zone, a rapid decrease in water content occurs.

3) Transmission Zone :

the water content varies slowly with depth as well as time.

Infiltration

4) Wetting Zone :

in which sharp decrease in water content is observed.

5) Wetting Front :

a region of very steep moisture gradient. This represents the limit of moisture penetration into the soil.

The infiltration rate, f expressed in inches per hour or centimeters per hour, **is the rate at which water enters the soil at the surface**.

If water is ponded on the surface, the infiltration occurs at the **Potential Infiltration Rate**.

Infiltration

If rainfall at the surface is less than the potential infiltration rate then **the actual infiltration rate will also be less than the potential rate**.

Most infiltration equations describe the potential rate.

The cumulative infiltration, F is **the accumulated depth of water infiltrated during a given time period** and is equal to the integral of the infiltration rate over that period.

$$F(t) = \int_0^t f(\tau) d\tau$$

τ is variable of time in the integration.

$$f(t) = \frac{dF(t)}{dt}$$

The infiltration rate is the time derivative of the cumulative infiltration.

Infiltration

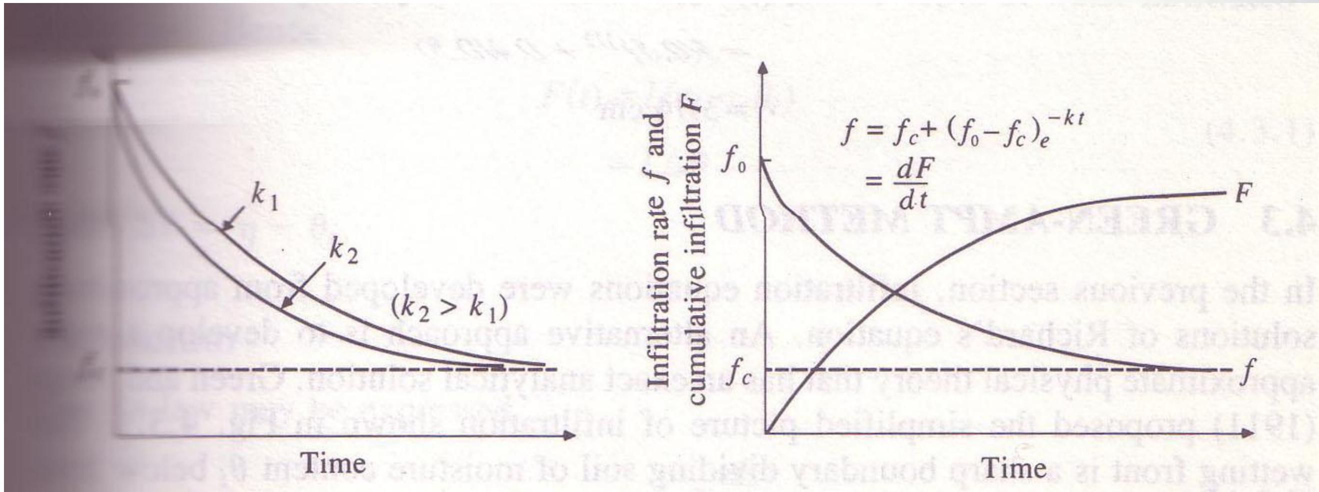
Horton's Equation

One of the earliest infiltration equations was developed by Horton (1933, 1939) who observed that

"infiltration begins at some rate, fo and exponentially decreases until it reaches a constant rate, fc"

$$f(t) = f_c + (f_0 - f_c)e^{-kt}$$

K = a decay constant having dimensions $[T^{-1}]$



(a) Variation of the parameter k. (b) Infiltration rate and cumulative infiltration.

Infiltration by Horton's Equation.

