Contents

•Soil water and hydraulic characteristics of the soil

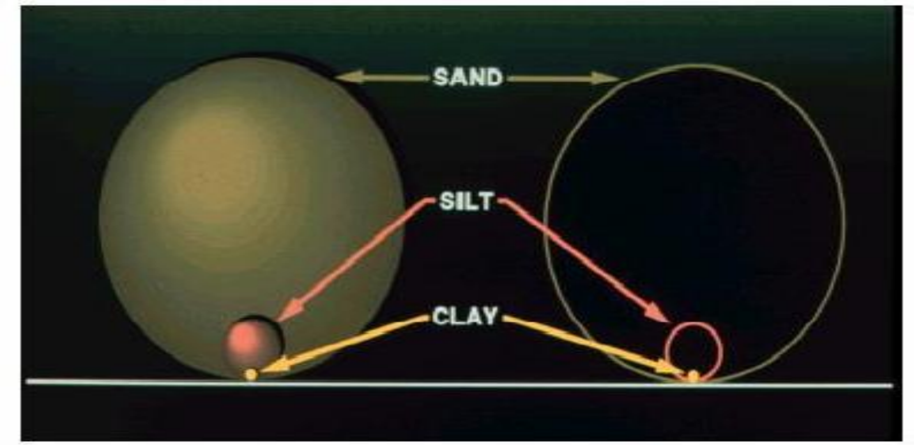
Learning objectives:

- Description of the soil hydraulic characteristics;
- Darcy law;
- Soil hydraulic properties;
- Saturated hydraulic conductivity.

Soil pores and soil particles

- Soils consist of particles with a range of size from clay to gravel
- Between the particles are irregular-shaped conduits called pores
- The diameter of the pores is roughly proportional to the sizes of the particles (pores in sand > pores in silt)

Particle size measurement

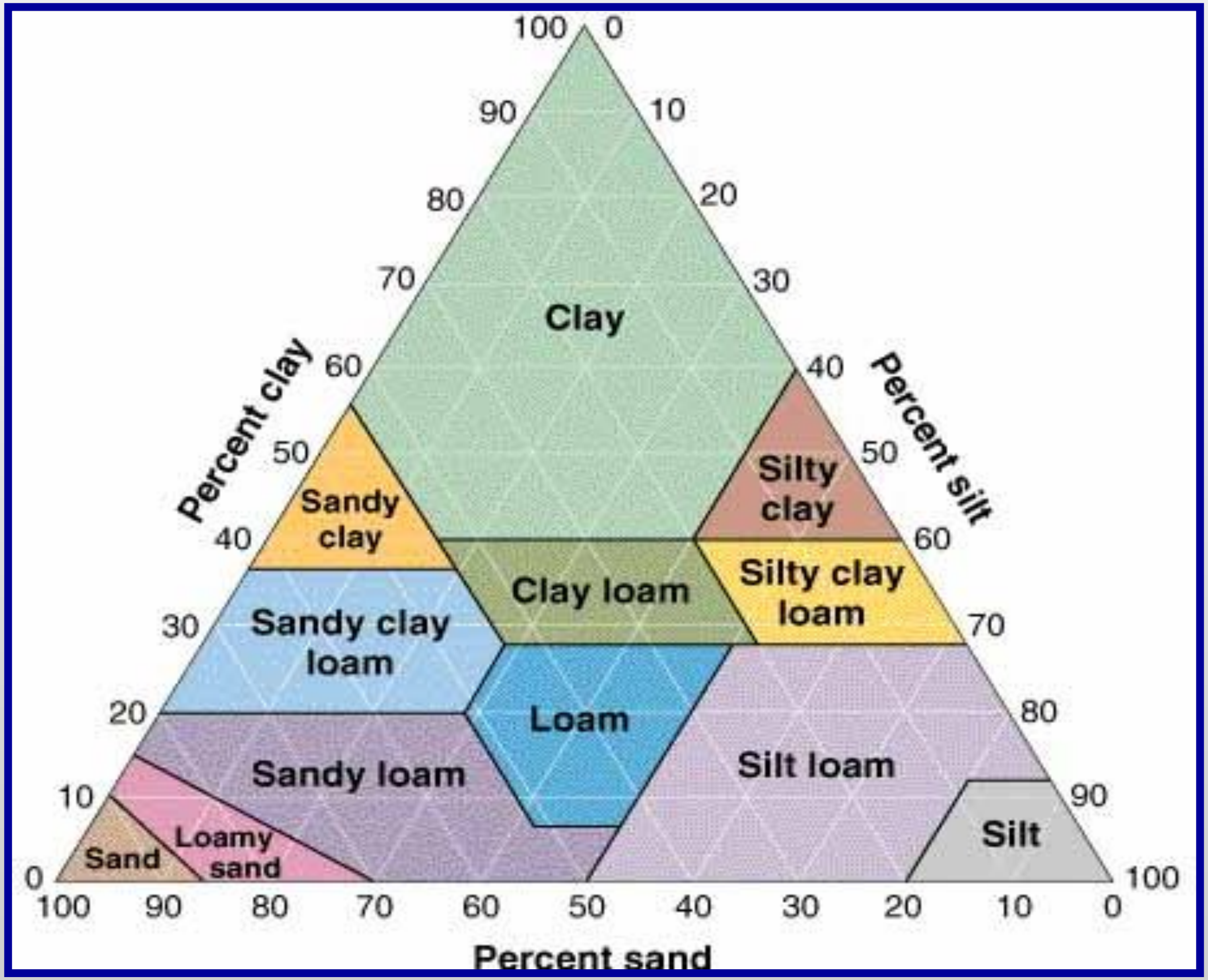


Relative sizes of sand, silt, and clay.

Seives of progressively smaller size to get size distribution of soil

http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s2chp1.htm

Soil texture



Use of the soil texture triangle: example

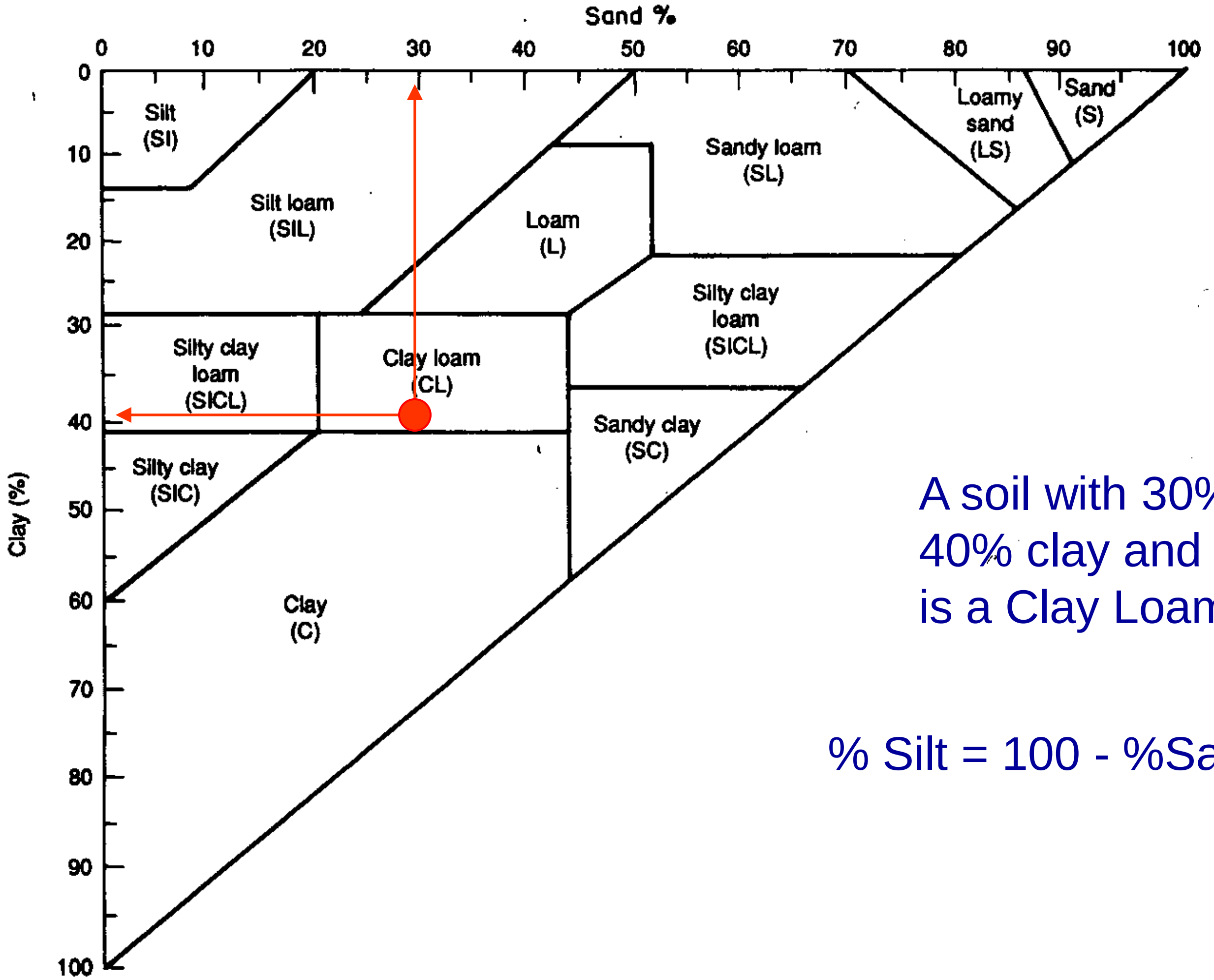


FIGURE 5.1.2 USDA soil textural triangle.

