Chapter 32: Runoff

Introduction

Runoff is a key component of the hydrological cycle and plays a vital role in water resources engineering. It represents the portion of precipitation that flows over the land surface towards rivers, lakes, or oceans. Understanding runoff is essential for the planning, design, and management of water resource systems, especially in flood control, irrigation, drainage, and hydropower generation.

The characteristics of runoff are influenced by various natural and anthropogenic factors. This chapter discusses the major **components of runoff**, the **factors affecting runoff**, methods to estimate **basin yield**, the **SCS-Curve Number (SCS-CN) method**, and the analysis techniques using **flow duration curves** and **mass curves**.

32.1 Components of Runoff

Runoff can be classified into three primary components based on the source and timing of flow:

1. Surface Runoff

- Also known as overland flow.
- It occurs when rainfall intensity exceeds the infiltration capacity of the soil.
- Surface runoff is the most visible and immediate form of runoff and is responsible for flash floods.

2. Interflow (Subsurface Runoff)

- This is the lateral movement of water through the upper soil layers before it enters the stream channel.
- It generally contributes to streamflow hours or days after the precipitation event.
- Influenced by soil porosity, vegetation, and slope.

3. Base Flow

- Also called groundwater runoff.
- It sustains river flows during dry periods and originates from groundwater seeping into stream channels.
- It represents the long-term storage component of the hydrological cycle.

32.2 Factors Affecting Runoff

Several factors influence the generation and magnitude of runoff. These factors can be grouped into:

A. Climatic Factors

- **Rainfall intensity, duration, and distribution**: High-intensity storms generate more surface runoff.
- **Temperature**: Influences evapotranspiration and snowmelt.
- **Wind and humidity**: Affect evaporation rates and soil moisture conditions.

B. Physiographic Factors

- **Topography**: Steeper slopes lead to faster runoff; flat terrains encourage infiltration.
- **Soil Type**: Sandy soils have high infiltration rates; clayey soils promote surface runoff.
- **Vegetation Cover**: Dense vegetation reduces runoff by enhancing infiltration and interception.
- **Land Use and Urbanization**: Impervious surfaces increase surface runoff and reduce infiltration.

C. Basin Characteristics

- **Shape and size of the watershed**: Compact basins yield faster runoff concentration.
- **Drainage density**: High drainage density increases runoff collection efficiency.
- **Antecedent Moisture Condition (AMC)**: Previous soil wetness significantly influences runoff yield.

32.3 Basin Yield

Definition

Basin yield refers to the total volume of water that can be extracted or used from a river basin during a specific period, generally a year, under defined conditions.

Types of Basin Yield

- **Safe Yield**: Maximum quantity of water that can be withdrawn regularly without depleting the source.
- **Maximum/Ultimate Yield**: Maximum theoretical quantity of water available from the basin, considering all resources and technologies.

Assessment of Basin Yield

- **Empirical methods**: Based on historical runoff data.
- **Hydrological modeling**: Simulates the hydrologic processes using rainfall-runoff models.
- **Mass curve analysis and flow-duration curves**: Used to determine dependable yield and storage requirements.

32.4 SCS-CN Method of Estimating Runoff

The **Soil Conservation Service Curve Number (SCS-CN) method**, developed by the USDA, is widely used for estimating direct runoff from rainfall events in small catchments.

Assumptions

- A fixed relationship between rainfall, retention, and runoff.
- Based on antecedent moisture condition, land use, and hydrologic soil group.

Key Equations

1. **Runoff Depth (Q):**

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad \text{for} \quad P > I_a$$

- Where:
  - Q = runoff depth (mm)
  - P = rainfall depth (mm)
  - I_a = initial abstraction (mm), typically $0.2S$
  - S = potential maximum retention (mm)

2. **Curve Number (CN) and Storage (S):**

$$S = \frac{25400}{CN} - 254$$

Curve Number (CN)

- Ranges from 30 to 100.
- Depends on land use, soil type, and AMC.
- Tables are available from USDA handbooks.

Advantages

- Simple and easy to apply.
- Requires limited data.
- Widely accepted in watershed and drainage projects.

Limitations

- Best suited for small to medium watersheds.
- Sensitive to CN value; errors in CN selection can lead to significant errors.

32.5 Flow Duration Curves

A **Flow Duration Curve (FDC)** is a graphical representation showing the percentage of time a particular streamflow is equaled or exceeded during a given period.

Construction Steps

1. Collect streamflow data (daily/monthly).
2. Rank data from highest to lowest.
3. Assign exceedance probability:

$$P = \frac{m}{n+1} \times 100$$

- Where:
  - m = rank
  - n = total number of observations

4. Plot discharge (Q) vs. exceedance probability (P).

Uses

- Hydropower potential assessment.
- Reservoir design.
- Environmental flow analysis.
- Reliability of water supply systems.

Types

- **Daily FDC**: Shows short-term flow variability.
- **Monthly/Annual FDC**: Highlights long-term trends and resource availability.

32.6 Mass Curve of Runoff – Analysis

A **Mass Curve** is a plot of cumulative runoff volume (or streamflow) against time. It helps in determining storage requirements for water supply and reservoir planning.

Construction

- Plot cumulative inflow or runoff on Y-axis and time on X-axis.
- Curve shape depends on the variability of inflow.
- Steep slopes indicate high inflow; flat regions show low inflow.

Applications

- Determining reservoir storage requirements:
  - **Demand line** is superimposed on the mass curve.
  - The **greatest vertical distance** between demand line and mass curve gives **required storage**.
- **Identifying periods of surplus and deficit**.

Advantages

- Simple graphical method for storage design.
- Can be constructed from historical flow data.
- Useful for analyzing time-distributed flow data.
