Chapter 27: Infiltration Capacity

Introduction

Infiltration is a fundamental hydrological process referring to the movement of water from the ground surface into the soil. The **infiltration capacity** represents the maximum rate at which soil can absorb rainwater or surface water under specific conditions. Understanding infiltration is crucial in hydrology, particularly in the design of irrigation systems, flood forecasting, watershed management, stormwater drainage, and groundwater recharge planning.

This chapter explores the concept of infiltration capacity in detail, discussing the influencing factors, measurement techniques, empirical models, and practical applications in civil engineering and water resources management.

27.1 Definition of Infiltration and Infiltration Capacity

- **Infiltration**: The process by which water on the ground surface enters the soil.
- **Infiltration Rate (f)**: The rate at which infiltration occurs, usually expressed in mm/hr or cm/hr.
- **Infiltration Capacity (fc)**: The maximum rate at which soil can absorb water at any given time under specified conditions.

If the rainfall intensity exceeds the infiltration capacity, the excess water contributes to surface runoff.

27.2 Factors Affecting Infiltration Capacity

27.2.1 Soil Characteristics

- **Texture**: Sandy soils have higher infiltration rates than clayey soils.
- **Structure**: Well-aggregated soils facilitate better infiltration.
- **Porosity and Permeability**: High porosity and permeability increase infiltration.

27.2.2 Vegetative Cover

- Plant roots improve soil structure and porosity.
- Organic matter from vegetation enhances water holding capacity and infiltration.

27.2.3 Land Use and Surface Conditions

- Compacted soils due to construction or heavy machinery reduce infiltration.
- Mulching and tilling can improve infiltration in agricultural areas.

27.2.4 Moisture Content of Soil

- **Dry soils** tend to absorb water faster initially.
- **Saturated soils** have reduced infiltration due to filled pore spaces.

27.2.5 Temperature

- Warmer temperatures can reduce water viscosity and increase infiltration slightly.
- Frozen soils drastically reduce infiltration.

27.2.6 Rainfall Characteristics

- **Intensity**: If rainfall exceeds infiltration capacity, ponding and runoff occur.
- **Duration**: Long rainfall events may saturate the soil, reducing infiltration.
- **Initial abstraction**: Water losses before infiltration begins (e.g., interception, depression storage).

27.3 Infiltration Process and Time Dependency

Infiltration capacity is **not constant over time**. It decreases rapidly in the early stages of a rainfall event and then gradually approaches a constant minimum value.

Typical infiltration behavior:

- **Initial Infiltration Rate (f_0)**: High at the beginning.
- **Final/Steady-State Infiltration Rate (fc)**: The constant rate achieved after prolonged rainfall.

This behavior is often represented using **infiltration curves**.

27.4 Measurement of Infiltration

Several experimental methods are used to measure infiltration rates:

27.4.1 Infiltrometers

- **Double Ring Infiltrometer**:
  - Two concentric rings inserted into the soil.
  - Water is added to both rings to minimize lateral flow.
  - The inner ring's infiltration rate is recorded.
- **Single Ring Infiltrometer**:
  - Simpler but less accurate due to lateral water movement.

27.4.2 Rainfall Simulator

- Artificial rainfall applied over a plot.
- Runoff is collected and infiltration is calculated.

27.4.3 Lysimeters

- Measure infiltration and percolation by isolating a soil column.

27.4.4 Tensiometers and Soil Moisture Sensors

- Indirect methods by monitoring soil water tension or content changes.

27.5 Empirical Infiltration Models

Several mathematical models are used to estimate infiltration capacity over time:

27.5.1 Horton's Equation

Proposed by Robert Horton (1933), this model assumes an exponential decay of infiltration rate over time.

$$f(t) = f_c + (f_0 - f_c)e^{-kt}$$

Where:

- $f(t)$: Infiltration rate at time t
- f_0: Initial infiltration rate
- f_c: Final steady infiltration rate
- k: Decay constant (infiltration index)

27.5.2 Philip's Equation

Based on the theory of capillarity and gravity:

$$f(t) = \frac{S}{\sqrt{t}} + A$$

Where:

- S: Sorptivity (capillary effect)
- A: Steady-state infiltration rate

27.5.3 Green-Ampt Model

A physically based model using soil suction head and moisture content:

$$f = K\left(1 + \frac{\Psi \cdot \Delta\theta}{F}\right)$$

Where:

- K: Hydraulic conductivity
- Ψ: Wetting front suction head
- $\Delta\theta$: Change in moisture content
- F: Cumulative infiltration

This model is suitable for infiltration under ponded conditions.

27.6 Infiltration Indices

Infiltration indices simplify the infiltration process for use in rainfall-runoff models:

27.6.1 ϕ-Index

- Average rainfall rate above which runoff begins.
- Assumes constant infiltration rate during a storm.

$$\phi = \frac{\text{Total rainfall} - \text{Runoff}}{\text{Duration of rainfall}}$$

27.6.2 W-Index

- Accounts for initial losses and gives more accurate runoff estimation.

$$W = \frac{P - Q}{t_r}$$

Where:

- P: Precipitation
- Q: Runoff
- t_r: Duration of effective rainfall

27.6.3 W❑$_{min}$-Index

- Minimum value of W-index during saturated conditions.

27.7 Applications of Infiltration Studies

- **Urban Drainage**: Designing pervious pavements and stormwater systems.
- **Agriculture**: Optimizing irrigation scheduling and soil water management.
- **Watershed Management**: Estimating runoff for flood forecasting and control.
- **Groundwater Recharge**: Identifying recharge zones and aquifer replenishment.
- **Erosion Control**: Managing surface runoff and sediment transport.

27.8 Infiltration and Watershed Models

Infiltration models are integrated into hydrologic models like:

- **SWAT (Soil and Water Assessment Tool)**
- **HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System)**
- **SCS Curve Number Method**, which accounts for land use, soil type, and antecedent moisture to estimate infiltration and runoff.

27.9 Infiltration in Arid and Semi-Arid Regions

- Soils often have crust formation, reducing infiltration.
- Management strategies include contour bunding, mulching, and check dams to enhance infiltration.

27.10 Limitations and Challenges in Infiltration Measurement

- High spatial variability in soil characteristics.
- Difficulty in replicating natural conditions during field experiments.
- Uncertainty in parameter estimation for models.