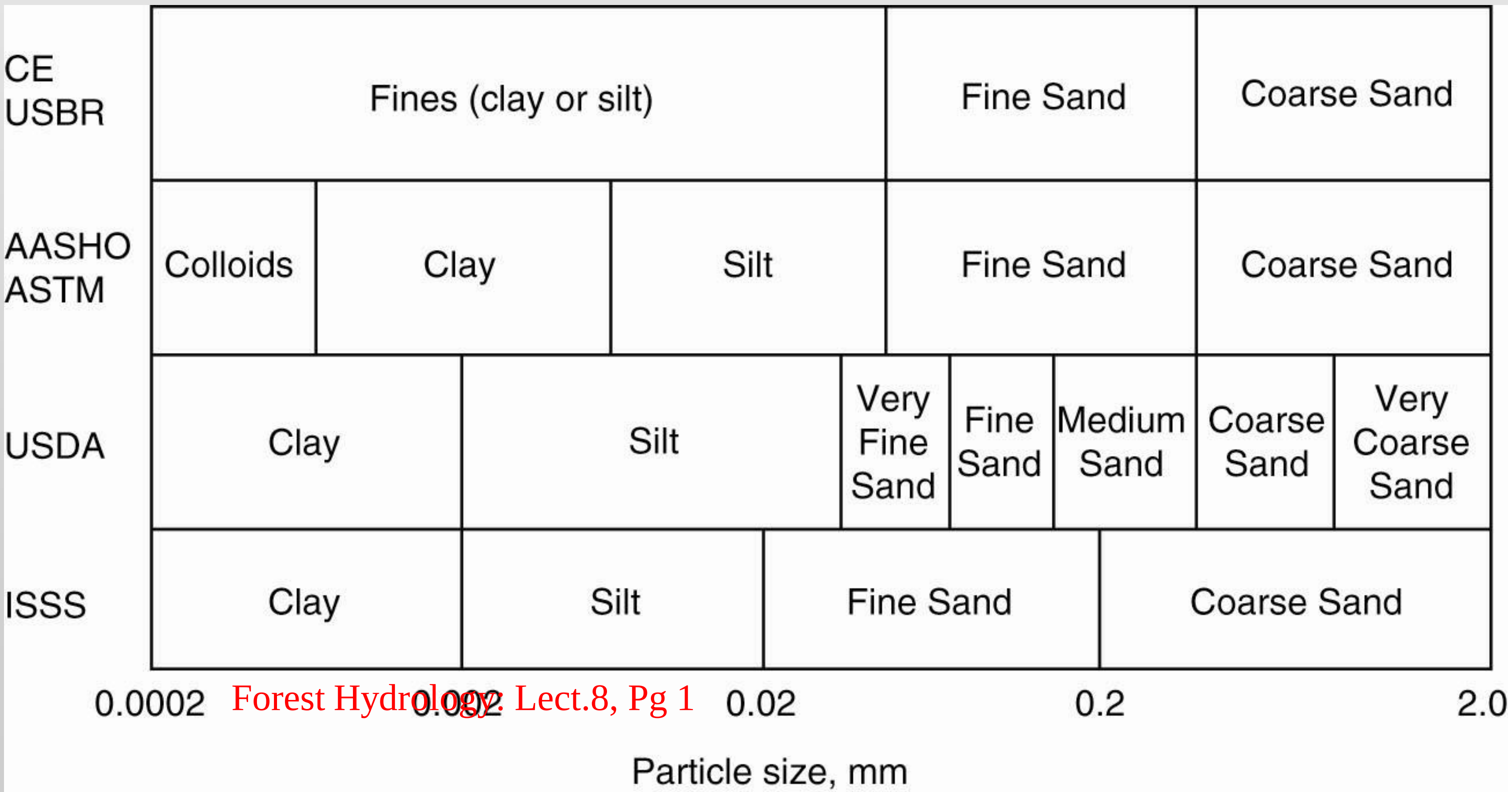
A soil with 30% sand, 40% clay and 30% silt is a Clay Loam

