Chapter 42: Root Zone Soil Water

Introduction

The *root zone* refers to the portion of the soil that contains the roots of plants and is the primary zone for water absorption by vegetation. Root zone soil water plays a pivotal role in hydrology and water resources engineering, as it links atmospheric processes (like precipitation and evapotranspiration) to surface and subsurface hydrological phenomena. Efficient understanding and management of root zone moisture is essential for irrigation planning, drought prediction, watershed management, and sustainable agriculture.

This chapter delves into the nature, movement, availability, and importance of water in the root zone, alongside methods for its estimation and practical applications in water resources engineering.

42.1 Soil Water in the Unsaturated Zone

The unsaturated zone, also known as the *vadose zone*, lies above the water table and includes the root zone. It contains water held by capillary forces and air in the pore spaces.

Types of Soil Water

Soil water is broadly classified into three types based on its availability to plants:

- **Gravitational Water**: Drains through the soil under the influence of gravity and is usually unavailable to plants.
- **Capillary Water**: Held in micropores and is the main source of water absorbed by plant roots.
- **Hygroscopic Water**: Thin film of moisture tightly bound to soil particles and not available to plants.

42.2 Field Capacity and Wilting Point

These two critical soil moisture constants define the available water range for plants:

- **Field Capacity (FC):** The amount of soil moisture remaining after excess water has drained away, typically 1–3 days after irrigation or rainfall.
  - Units: % by volume or weight.
  - Significance: Marks the upper limit of available water.

- **Permanent Wilting Point (PWP):** The soil moisture level at which plants can no longer extract water, leading to permanent wilting.
  - At this stage, only hygroscopic water remains.
  - Varies by plant species and soil texture.
- **Available Water (AW):** $AW = FC - PWP$ It is the water stored in the soil profile between field capacity and wilting point, usable by plants.

42.3 Rooting Depth and Root Zone Storage Capacity

Rooting Depth

- Refers to the depth to which the majority of a plant's roots extend and actively absorb water.
- Typical root depths vary with crop type:
  - Shallow-rooted (e.g., grasses): ~30–60 cm
  - Deep-rooted (e.g., trees): >1 m

Root Zone Storage Capacity (RZSC)

The total volume of water that can be stored and held between FC and PWP within the root zone:

$$RZSC = AW \times RD$$

Where:

- AW = available water content (mm/m)
- RD = rooting depth (m)

42.4 Soil-Water Characteristic Curve (SWCC)

Also known as the *moisture retention curve*, it describes the relationship between **soil moisture content** and **matric potential** (suction pressure). This curve is critical for:

- Modeling water movement
- Estimating plant-available water
- Determining irrigation schedules

The curve varies with soil texture:

- Sandy soils: steep slope, less water retention
- Clayey soils: flatter curve, more retention but slower movement

42.5 Infiltration and Redistribution in the Root Zone

Infiltration

The process by which water enters the soil surface and begins moving downward. Infiltration rate depends on:

- Soil texture and structure
- Initial moisture content
- Vegetation and surface cover

Redistribution

Post-infiltration, water redistributes due to capillarity and gravity. This affects the availability of water in the root zone and impacts:

- Deep percolation
- Recharge to groundwater
- Root water uptake

42.6 Plant-Water Interaction and Uptake

Plants extract water via **root uptake**, driven by gradients in water potential. The rate of uptake is influenced by:

- Root density and distribution
- Soil moisture levels
- Evaporative demand

Uptake declines sharply as the soil water approaches the wilting point, affecting transpiration and plant health.

42.7 Evapotranspiration from the Root Zone

Evapotranspiration (ET) includes:

- **Evaporation** from soil and plant surfaces
- **Transpiration** through plant stomata

Types of ET Estimates:

- **Potential ET (PET):** Max ET rate under ideal moisture.
- **Actual ET (AET):** Real ET under current soil moisture.

ET depletes root zone soil moisture and must be replenished through irrigation or rainfall.

42.8 Moisture Movement in Unsaturated Soil

Water movement in the unsaturated zone is governed by:

- **Darcy's Law for Unsaturated Flow:**

$$q = -K(\theta) \left(\frac{dh}{dz} + 1 \right)$$

Where:

- q = flux (cm/hr)
- $K(\theta)$ = unsaturated hydraulic conductivity
- $\frac{dh}{dz}$ = matric potential gradient
- **Hydraulic Conductivity** depends on:
  - Soil texture
  - Moisture content
  - Soil compaction

42.9 Methods to Estimate Root Zone Soil Moisture

Several direct and indirect methods are used to estimate root zone water content:

Gravimetric Method

- Weighing soil samples before and after drying.
- Most accurate but destructive and time-consuming.

Neutron Scattering

- Measures hydrogen atoms in soil.
- Requires calibration, non-destructive, commonly used in research.

Time Domain Reflectometry (TDR)

- Measures dielectric constant to estimate moisture content.
- Precise and widely adopted.

Remote Sensing & Satellite-Based Estimation

- MODIS, SMAP, and other satellites estimate surface moisture.
- Combined with modeling for root zone estimates.

42.10 Irrigation Scheduling Based on Root Zone Water Balance

Using the water balance approach:

$$\Delta S = P + I - ET - D - R$$

Where:

- ΔS = change in soil water storage
- P = precipitation
- I = irrigation
- ET = evapotranspiration
- D = deep percolation loss
- R = surface runoff

Maintaining soil moisture within the AW range ensures optimal plant growth and efficient irrigation.

42.11 Modeling Root Zone Water Dynamics

Common Models:

- **FAO CROPWAT**
- **SWAT (Soil and Water Assessment Tool)**
- **HYDRUS-1D and 2D** These models simulate:
- Soil moisture
- ET
- Root uptake
- Percolation

They are vital in integrated water resource planning and climate impact studies.

42.12 Factors Affecting Root Zone Water Availability

- **Soil Texture & Structure**: Sandy soils drain quickly, clay retains water.
- **Bulk Density**: Compacted soils reduce infiltration and root penetration.
- **Organic Matter**: Improves structure and water-holding capacity.

- **Soil Salinity**: High salt concentrations lower water availability due to osmotic effects.
- **Soil Temperature**: Affects root activity and microbial processes.

42.13 Engineering Applications and Importance

Understanding and managing root zone water is essential for:

- **Irrigation System Design**
- **Water Use Efficiency Studies**
- **Climate-Resilient Agriculture**
- **Drought Mitigation Strategies**
- **Watershed Hydrology and Soil Conservation**

Proper root zone moisture control ensures sustainable agricultural yields and prevents over-irrigation or water stress.
