Chapter 26: Infiltration

Introduction

Infiltration is the process by which water on the ground surface enters the soil. It is a fundamental component in the hydrologic cycle, influencing surface runoff, groundwater recharge, soil moisture, and evapotranspiration. The rate and volume of infiltration are crucial for the design of irrigation systems, drainage systems, flood control structures, and groundwater recharge schemes.

Understanding infiltration is essential in water resources engineering to accurately estimate the amount of effective rainfall that contributes to runoff. This chapter delves deep into the mechanisms, factors, mathematical models, and methods to determine infiltration, with emphasis on practical applications in civil engineering.

26.1 Definition of Infiltration

Infiltration is defined as the movement of water from the surface into the soil profile. It begins when rainfall or irrigation water is applied to the land surface and continues until the soil becomes saturated. It is expressed in terms of:

- **Infiltration rate (f)**: Rate at which water enters the soil, usually in mm/hr or cm/hr.
- **Cumulative infiltration (F)**: Total volume of water that has infiltrated per unit area over a given time period.

26.2 Infiltration Capacity

Infiltration capacity refers to the maximum rate at which a given soil can absorb rainfall. It varies with time and soil conditions and is represented by a curve that typically decreases with time.

- Initially high due to dry soil and large capillary suction.
- Gradually decreases as the soil becomes wet.
- Eventually reaches a nearly constant value (steady-state infiltration).

26.2.1 Typical Infiltration Curve

A typical infiltration rate vs. time graph shows:

- Steep decline initially.
- Slower reduction as time progresses.
- Final constant rate indicating saturation or steady conditions.

26.3 Factors Affecting Infiltration

Infiltration is influenced by several interrelated factors:

26.3.1 Soil Characteristics

- Texture: Sandy soils have higher infiltration due to large pores.
- Structure: Well-aggregated soils allow more rapid infiltration.
- Porosity and permeability.
- Presence of impervious layers.

26.3.2 Vegetative Cover

- Reduces runoff velocity.
- Enhances soil porosity through root activity.
- Provides organic matter improving soil structure.

26.3.3 Soil Moisture Content

- Dry soils have higher initial infiltration due to suction.
- As moisture increases, suction decreases, lowering the infiltration rate.

26.3.4 Rainfall Intensity

- If rainfall intensity > infiltration capacity → runoff occurs.
- High-intensity rainfall often leads to surface ponding.

26.3.5 Land Use and Land Management

- Urbanization reduces infiltration due to impervious surfaces.
- Tillage, mulching, and compaction affect soil structure and infiltration.

26.3.6 Temperature

- Affects viscosity of water and biological activity.
- Frozen soils reduce infiltration drastically.

26.4 Measurement of Infiltration

Various field methods are used to measure infiltration rates:

26.4.1 Infiltrometer Methods

(a) ***Double Ring Infiltrometer***

- Consists of two concentric rings.
- Water is maintained in both rings; infiltration from the inner ring is measured.
- Reduces lateral flow effects.

(b) ***Single Ring Infiltrometer***

- Simpler but less accurate due to lateral water movement.

26.4.2 Basin or Flooding Method

- A known quantity of water is applied to a bounded area.
- Change in depth over time gives the infiltration rate.

26.4.3 Soil Moisture Accounting Method

- Based on changes in soil moisture profiles before and after rainfall.

26.5 Infiltration Indices

Infiltration indices are average values used to simplify infiltration estimation for hydrologic models.

26.5.1 ϕ-Index (Phi Index)

- Average rate of infiltration above which rainfall results in runoff.
- Simplifies infiltration loss as a constant rate during a storm.
- Used in Rational Method and unit hydrograph analysis.

26.5.2 W-Index

- Accounts for initial losses and represents average infiltration during periods of excess rainfall.

26.5.3 Wmin-Index

- Minimum value of W-index observed over a specific period, used for design purposes.

26.6 Infiltration Equations and Models

Mathematical models describe infiltration behavior over time. Commonly used empirical and semi-theoretical equations include:

26.6.1 Horton's Equation

Developed by Robert E. Horton:

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

Where:

- $f(t)$: infiltration rate at time t
- f_0: initial infiltration rate
- f_c: final/constant infiltration rate
- k: decay constant
- t: time

Horton's model fits well with field data and represents the declining infiltration rate over time.

26.6.2 Philip's Equation

Based on capillarity and gravity forces:

$$f(t) = \frac{1}{2} S t^{-1/2} + A$$

Where:

- S: sorptivity (depends on soil suction and porosity)
- A: steady infiltration rate due to gravity

It is useful for short-duration infiltration analysis.

26.6.3 Green-Ampt Equation

A physically based model assuming a sharp wetting front:

$$f = K\left(1 + \frac{\psi(\theta_s - \theta_i)}{F}\right)$$

Where:

- K: hydraulic conductivity
- ψ: wetting front suction head
- θ_s: saturated moisture content
- θ_i: initial moisture content
- F: cumulative infiltration

Accurate for homogeneous soils under ponded infiltration.

26.7 Infiltration in Hydrologic Modeling

Infiltration losses are critical for determining runoff and peak flows in hydrologic models.

- **Used in**: SCS-CN method, Rational method, Unit Hydrograph, HEC-HMS, SWAT.
- **Impact**: Underestimation leads to overprediction of runoff and vice versa.
- Infiltration-excess and saturation-excess runoff mechanisms are modeled based on infiltration capacity.

26.8 Importance in Water Resources Engineering

- **Design of Drainage Systems**: Reducing waterlogging and surface runoff.
- **Groundwater Recharge Studies**: Estimating percolation rates.
- **Irrigation Design**: Scheduling and determining application efficiency.
- **Soil Conservation**: Preventing erosion through infiltration enhancement.
- **Urban Planning**: Designing pervious pavements and rain gardens.

26.9 Techniques to Improve Infiltration

Civil engineers often implement methods to enhance infiltration:

- **Soil Amendment**: Adding organic matter.
- **Contour Bunding and Trenches**: Reducing surface runoff velocity.

- **Artificial Recharge**: Infiltration basins and recharge wells.
- **Vegetative Measures**: Cover crops, agroforestry.