% Silt = 100 - %Sand - %Clay

Soil classification

USDA particle size classification

< 0.002mm is clay
0.002 – 0.05mm is silt
0.05mm – 2 mm is sand
> 2 mm is gravel



The soil matrix

Consider a sample of soil of total volume V_t

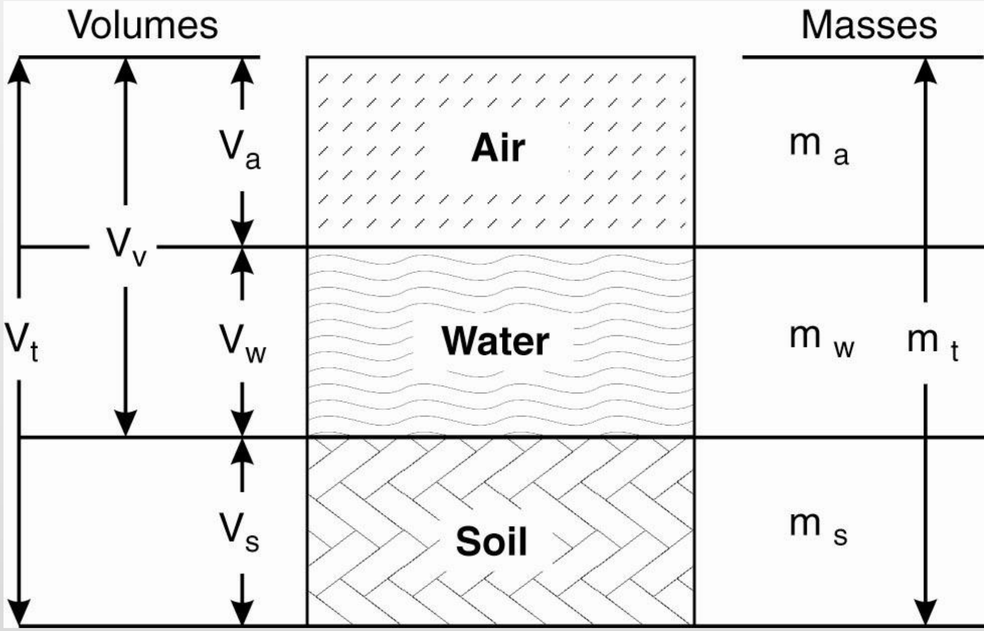
Solid:: volume $\Rightarrow V_s$

Void: volume $\Rightarrow V_v = V_t - V_s$

Water: volume $\Rightarrow V_w$ $(V_w < V_v)$

Porosity: $n = \dfrac{V_v}{V_t}$ $n<1$

Void index: $\boldsymbol{e = \dfrac{V_v}{V_s}}$



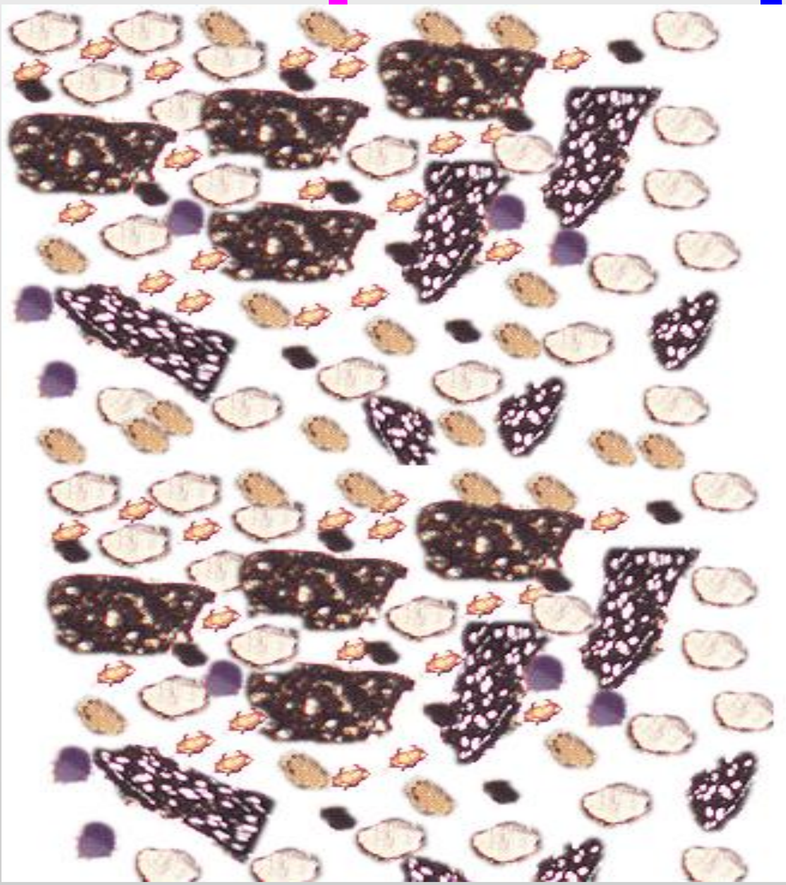
$\Rightarrow$ ***Volumetric soil water content*** $\theta = V_w / V_t$

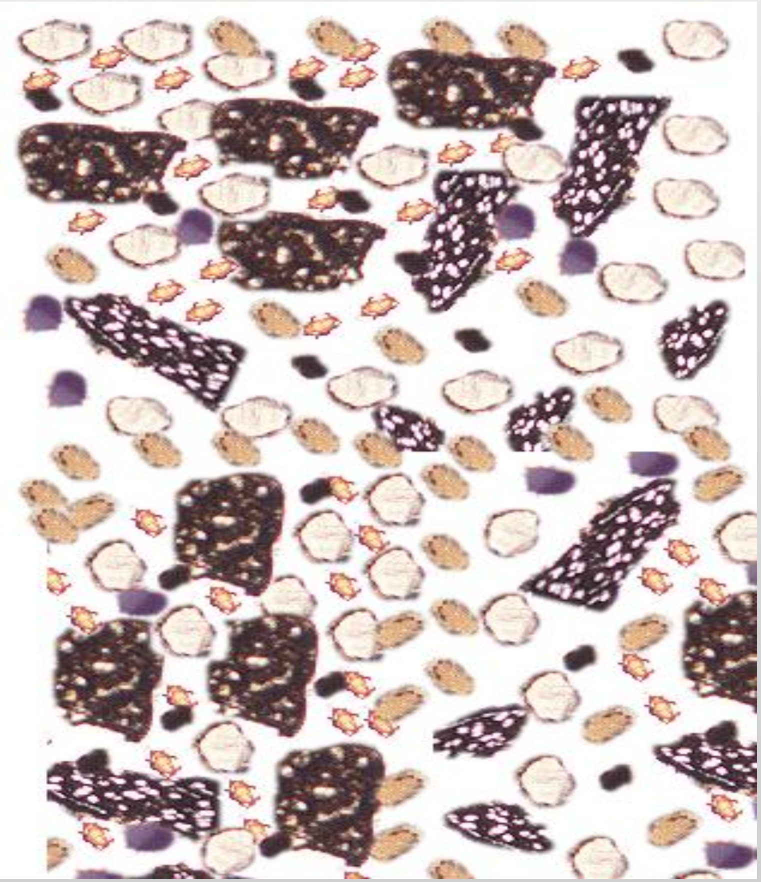
Degree of saturation $S = V_w/V_v$

Movement of water into the soil

Water moves through the spaces between soil particles

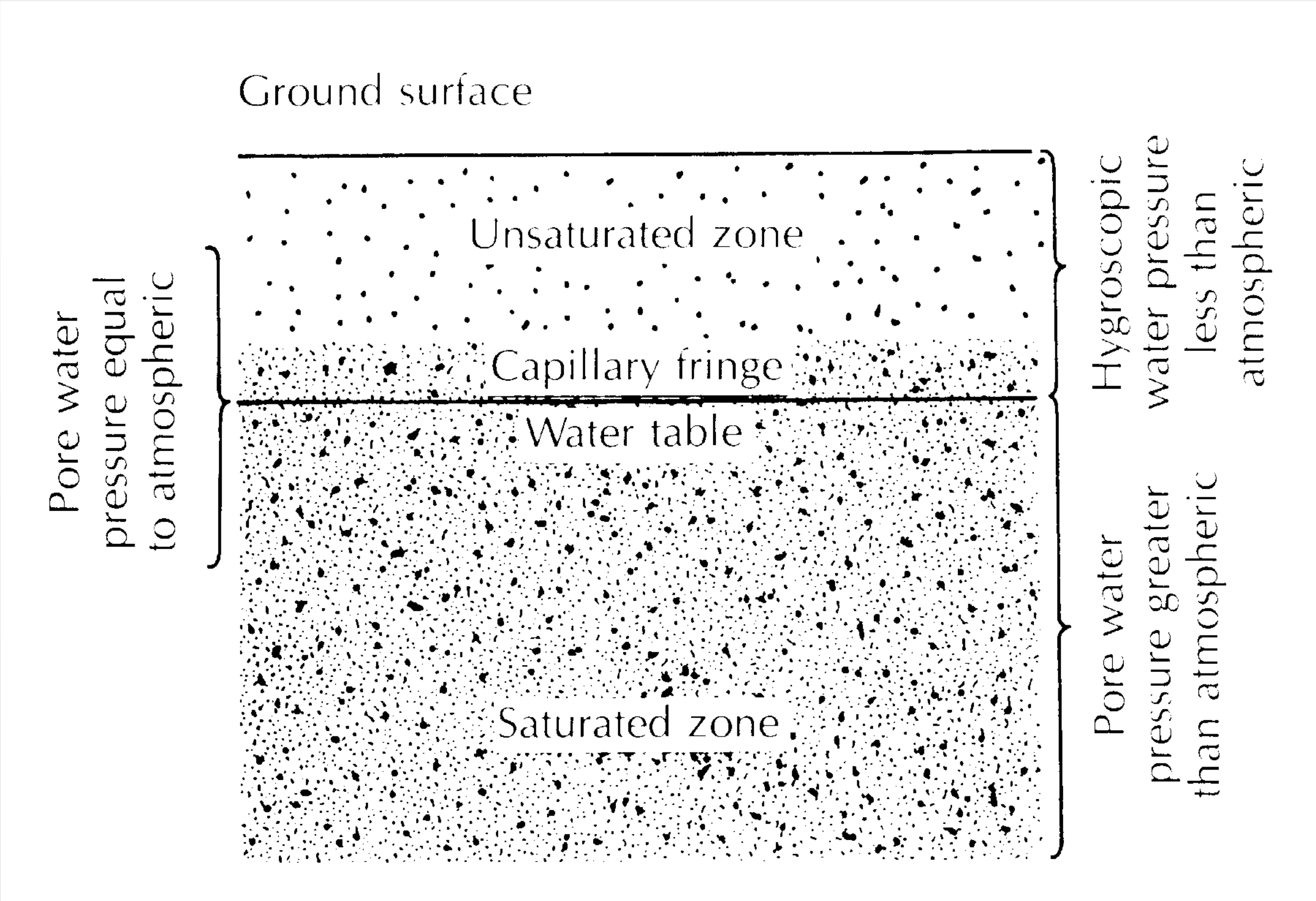
Water moves through old root channels, animal burrows, and between soil blocks.





