Chapter 41: Soil-Water Relationships

Introduction

Soil-water relationships are a critical aspect of hydrology and water resources engineering. Understanding the behavior of water in the soil, its movement, retention, and availability is essential for various engineering applications including irrigation design, watershed management, drainage systems, flood control, and groundwater recharge projects. This chapter provides a comprehensive understanding of how water interacts with soil, covering properties of soil, types of soil moisture, movement of water in soils, and methods to measure and manage soil moisture.

41.1 Types and Properties of Soil

41.1.1 Soil Texture and Structure

- **Soil Texture:** Refers to the relative proportion of sand, silt, and clay particles in a soil mass. Texture affects porosity, permeability, and water holding capacity.
    - **Sand:** Coarse particles (0.05 to 2 mm) – low water retention.
    - **Silt:** Medium-sized particles (0.002 to 0.05 mm).
    - **Clay:** Fine particles (<0.002 mm) – high water retention.
- **Soil Structure:** The arrangement of soil particles into aggregates (peds) which influence pore spaces and water movement.

41.1.2 Soil Porosity

- **Definition:** The ratio of volume of voids to the total volume of soil.
- **Expression:**

$$n = \frac{V_v}{V_t} \times 100$$

  Where n = porosity (%), V_v = volume of voids, V_t = total volume.

- High porosity favors water retention but may reduce water flow.

41.1.3 Bulk Density and Particle Density

- **Bulk Density (ρb):** Mass of dry soil per unit volume (includes pore spaces). Typical range: 1.1–1.6 g/cm³.
- **Particle Density (ρp):** Mass of solid particles per unit volume (excluding pore spaces), usually ~2.65 g/cm³.
- **Void Ratio (e):**

$$e = \frac{V_v}{V_s}$$

41.2 Soil Moisture and Its Forms

41.2.1 Saturation

- All pores are filled with water.
- Occurs after heavy rainfall or irrigation.

41.2.2 Field Capacity

- The amount of water retained in soil after gravitational water has drained.
- Optimal moisture for plant uptake.

41.2.3 Permanent Wilting Point

- Moisture level at which plants cannot extract water and begin to wilt.
- Water is held too tightly in micropores.

41.2.4 Available Water

- Difference between field capacity and wilting point.

$$\text{Available Water} = \theta_{FC} - \theta_{WP}$$

Where θ_{FC} and θ_{WP} are volumetric moisture contents.

41.3 Soil Water Potential

Soil water potential defines the energy status of water in the soil and affects movement and availability.

41.3.1 Types of Potentials

- **Gravitational Potential (Ψg):** Energy due to position above a reference level.
- **Matric Potential (Ψm):** Due to capillary and adsorptive forces (negative value).
- **Osmotic Potential (Ψo):** Due to solute concentration (important in saline soils).
- **Total Soil Water Potential (Ψt):**

$$\Psi_t = \Psi_g + \Psi_m + \Psi_o$$

41.4 Movement of Water in Soil

41.4.1 Infiltration

- Entry of water into soil surface.
- Measured using infiltrometers (double-ring or rainfall simulators).
- Influenced by soil texture, structure, initial moisture content, surface conditions.

41.4.2 Percolation

- Downward movement of water through soil profile.
- Occurs after saturation of upper layers.
- Important in groundwater recharge.

41.4.3 Capillary Rise

- Upward movement of water due to surface tension.
- Important in root zone water availability in fine soils.

41.5 Water Retention Characteristics

41.5.1 Soil Moisture Characteristic Curve (Retention Curve)

- Relationship between soil moisture content and matric suction.
- Also called the pF curve.
- Affected by soil type: clayey soils retain more water at higher suction.

41.5.2 Hysteresis

- Difference in retention curves during drying and wetting due to:
    - Air entrapment
    - Contact angle differences
    - Pore shape and connectivity

41.6 Hydraulic Conductivity

41.6.1 Definition

- The rate at which water moves through a soil under a hydraulic gradient.
- Measured in cm/s or m/day.

41.6.2 Darcy's Law

For saturated soils:

$$Q = -K \cdot A \cdot \frac{dh}{dl}$$

Where:

- Q: Discharge (cm³/s)
- K: Hydraulic conductivity
- A: Cross-sectional area
- $\frac{dh}{dl}$: Hydraulic gradient

41.6.3 Factors Affecting Hydraulic Conductivity

- Soil texture and structure
- Moisture content
- Temperature (affects viscosity)
- Organic matter content

41.7 Measurement of Soil Moisture

41.7.1 Gravimetric Method

- Oven-drying a soil sample at 105°C.

- Moisture content by weight:

$$\theta = \frac{W_w}{W_d} \times 100$$

41.7.2 Tensiometers

- Measure matric suction up to 0.85 atm.
- Suitable for coarse to medium soils.

41.7.3 Electrical Resistance Blocks

- Gypsum or fiberglass blocks inserted in soil.
- Resistance varies with moisture content.

41.7.4 Neutron Probe

- Measures hydrogen content (indicative of water).
- Highly accurate; used in research and irrigation management.

41.7.5 Time Domain Reflectometry (TDR)

- Measures dielectric constant of soil using wave reflections.
- Rapid and accurate for real-time monitoring.

41.8 Soil-Water-Plant Relationships

41.8.1 Root Zone Water Availability

- Crop water uptake is limited to root depth.
- Understanding soil moisture dynamics is key for irrigation scheduling.

41.8.2 Management Allowable Depletion (MAD)

- Fraction of available water that can be depleted before irrigation is required.

41.8.3 Water Use Efficiency (WUE)

- Ratio of crop yield to amount of water used.

$$\text{WUE} = \frac{\text{Yield (kg)}}{\text{Water used (m}^3\text{)}}$$

41.9 Soil Moisture and Irrigation Practices

41.9.1 Soil Moisture Zones

- Saturation zone
- Transmission zone
- Depletion zone
- Root extraction zone

41.9.2 Irrigation Scheduling Based on Soil Moisture

- Monitoring using sensors
- Calculating water balance
- Timing irrigations to avoid water stress

41.9.3 Role in Hydrologic Cycle

- Infiltration, percolation, and evapotranspiration are regulated by soil moisture.
- Impacts runoff, groundwater recharge, and storage.
