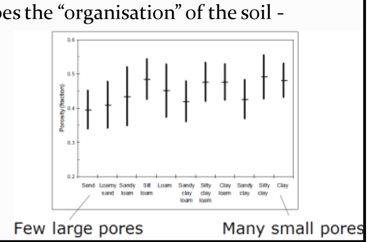
Water in the soil

GG22A: GEOSPHERE & HYDROSPHERE
Hydrology

Key soil properties

- Soils are divided into layers, or horizons
- **Texture** is a function of the amount of sand, silt and clay in the soil
- **Structure** describes the "organisation" of the soil - cracks, voids etc
- **Porosity** is the proportion of soil volume that is air



Soil water content

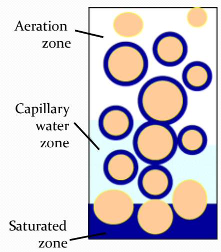
- Measured in terms of the soil column containing the water:

$$\theta = \frac{V_w}{V_s} \quad \text{m}^3\ \text{m}^{-3}$$

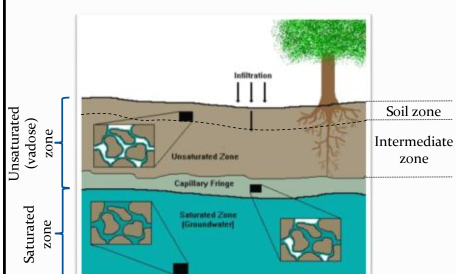
- V_s is the volume of the soil column
- V_w is the volume of the water

How much water is held in the soil?

- Water is held in pore spaces
- **Gravitational** forces try to pull the water down
- **Capillary**, **adsoptive** and **osmotic** forces keep it up (***matric potential***)



Distribution of water through the soil



Key concepts

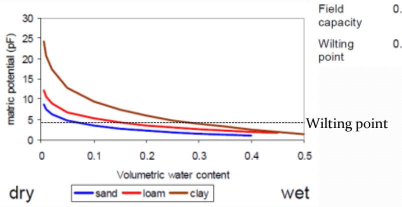
- Water is held in pore spaces by "forces":
  - **Capillary forces**: resulting from surface tension
    - Water held more strongly in smaller pores than large ones
  - **Adsorption forces**: resulting from electrostatic forces with the water molecules
  - **Osmotic forces**: water retained due to solutes in the soil.
  - Units: of pressure (e.g. kPa); head of water (cm or pF = -log10 (cm))

Key concepts

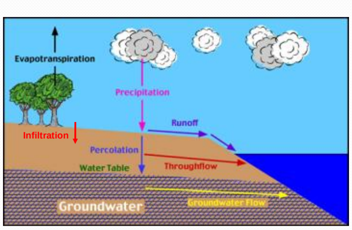
- **Saturation:** all the pores are filled (pF = 0)
- **Field capacity:** water that can be held in the soil against gravity (pF = 2.5)
- **Wilting point:** point at which plants cannot extract water (pF = 4.2)
- **Available water = field capacity - wilting point**

Soil moisture characteristics

	Volumetric content θ		
	Sand	Loam	Clay
Saturation	0.40	0.45	0.48
Field capacity	0.17	0.31	0.40
Wilting point	0.07	0.16	0.29



Soil water movement



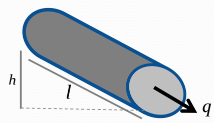
- Infiltration
- Percolation
- Throughflow
- Groundwater flow

Soil water movement

- Flow through a porous media is proportional to the pressure difference (Darcy's Law):

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

q = specific discharge
K = Hydraulic Conductivity
$\partial h/\partial l$ = Hydraulic Gradient
h = Hydraulic pressure head
l = Length