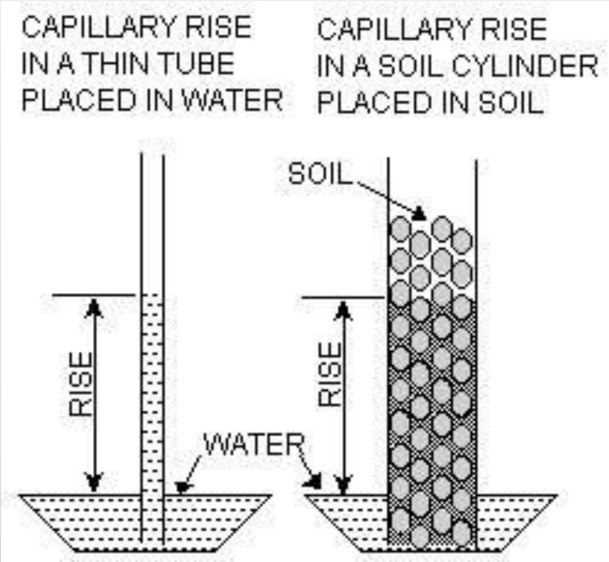
Percolation is the movement of water through soil

Wetting Profiles

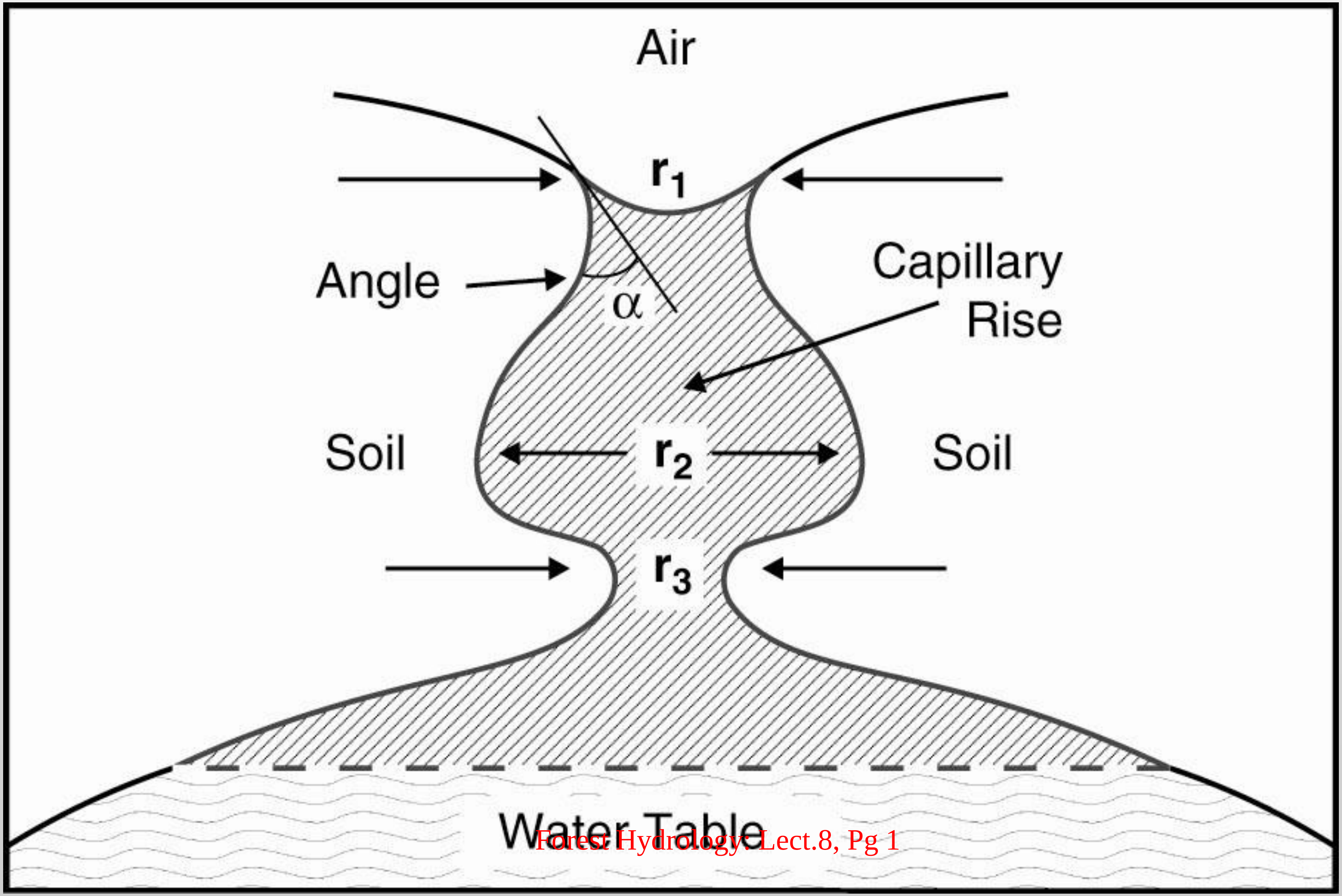


Matrix Potential

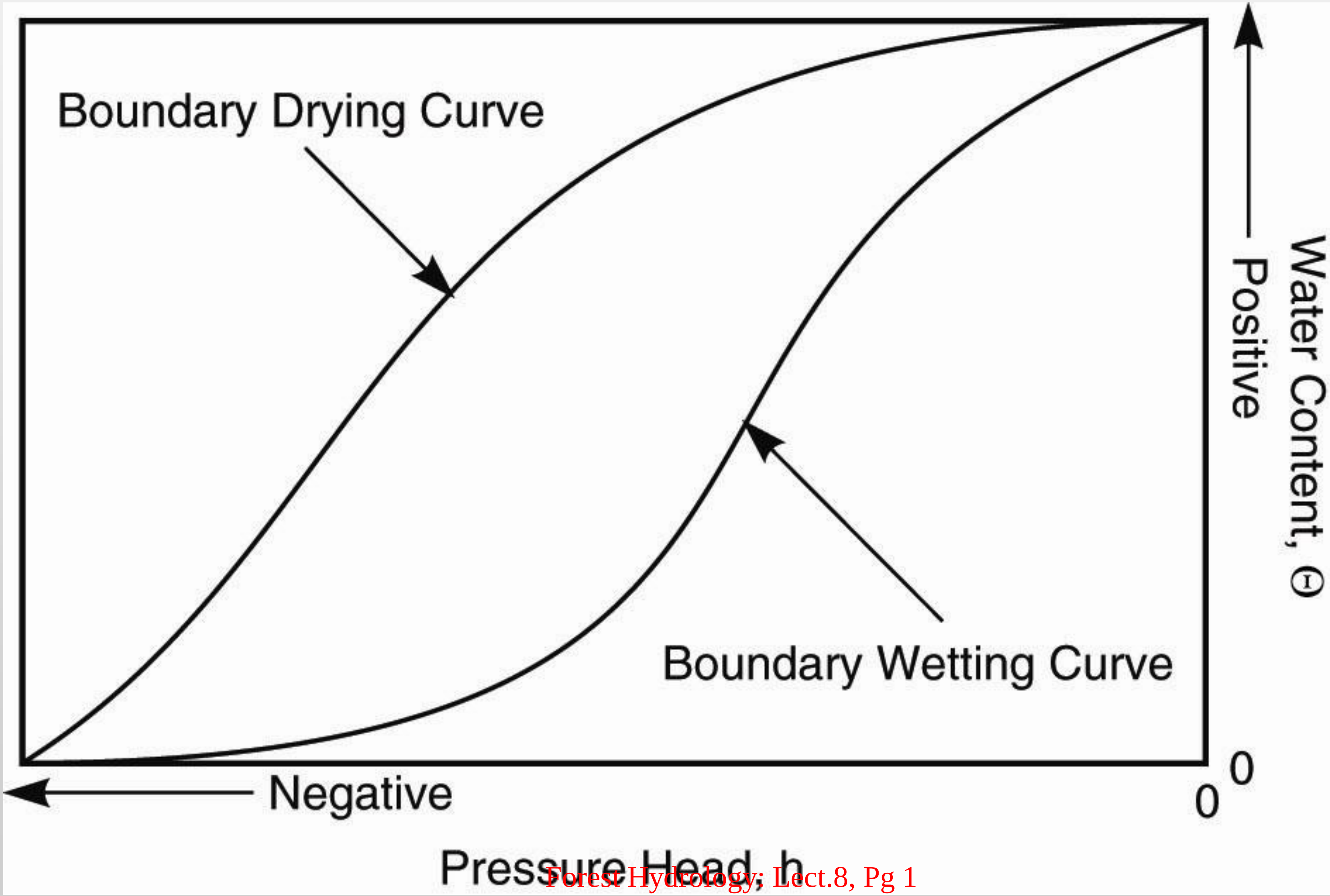
- Capillary forces
  - Water has high surface tension
- Leads to zone above the “water table” that where pores are saturated
  - Capillary Rise
  - Varies from a few cm to a few m(!)
  - Texture dependent
- Also accelerates infiltration into unsaturated soils



