5 Soil Moisture and Infiltration

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Objectives of this Lecture

• Introduction to the subsoil as a three phase system
• Principles of infiltration and its measurement
Soil Water – saturated vs. unsaturated zone

(Hornberger et al., 1998)
Flow components above the water table

- Precipitation
  - Infiltration
  - Surface runoff

- Evaporation-transpiration

- Capillary rise

- Irrigation

- Percolation

- Unsaturated zone

- Saturated zone

- Water-table
Unsaturated zone above an aquifer
Soil – Irregularities and Heterogeneities
What makes a soil?

- **Mineral particles**
  - Coarse fragments (stones etc.): over 2 mm diameter
  - Sand: 0.063 to 2 mm
  - Silt: 0.002 to 0.063 mm
  - Clay: under 0.002 mm

- **Organic material**
  - Living plants and animals
  - Decomposing plant and animal material
  - Usually under 5 percent

- **Water** (in 3 possible phases)

- **Air** (usually water saturated; 0.3 – 1% CO₂)

- **Note:** The proportions of the solid particles determine the soil texture
Soil Classification – Soil Texture

Figure 3.1. Classification of soil based on particle size.
Soil Textural Triangle

Figure 3.2. USDA triangle for determining textural classes.
A soil is a 3-phase system
Volumetric Relations

Porosity \((n)\):

\[
n = \frac{V_v}{V_t} = 1 - \frac{V_s}{V_t}
\]

Range:
- 0.30 – 0.46 (sand)
- 0.48 – 0.55 (clay)

Higher values are not uncommon, i.e. in organic soils!!

Note: Units of \(n\) and \(\theta_v\) are dimensionless, or %
Porosity

32%

17%
A note on porosity

A substantial fraction of water can be held within larger particles!!
Porosity

- **Micropores**: soil matrix, immobile or very slow water movement
- **Macropores**: biopores, root channels, fissures, mobile component, flow velocities up to > 1 cm/s

- **Clay soil**: high porosity, high storage capacity, but micropores (‘immobile’ water), hardly any permeability
- **Sand soil**: lower total porosity, low storage capacity, but high permeability
Soil water distribution and macropores

(Peranginangin, 2002)
Fissures in a dry clay soil
Soil water distribution with depth

Fig. 4.5 An example of the distribution of water, air and solids with the depth and the schematisation into a root zone and subsoil with a constant porosity.
Some more key soil moisture parameters

**Saturation**: All pores filled (S=100%)

**Field Capacity**: $\theta_{fc}$ after gravity drainage has ceased (2-3 days after saturation).

**Wilting Point**: $\theta_{wp}$ at which plants wilt and die (~15 bars – varies by species).

**Plant Available Water**: $\theta_{PAW} = \theta_{fc} - \theta_{wp}$
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What happens to this water?
Terminology

Infiltration – The process by which water enters the soil (surface water becomes sub-surface water)

Percolation – Downward movement of water through soil (unsaturated) to the groundwater

Infiltration Capacity – The maximum infiltration rate [mm/h]

– Infiltration rate can exceed infiltration capacity under conditions of positive pressure (ponding infiltration)
– Infiltration rate decreases as soil moisture increases
Infiltration Equation

Decrease of the infiltration capacity, $f_p$ (mm/h), during a rainstorm with intensity $i \geq f_p$.
Empirical infiltration formula of Horton

\[ f_p = f_c + (f_0 - f_c) e^{-kt} \]

- \( f_p \): infiltration capacity (mm/h)
- \( f_0 \): initial infiltration capacity at \( t = 0 \) (mm/h)
- \( f_c \): infiltration capacity at large value of \( t \) (mm/h)
- \( t \): time from beginning of infiltration period (min)
- \( k \): constant for a particular soil and surface cover (min\(^{-1}\))

**Example infiltration curves**

![Example infiltration curves graph](image-url)
Infiltration rate (mm/h)

\[ f_p = f_c + (f_0 - f_c) e^{-kt} \]

Cumulative infiltration (mm)

\[ F(t) = f_c(t - t_0) + \frac{f_0 - f_c}{k} \left( e^{-kt_0} - e^{-kt} \right) \]

Example infiltration curves

- Dry soil
- Wet soil

Cumulative infiltration example in dry soil
Determination of infiltration rate

Direct measurement
An infiltrometer consists of one or two concentric metallic rings designed to isolate a section of the soil. It is set in the ground with the upper portion projecting above the ground while the lower portion is a few cms under the ground (‘pushed in’). Water is then filled in both the compartments and always maintained at the same level. The outer ring prevents the water of inner ring from spreading over a large area after penetrating below the bottom of the ring. The rate at which the water is required to be added to the inner rings so as to maintain constant level, determines the infiltration rate.
Determination of infiltration rate using a double ring infiltrometer
Determination of infiltration rate

Direct measurement

Alternatively, water is applied by sprinklers simulating natural rainfall. The total infiltration rate is computed indirectly as the difference between the rate at which water is supplied to the plot \( (q_{in}) \) and the measured surface runoff \( (q_{out}) \):

\[
f_p = q_{in} - q_{out}
\]
Key factors affecting infiltration

- Soil texture, soil structure
- Land use (roots etc.)
- Biological activities
- Hydrophobicity
  - Deposition of organics after fires or growing season
- Soil frost
  - Variable depending on soil moisture at freezing (in- or decrease of infiltration)
  - Process of freezing (depth and frequency) can be enhanced by vegetation removal
- Swelling-drying depending on clay content
- Rainfall convergence through vegetation (‘localizing’ for throughfall)
- Fine sediment in-washing
- Compaction of soil
- ETC!!
Take Home Messages

- Central role of infiltration for water cycle dynamics/hydrological processes
- Subsurface water: soil moisture and groundwater
- Porosity and other important soil moisture parameters
- Macropores vs. micropores (soil matrix)
- Horton’s infiltration curve
- Initial infiltration rate depends on the initial moisture content of the soil
- Different measurement techniques in the field
- Know the main factors influencing infiltration