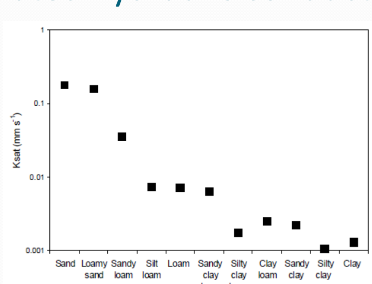
Darcy's law

- Hydraulic pressure head = $h = z + \psi$
  - Where z is the height above a datum and ψ is the matric potential
- If the movement of the water is vertical:

$$q_z = -K\left(\frac{\partial \psi}{\partial z} + 1\right)$$

- Both K and ψ vary with soil texture and soil moisture content θ

Saturated hydraulic conductivity

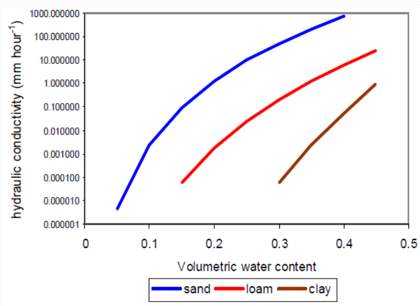


Few large pores — Many small pores

Compilications in practice

1. Soils are not homogeneous
2. Water flows through cracks and voids (*macropores)* at up to 3 mm s-1 (K_{sat} is up to 0.2 mm s-1)

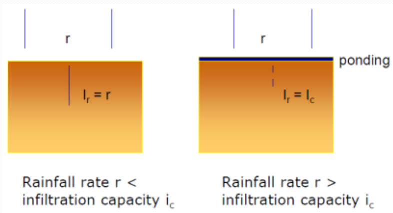
Hydraulic conductivity and soil moisture content



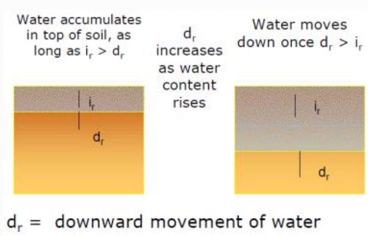
Movement of water into the soil

- ***Infiltration*** describes the process of water entry into the soil through the soil surface.
- *Infiltration Capacity*:
  - the maximum rate at which water may soak into or be absorbed by the soil.
- *Infiltration Rate*:
  - the actual rate at which water soaks into the soil.
  - The rate may be somewhat less than the infiltration capacity due to some limiting factor, such as a limited supply of rainfall.

Infiltration into the soil



Infiltration into the soil



Infiltration capacity

- Soil surface conditions may impose a limit to infiltration capacity
  - Reduced by surface compaction and clogging of pores.
  - Some dry lands soils develop crusts when wet.
- Infiltration capacity increases with greater depth of water on the surface and with greater presence of surface cracks.
  - clay minerals may swell when wet - and crack when dry

Infiltration capacity

- The presence of vegetation generally increases the infiltration capacity of the soil.
- Infiltration capacity is also higher beneath a forest than grass, due to increased ground litter.
- Infiltration capacity is also influenced by the rate of percolation of moisture from the surface soils.

Types of infiltration

1. Ponded-Water (Standing Water) Infiltration: there is no limit to the amount of water that can be infiltrated. The surface soils are saturated with ponds and standing water on the surface.
2. Rainfall-Limited Infiltration: there is a limit to the amount of water infiltrating.

Moisture zones during ponded infiltration

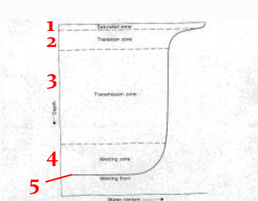
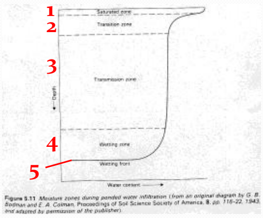


Figure 5.11 Moisture zones during ponded water infiltration (from an original diagram by G. B. Bodman and E. A. Colman, Proceedings of Soil Science Society of America, 8, pp. 116–22, 1943, and adapted by permission of the publisher)

- The wetted column of soil during ponded infiltration takes place can be divided into a number of zones:

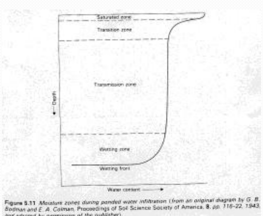
1. Saturated Zone
2. Transition Zone: steep water gradient.