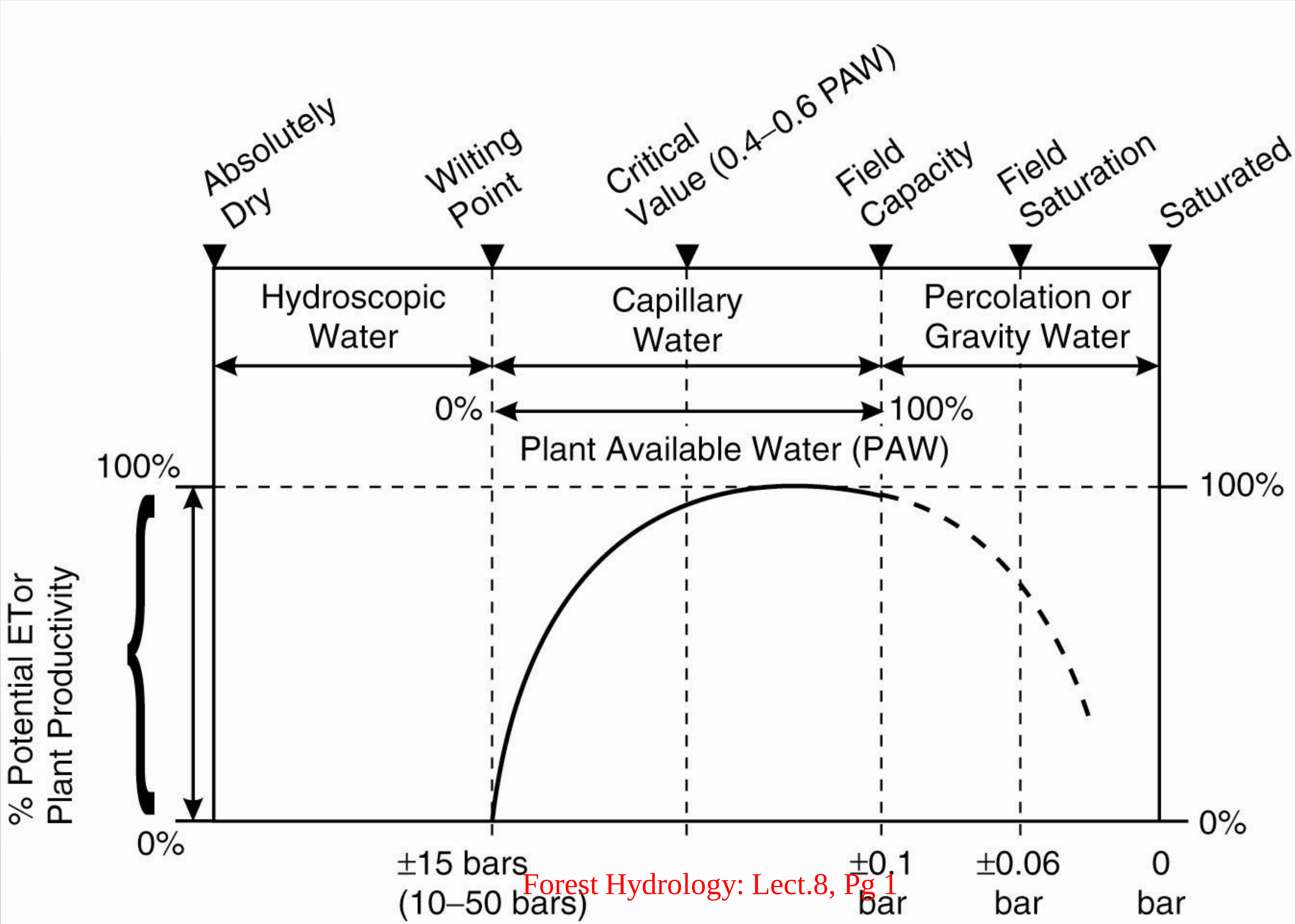
Water Retention



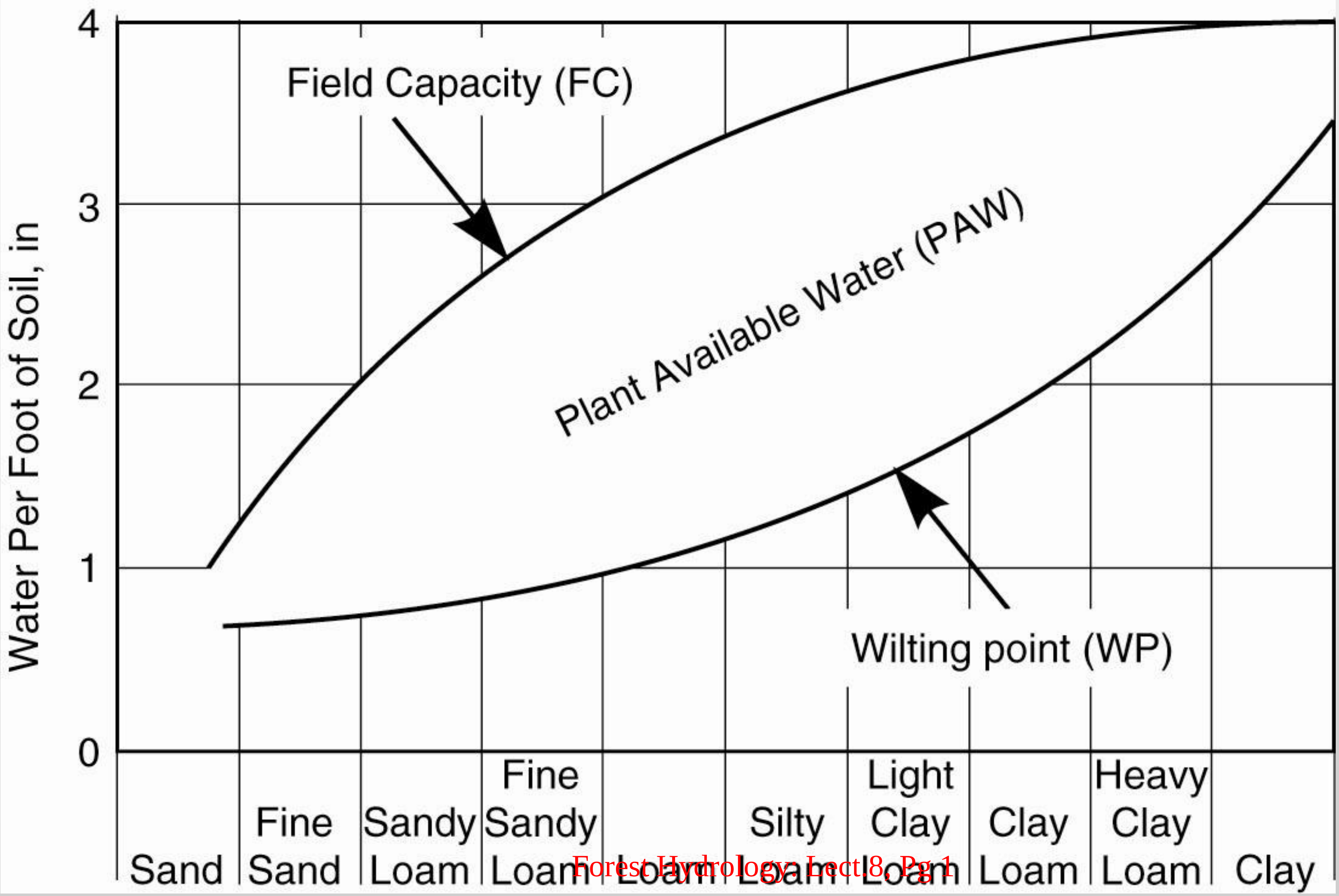
Hysteresis


Boundary Drying Curve
Boundary Wetting Curve
Water Content, Θ
Positive
0
Negative
0
Pressure Head, h