Infiltration

Phillip's Equation

Philip (1957, 1969) solved the equation to yield an infinite series for cumulative infiltration, F(t), which is approximated by

$$F(t) = St^{1/2} + Kt$$

S = a parameter called sorptivity (which is a function of the soil suction potential)

K = hydraulic conductivity

By differentiation

$$f(t) = \frac{1}{2} St^{1/2} + K$$

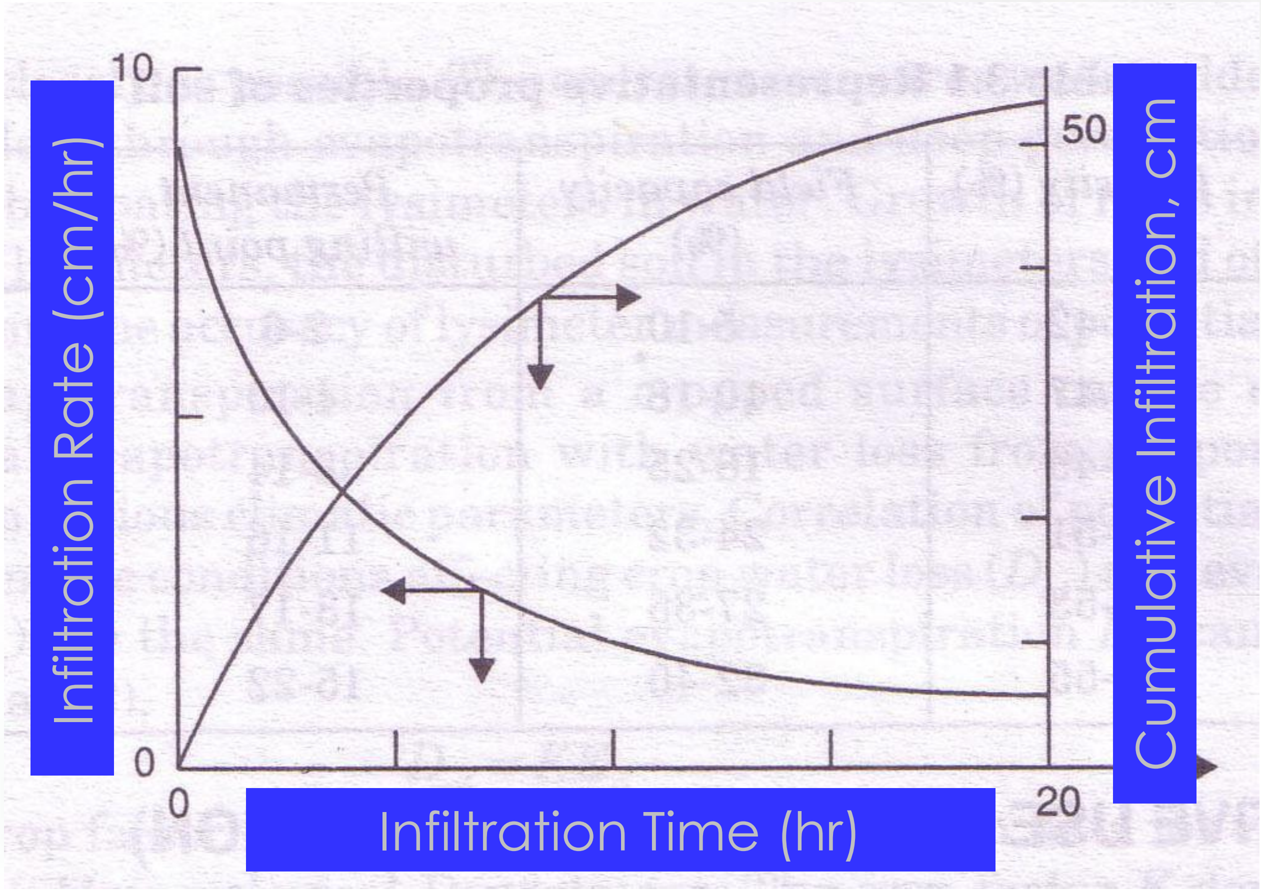
As $t \rightarrow \infty$, f(t) tends to K

For a horizontal column of soil, soil suction is the only force drawing water into the column

$$F(t) = St^{1/2}$$

Infiltration

Phillip's Equation



Variation of infiltration rate and cumulative infiltration with time

Infiltration

Soil Texture	Porosity (%)	Basic Infiltration Rate (cm/hr)
Sand	32-42	2.5-25
Sandy Loam	40-47	1.3-7.6
Loam	43-49	0.8-2.0
Clay Loam	47-51	0.25-1.5
Silty Clay	49-53	0.03-0.5
Clay	51-55	0.01-0.1