

Module 4: Runoff and Surface Water Hydrology

1. Runoff and Runoff Volume

Runoff is the portion of precipitation that flows over the land surface into water bodies when infiltration, evaporation, and other losses are satisfied.

Types of Runoff:

- **Surface runoff:** Water that flows directly over land to streams.
- **Subsurface runoff:** Water that infiltrates then emerges into streams.
- **Base flow:** Groundwater contribution to streamflow during dry periods.

Runoff Volume (Q):

The total quantity of runoff from a watershed after a storm is:

$$Q = P - (Losses)$$

Where:

- \$ P \$: Precipitation
- Losses include infiltration, evaporation, and detention (e.g., interception, depression storage).

Volume is often expressed as depth over the basin area (mm) or as total volume (m³).

2. SCS-Curve Number (SCS-CN) Method

- Developed by the **US Soil Conservation Service (SCS)**.
- Estimates direct runoff from rainfall using land use, soil type, and antecedent moisture.

Equation:

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

Where:

- \$ Q \$ = runoff (mm)
- \$ P \$ = precipitation (mm)
- \$ I_a \$ = initial abstraction $\approx 0.2S$
- \$ S \$ = potential maximum retention (mm), related to Curve Number (CN):

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

Curve Number (CN):

Ranges from **30 to 100**, with higher CN indicating less infiltration and higher runoff. Depends on:

- Soil hydrologic group (A to D)
- Land use (urban, forest, agriculture)
- Slope and land treatment
- Antecedent moisture condition (AMC I, II, III)

3. Flow-Duration Curve (FDC)

- **Definition:** A plot showing the percentage of time a certain flow rate is equaled or exceeded.
- Useful in **hydropower, water supply design, and environmental flows**.

Interpretation:

- Steeper curve → High variability.
- Flatter curve → Stable baseflow (e.g., in groundwater-fed rivers).

4. Flow-Mass Curve

- A **cumulative plot** of flow data over time (volume vs. time).
- Used for reservoir design and determination of **required storage**.

Applications:

- Identifying storage volumes required during dry periods.
- Comparing water demand with cumulative inflow availability.

5. Hydrograph

A **hydrograph** is a plot of streamflow (discharge) versus time for a specific point in a river.

Components:

- **Rising limb:** Steeply rising portion after storm begins.
- **Peak discharge:** Maximum flow.
- **Falling limb (recession limb):** Gradual decline after peak.
- **Base flow:** Normal groundwater-fed flow before/after the event.

6. Factors Affecting Runoff and Hydrograph Shape

Factor	Effect
Rainfall intensity/duration	Higher intensity → higher/steeper hydrograph
Soil Type	Sandy → lower runoff; clay → high runoff
Land Use	Urban areas have lower infiltration (flashy hydrographs)
Watershed Size/Shape	Compact → faster runoff and shorter time to peak
Topography/Slope	Steep slope → faster runoff
Antecedent Moisture	Wet conditions → increased immediate runoff
Vegetation	Increases interception, delays peak

7. Base Flow Separation

Base flow is separated from surface runoff in hydrographs using graphical or analytical methods to isolate direct runoff.

Common Methods:

- **Straight-line method**
- **Fixed percentage method**
- **Recession curve extrapolation**
- **Digital filtering techniques**

8. Effective Rainfall

- Portion of rainfall that generates **direct runoff**, excluding:
 - Interception
 - Initial losses
 - Infiltration during early periods

Used in **unit hydrograph** construction.

9. Unit Hydrograph

A **unit hydrograph (UH)** is the hydrograph resulting from **1 unit depth of effective rainfall** (usually 1 cm) **uniformly distributed** over a catchment over a specific duration (D hours).

Assumptions:

- Linearity
- Time invariance
- Uniform rainfall excess

Uses:

- Predicting flood hydrographs from rainfall excess
- Catchment response modeling

10. Surface Water Resources of India

- **Total potential:** Approx. 1,869 BCM/year
- **Usable resources:** About 690 BCM (surface) due to topography, accessibility
- **Major River Basins:** Ganga, Brahmaputra, Godavari, Krishna, Narmada, Cauvery

Features:

- Monsoon-dependent
- Geographic imbalances: Eastern rivers (e.g., Brahmaputra) are surplus; western and southern regions face scarcity

11. Environmental Flows (E-Flows)

E-Flows are the **quantity, timing, and quality** of water flows required to sustain freshwater and estuarine ecosystems.

Importance:

- Prevents ecological degradation
- Maintains sediment transport
- Supports fisheries, wetland habitats

Implementation:

- Environmental flow assessments required during dam design, diversions
- **E-flow norms** are part of India's river basin management plans (e.g., Ganga Basin)

Summary Table

Concept	Purpose/Definition
Runoff Volume	Estimate streamflow from rainfall
SCS-CN Method	Simple runoff estimation using land and soil data
Flow-Duration Curve	Flow reliability analysis
Flow-Mass Curve	Storage requirement calculation
Hydrograph	Streamflow variation over time post rainfall
Base Flow Separation	Distinguishes groundwater contribution from runoff
Unit Hydrograph	Predicts runoff from unit rainfall

Concept	Purpose/Definition
Environmental Flows	Flow regime needed for ecosystem health

This module equips students with essential tools and concepts required to quantify, analyze, and manage runoff and streamflow, a critical component of flood forecasting, water resources planning, and ecological sustainability.