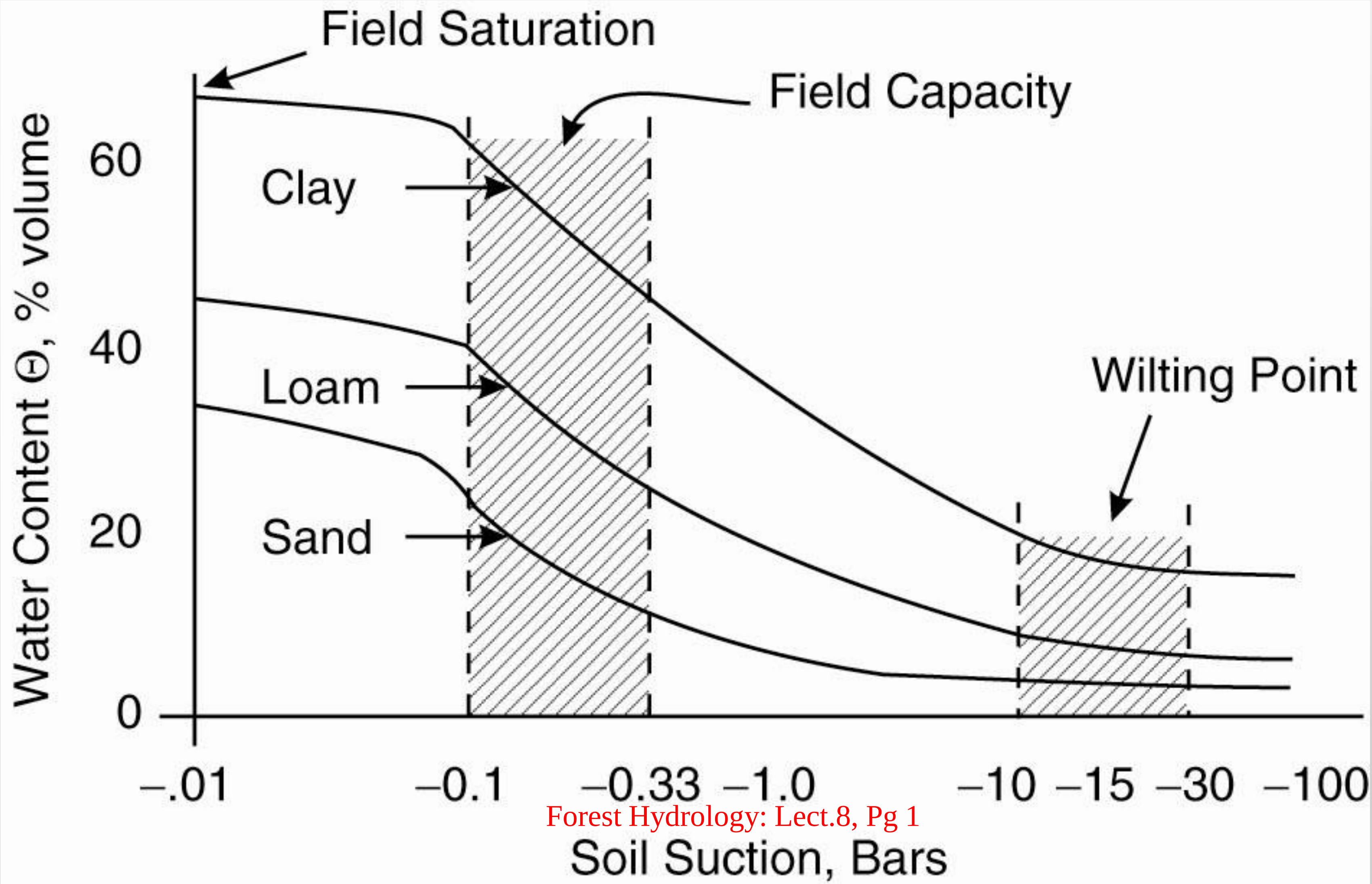
Plant Response to Soil-Water Content



Plant Available Water versus Texture



Soil-Water Relationships



Darcy law: first quantitative understanding of saturated flow in porous media

Darcy 1856 study of the aquifers under Dijon;

He introduced the concept of potential flow

Water moves in direct proportion to:
- the gradient of potential energy
- the permeability of the media

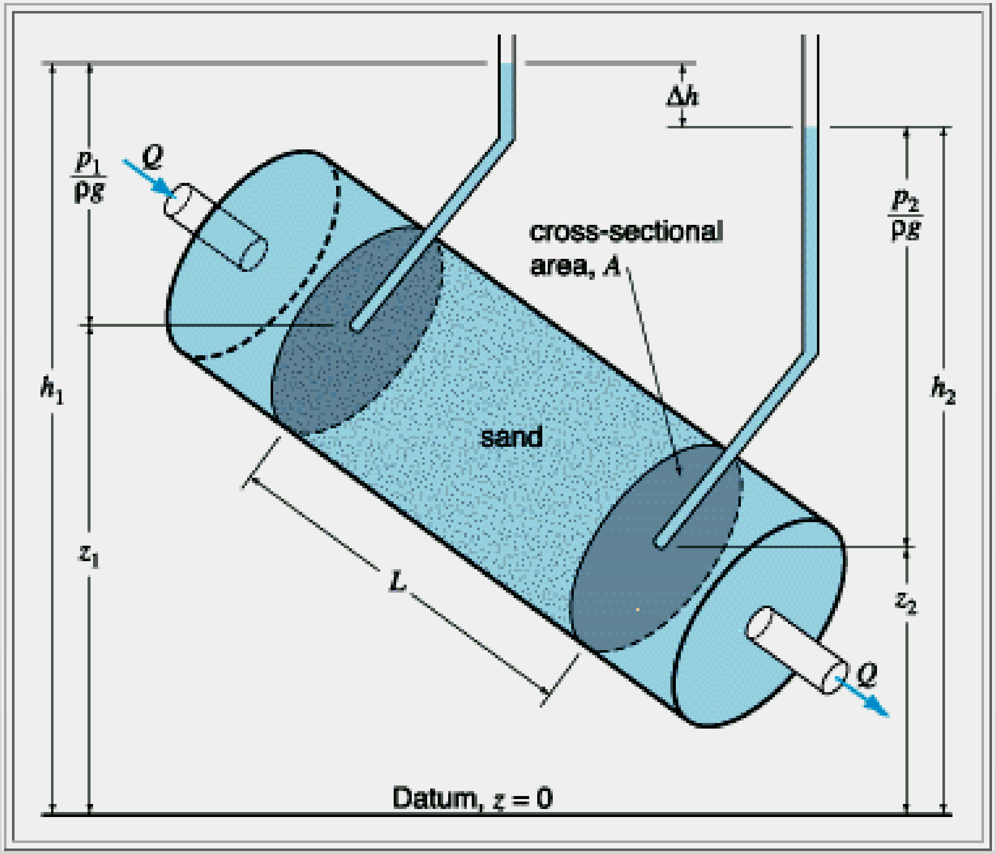
Darcy Law

The figure provides a schematic description of the apparatus used by Darcy in his experiments in 1856.

In 1856, Darcy carried out a number of experiments on the water flow through sand columns.

By varying L (lenght of the sand column) and the difference in the hydraulic head (Δh), Darcy found that the discharge Q varied in direct proportion to the cross section area A and to Δh and inversely to L.

This can be written down as:



$$Q = KA\frac{h_1 - h_2}{L}$$

where K is the ***hydraulic conductivity*** [L T^{-1}]

Darcy Law

The Darcy equation may be written more generally as

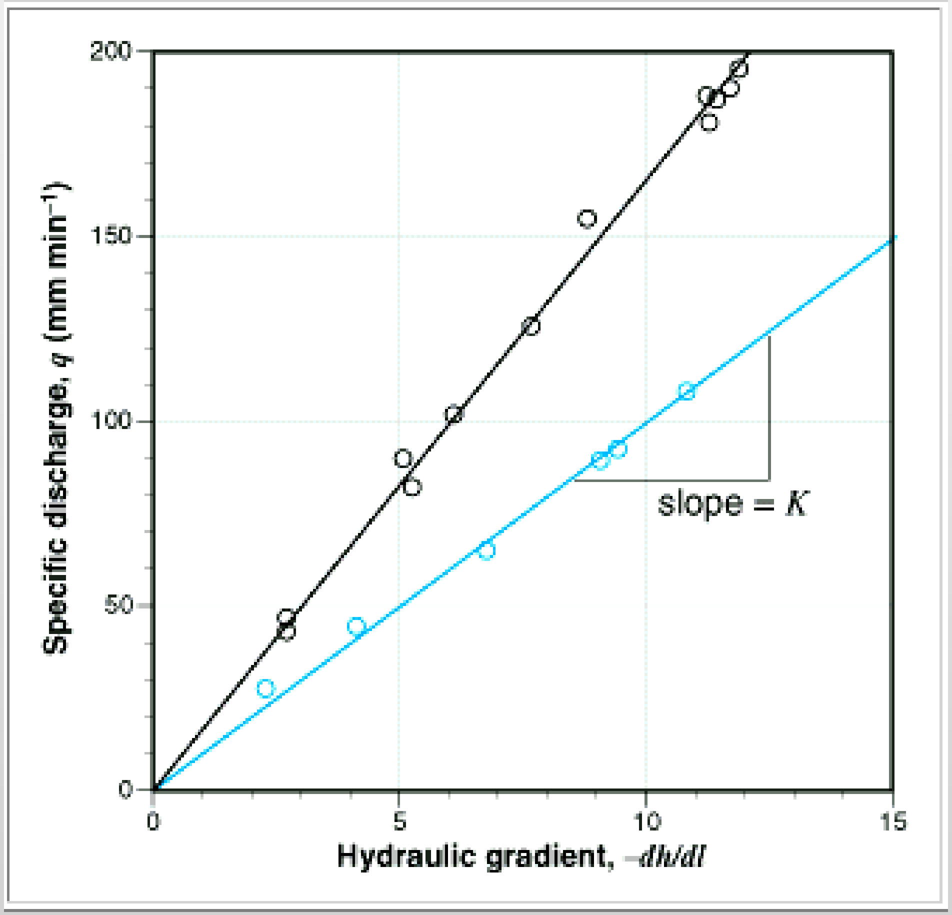
$$\frac{Q}{A} = -K\frac{h_2 - h_1}{L}$$

$$\Rightarrow \quad q = -K\frac{dh}{dl}$$

q = specific discharge (discharge per unit cross sectional area)

