Chapter 31: Infiltration Indices

Introduction

Infiltration is the process by which water on the ground surface enters the soil. In hydrology, understanding infiltration is critical for analyzing rainfall-runoff processes, flood estimation, groundwater recharge, and irrigation planning. Since infiltration varies significantly in time and space due to changing soil moisture, land cover, and rainfall intensity, hydrologists use simplified representations called **infiltration indices** to analyze storm runoff events and to estimate the volume of rainfall that becomes surface runoff.

Infiltration indices are empirical tools that represent average infiltration characteristics of a storm event or catchment area. These indices are particularly useful in engineering hydrology for estimating direct runoff from rainfall excess.

31.1 Infiltration Concept Recap

Before exploring indices, it's important to revisit key infiltration concepts:

- **Infiltration Capacity (f):** The maximum rate at which soil can absorb water at any given time.
- **Infiltration Rate:** Actual rate at which water enters the soil.
- **Cumulative Infiltration (F):** Total volume of water infiltrated over a period.
- **Infiltration Excess (Hortonian Flow):** Runoff generated when rainfall intensity exceeds infiltration capacity.

31.2 Need for Infiltration Indices

While infiltration can be measured directly using devices like double-ring infiltrometers or indirectly through models (e.g., Horton's, Philip's equations), storm event analysis often requires simplification. For this reason, hydrologists use infiltration indices that assume average rates of infiltration during the storm period.

These indices help to:

- Estimate effective rainfall (i.e., rainfall excess) that contributes to runoff.
- Simplify complex infiltration behavior.
- Aid in flood hydrograph development and design storm calculations.

31.3 Common Infiltration Indices

31.3.1 ϕ-index (Phi Index)

- **Definition:** It is the average rate of infiltration (in mm/hr or cm/hr) such that the volume of rainfall in excess of this rate equals the volume of observed direct runoff.
- **Mathematical Formulation:**

$$\phi = \frac{P - Q}{t}$$

  Where: P = total rainfall (mm) Q = direct runoff (mm) t = duration of rainfall (hr)

- **Assumptions:**
  - Constant infiltration rate during the storm.
  - Neglects initial losses and assumes uniform infiltration.
- **Use:** Suitable for estimating runoff volume over a catchment when storm data is available.

31.3.2 W-index

- **Definition:** The W-index is a modified form of the ϕ-index, which accounts for initial losses such as interception and surface storage before infiltration begins.
- **Formula:**

$$W = \frac{P - Q - I_a}{t}$$

  Where: I_a = initial abstraction (interception + depression storage + early infiltration)

- **Key Difference from ϕ-index:** W-index subtracts the initial losses and gives a more accurate estimation of actual infiltration.
- **Application:** Used when initial losses are known or can be estimated.

31.3.3 W❑$_{min}$-index

- **Definition:** Represents the minimum average infiltration rate during a storm, typically calculated during the most intense periods of rainfall that generate direct runoff.
- **Utility:** Used to analyze design storms and critical runoff conditions.

31.3.4 Horton's Infiltration Index

- **Horton's Equation:** Though not an index per se, Horton's infiltration model provides a time-dependent expression for infiltration rate:

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

  Where: f_0 = initial infiltration capacity f_c = final constant infiltration capacity k = decay constant t = time

- **Relation to indices:** Can be used to generate average infiltration rates over a period, which may be used as an index for specific storms.

31.4 Selection of Appropriate Index

The choice of infiltration index depends on:

- **Data Availability:** If runoff and rainfall data are both available, ϕ-index is easier to apply. If initial losses are known, W-index is preferable.
- **Storm Characteristics:** For short-duration, high-intensity storms, W❑$_{min}$-index gives a better estimation of peak runoff.
- **Catchment Characteristics:** Land use, soil type, slope, vegetation, and antecedent moisture condition affect infiltration and, therefore, the choice of index.

31.5 Estimation of Infiltration Indices from Hydrographs

To derive indices from actual rainfall-runoff data:

1. **Rainfall Hyetograph and Runoff Hydrograph** are plotted.
2. **Total rainfall (P)** and **direct runoff (Q)** are estimated.
3. Using area under the hydrograph, total runoff volume is computed.
4. Initial losses are estimated (if required).
5. Substituting values in the ϕ or W-index formula yields the index.

31.6 Limitations of Infiltration Indices

- Oversimplify time-variable infiltration behavior.
- Sensitive to accurate measurement of runoff and rainfall.
- Do not account for spatial variability within a basin.
- Inapplicable where rainfall intensity is always less than infiltration capacity (i.e., no runoff generated).

31.7 Applications in Engineering

- **Urban Drainage Design:** For designing stormwater drainage systems using rational method or unit hydrograph method.
- **Flood Forecasting:** Estimating rainfall excess for flood modeling.
- **Catchment Modeling:** Simplified inputs for hydrologic models like HEC-HMS.
- **Irrigation Planning:** Determining percolation losses in agricultural fields.

31.8 Comparison Table: ϕ-index vs W-index

Feature	ϕ-index	W-index
Initial abstraction	Not considered	Considered
Accuracy	Less accurate	More accurate
Use	General estimation	Storm analysis with detailed data
Required data	Rainfall and runoff	Rainfall, runoff, and

Feature	ϕ-index	W-index
		initial losses