Moisture zones during ponded infiltration



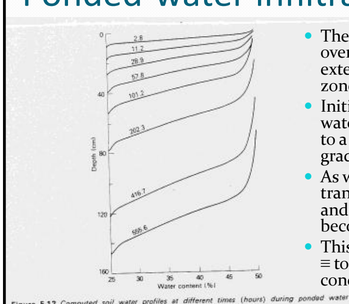
3. Transmission Zone: little or no change in water content.
4. Wetting Zone: a fairly steep moisture gradient.
5. Wetting Front: the base of the wetted zone, with dry soil below.

Moisture zones during ponded infiltration



- During infiltration, moisture content changes in the wetting zone and wetting front.
- The transmission zone becomes larger and the wetting zone moves farther downwards into the soil.

Ponded-water infiltration



- The increase in profile water over time is due to an extension of the transmission zone.
- Initial rates of downward water movement are high due to a steep matric suction gradient.
- As wetting continues, the transmission zone lengthens and the gravitational gradient becomes more important.
- This gravity controlled rate is ≡ to the saturated hydraulic conductivity of the soil.

Rainfall-limited infiltration

- In most humid, vegetated areas, ponded infiltration will not occur as the infiltration capacity exceeds rainfall intensity.
  - The infiltration rate = the rate of water supply to the soil surface.
- The surface soil does not become saturated, but the moisture content increases until it reaches a value at which the unsaturated hydraulic conductivity ≡ to rainfall rate.

Rainfall-limited infiltration

- This leads to a "wave" of moisture which percolates downwards.
- Increasing the rainfall intensity = wetter soil and a larger conductivity.
  - In a more intense rainfall event, infiltration rate is higher.
  - The resulting moisture profile is similar in shape to ponded-infiltration.

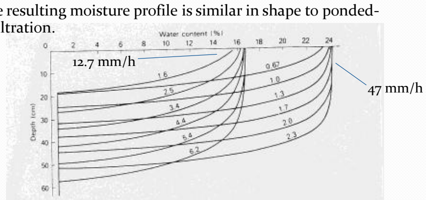


Figure 5.13 *Computed soil water profiles at different times (hours) during non-ponding infiltration for constant rate rainfall intensities of 12.7 and 47.0 mm/h (after an original diagram by Rubin 1966).*

Temporal variations in infiltration capacity

- Infiltration decreases with time during rainfall until after 2-3 hours a constant value is reached.

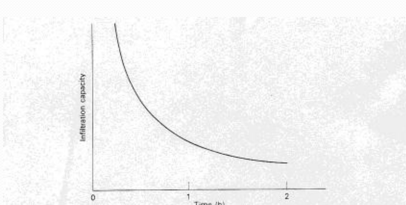


Figure 5.10 *Schematic relation showing the rapid decline in infiltration capacity generally observed.*

Temporal variations in infiltration capacity

- In a deep soil with uniform texture, infiltration capacity is high at the start, but falls rapidly to a value ≡ saturated hydraulic conductivity.
- Other limits to infiltration could be the presence of relatively impermeable layers in the soil, when the rate of infiltration will be related to the speed at which water can pass through this layer of lower conductivity.

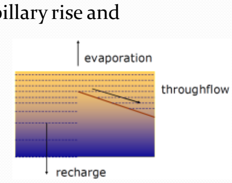
Spatial variations in infiltration

- There are large variations in soil type, soil depth and vegetation, over very small areas.
- Infiltrating water may meet a **barrier or a preferential pathway and move downslope** - and accumulate in certain (topographically defined) places.

Soil water redistribution

- Soil water may become redistributed after infiltration has ceased:

1. Downwards Movement: by percolation under gravity and matric forces (suction into drier soils at depth).
2. Upwards Movement: by capillary rise and evaporation.



Soil water redistribution

- Downward percolation and matric suction: may redistribute soil water after infiltration at the surface stops.
  - The transmission zone becomes a draining zone as water moves to deeper layers in the soil.
  - Redistribution has a control on:
    - the amount of water retained in the root zone
    - the available air-filled pores for water storage during the next rainfall
    - the rate of recharge to the groundwater.

Soil water redistribution

- Upwards movement occurs by capillary rise.
  - Evaporation and transpiration create a suction gradient to the soil surface or root zone.
  - The maximum rate and vertical extent of capillary rise is related to water table depth and soil texture.
  - The rate of capillary rise in coarse textured soils is greater than for finer textured soils, but the vertical extent is greater for finer soils.