dh/dl = hydraulic gradient

(the negative sign means that the positive discharge corresponds to negative values of the gradient: i.e. the water moves towards decreasing values of head).



Original data by Darcy (1856): it is possible to identify the linear relationship between the specific discharge q and the hydraulic gradient (for two different types of sand)

Hydraulic conductivity and intrinsic permeability

The coefficient K depends on

:geometrical properties of the soil

:properties of the flow (water)

Lets consider the movement of a flow of viscosity μ and specific weigth γ through a porous media characterised by uniform soil particles of diameter d

Then:

$K = C\, d^2\, \gamma / \mu$

k = intrinsic permeability= $C\, d^2$ $[L^2]$

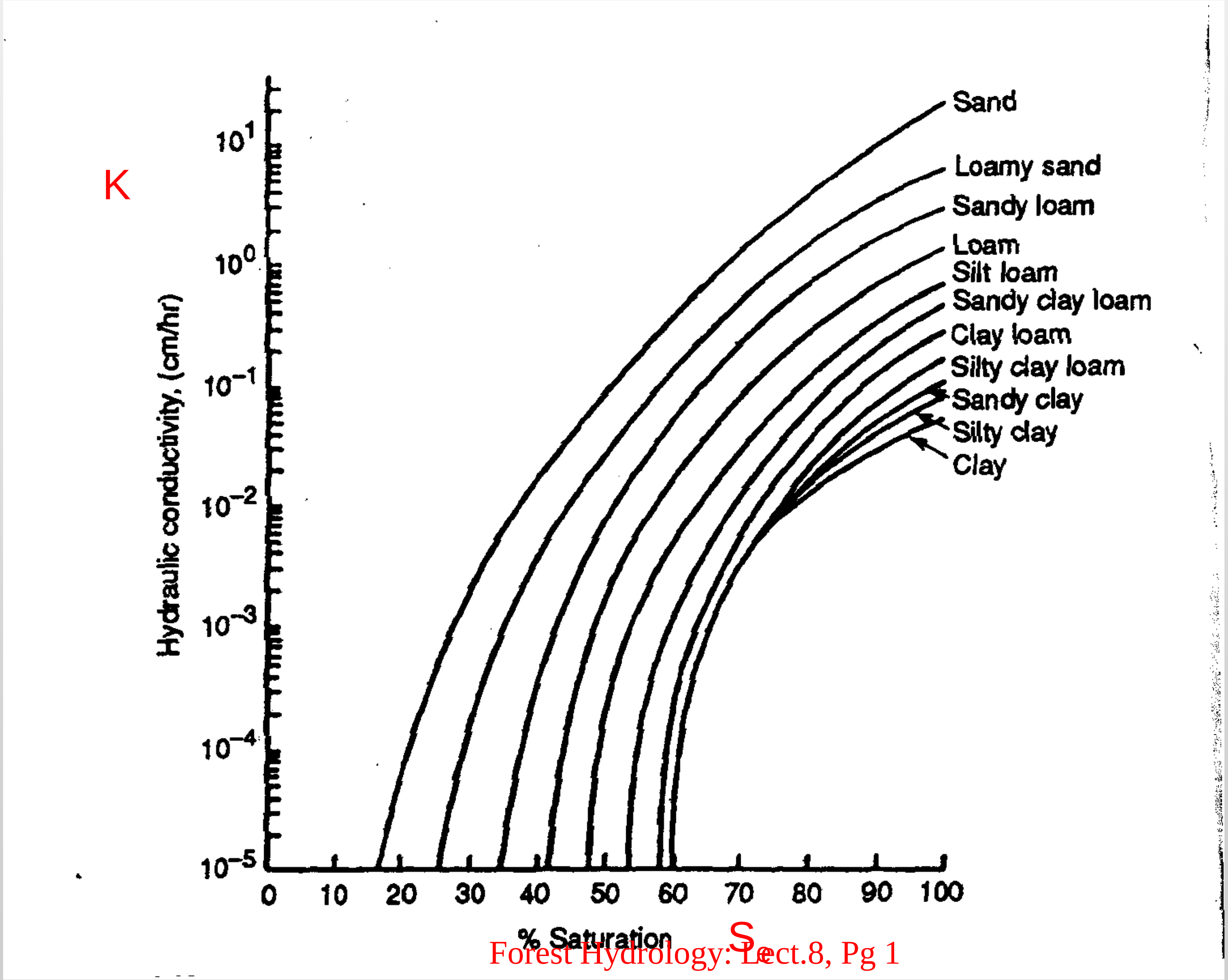
Unit: Darcy 1 Darcy = $0.987\ 10^{-8}\ cm^2$

$K = k\, \gamma/\mu$ $[L\, T^{-1}]$

Hydraulic properties of typical soils

Soil	K (cm s^{-1})	Property
Gravel	$1 - 10^{2}$	very pemeable
Clean sand / mixed with gravel	$10^{-3} - 1$	permeable
Fine sand, Clayey sand	$10^{-7} - 10^{-3}$	reduced permeability
clay	$10^{-9} - 10^{-7}$	almost impervious

Variation of Hydraulic Conductivity with degree of saturation and Soil Texture



Infiltration (1)

- Infiltration is the movement of water through the soil surface into the soil profile. After precipitation, it is the most important process controlling the water balance on a field. Infiltration is generally expressed as total depth or as a velocity called the infiltration rate.

- Terminology:

- **Infiltration capacity:** The maximum rate at which water can enter the soil at a particular point. It varies with time and depends on the hydraulic characteristics of the soil. A standard infiltration capacity curve shows the time-variation of the infiltration rate which would occur if the supply were continually in excess of infiltration capacity.
- **Infiltration rate (f(t))**

  The rate at which infiltration takes place expressed in depth of water per unit time.

Terminology…

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.

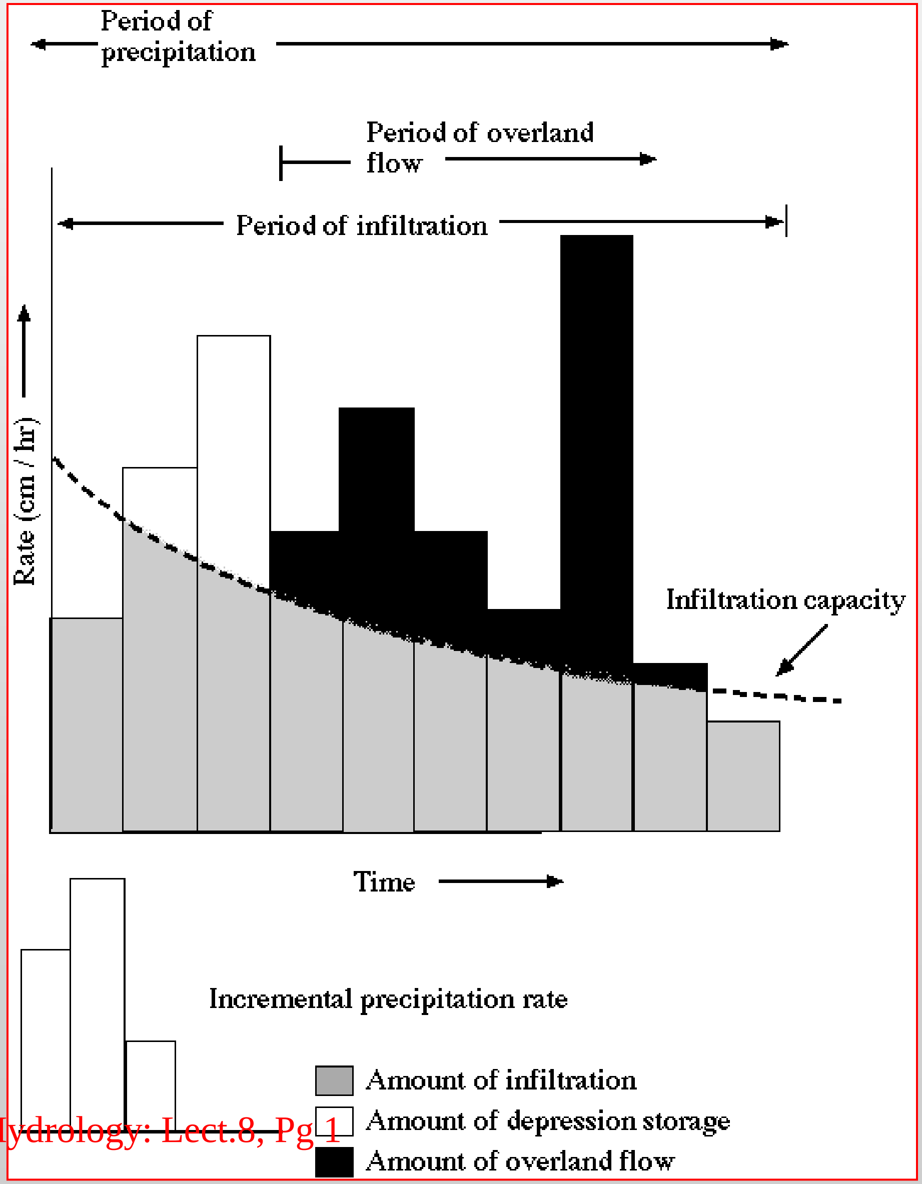
$$F(t) = \int_0^t f(\tau)d\tau$$

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.

Rain rate, infiltration capacity, infiltration and generation of Overland Flow



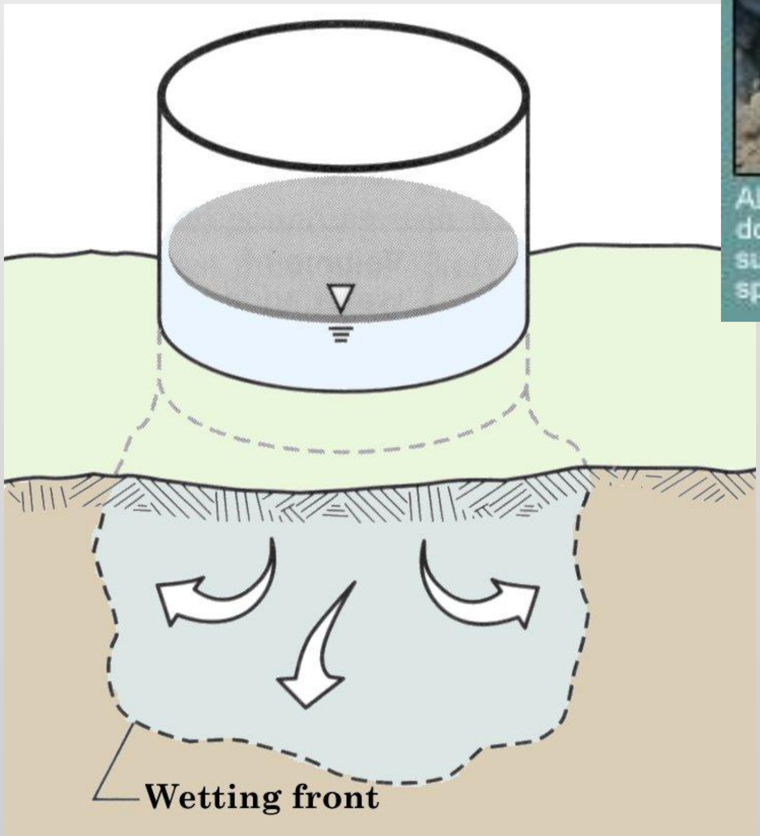
Ring infiltrometer

- Measuring infiltration rate for a constant (or changing) water head
- Boundary condition!
- Water flow assumed 1 D, though it is 3 Dimensional

ALWI soil scientists perform double-ring infiltrometer testing in support of a municipal client's spray irrigation project.

Double Ring

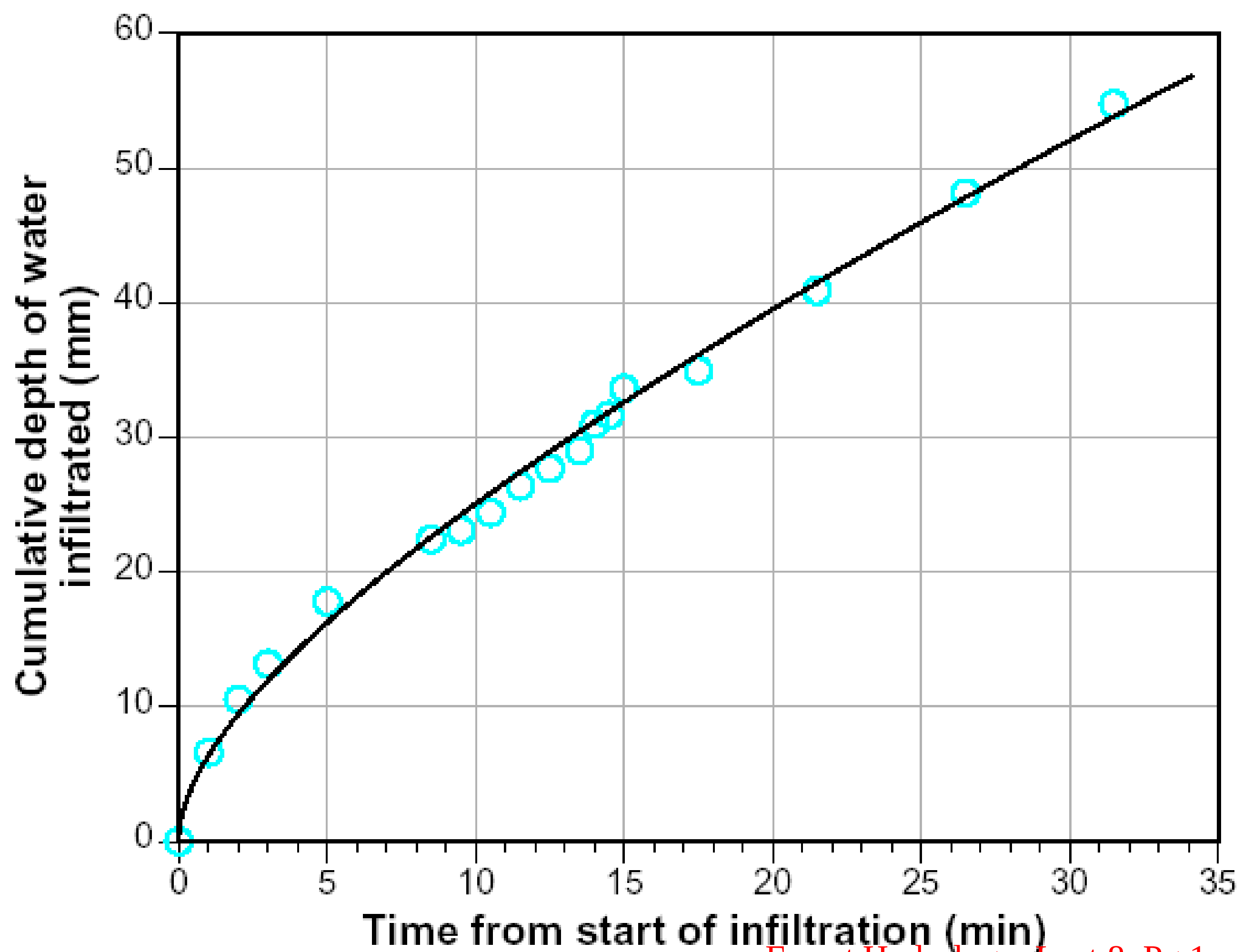
Single Ring



Sprinkling experiments - simple

- More details about infiltration process
- One or more nozzles
- Infiltrometer ring
- Overland flow or runoff measurements
- In addition TDRs or tensiometer
- Allow for the study of soil erodibility characteristics

Field data from a ring infiltrometer



Observations are circles, the line represents an approximation using the Green-Ampt Equation

Figure 8.11, *Hornberger et al., 1998*