Chapter 1: Concepts of Hydrologic Cycle

Introduction

Hydrology is the science that deals with the occurrence, distribution, movement, and properties of the waters of the Earth. It is one of the core areas of study in water resources engineering. Understanding the **hydrologic cycle** is foundational to grasping more advanced concepts in this domain. The hydrologic cycle describes the continuous movement of water on, above, and below the surface of the Earth. It includes processes such as precipitation, evaporation, infiltration, runoff, and groundwater flow.

In this chapter, we explore the various components of the hydrologic cycle, the forces that drive it, and the interactions among its elements. The knowledge acquired here serves as a baseline for the analysis, design, and management of water resources systems.

1.1 Definition and Scope of Hydrology

- **Definition of Hydrology:** Hydrology is defined as the science that deals with the waters of the Earth, including their occurrence, circulation, and distribution, both on the surface and underground, and their physical and chemical properties.
- **Scope in Engineering:**
  - Planning and management of water resources projects.
  - Flood prediction and control.
  - Irrigation system design.
  - Dams and reservoir operation.
  - Urban drainage system planning.
  - Hydropower generation.

1.2 The Hydrologic Cycle

- **Definition:** The hydrologic cycle (also known as the water cycle) is a natural process through which water circulates between the Earth's surface and the atmosphere.
- **Major Components of the Hydrologic Cycle:**
  a. **Evaporation and Transpiration (Evapotranspiration)**
     - Evaporation: Conversion of water from liquid to vapor form.

- Transpiration: Release of water vapor by plants.
- Factors affecting evaporation: temperature, wind, humidity, solar radiation, and surface area.

b. **Condensation**

- Conversion of water vapor into water droplets.
- Forms clouds or fog.
- Occurs due to cooling of air containing water vapor.

c. **Precipitation**

- Any form of water falling to the Earth from the atmosphere (rain, snow, hail, sleet).
- Measured using rain gauges.
- Types: Convective, Orographic, Cyclonic (Frontal).

d. **Infiltration**

- Movement of water from the surface into the soil.
- Influenced by soil type, vegetation, land use, and rainfall intensity.
- Infiltration capacity and rate are key parameters.
- Measured using infiltrometers.

e. **Percolation**

- Downward movement of infiltrated water through the soil layers.
- Replenishes groundwater aquifers.

f. **Runoff**

- Excess water that flows over the land surface.
- Occurs when infiltration capacity is exceeded.
- Types: Surface runoff (overland flow), subsurface runoff (interflow), and base flow.

g. **Groundwater Flow**

- Water that moves through aquifers below the surface.
- Plays a crucial role in sustaining streamflow during dry periods.
- Controlled by hydraulic gradient and permeability of the subsurface materials.

h. **Return Flow to the Atmosphere**

- Through evaporation from soil and water bodies.
- Through transpiration from vegetation.

1.3 Hydrologic Cycle in Global and Local Context

- **Global Water Budget:**

  - Oceans hold 97% of Earth's water.
  - Ice caps and glaciers: ~2%.
  - Freshwater (rivers, lakes, groundwater): ~1%.
  - Only a small fraction is available for human use.

- **Residence Time:**
  - Average time water stays in one part of the cycle.
  - Example: Water in the atmosphere has a short residence time (~10 days), whereas groundwater may take years.

- **Local Water Cycle Dynamics:**
  - Vary by geography, climate, land use, and vegetation cover.
  - Urbanization affects infiltration and runoff.

1.4 Water Balance Equation

- **Concept:** The water balance equation is based on the law of conservation of mass. It relates the input, output, and storage of water in a system.

$$P = ET + Q + \Delta S$$

- Where: P = Precipitation ET = Evapotranspiration Q = Runoff (surface and subsurface) ΔS = Change in storage (soil moisture, groundwater, surface water)

- **Application:**
  - Watershed studies.
  - Reservoir operation.
  - Agricultural water budgeting.

1.5 Systems Concept in Hydrology

- **Hydrologic System:** A defined volume of the Earth where the water budget is considered.

- **Types of Systems:**
  - **Closed System:** No exchange with external environment.
  - **Open System:** Inputs and outputs are considered.

- **System Elements:**
  - **Input:** Precipitation.
  - **Output:** Evapotranspiration, runoff.
  - **Storage:** Surface water bodies, soil moisture, groundwater.

1.6 Watershed and Catchment Concepts

- **Watershed:**
  - A land area that drains all the precipitation to a common outlet.
  - Also known as drainage basin or catchment area.
- **Classification of Watersheds:**
  - Macro, Meso, Micro based on area.
  - Natural vs. artificial.
- **Importance in Hydrology:**
  - Basic unit for hydrologic analysis and planning.
  - Helps in estimating runoff, sediment yield, and flood potential.

1.7 Precipitation Mechanisms and Weather Systems

- **Mechanisms:**
  - **Orographic Lifting:** Moist air lifted over mountains.
  - **Convective Lifting:** Localized heating causes air to rise.
  - **Frontal Lifting:** Cold and warm air masses interact.
- **Weather Systems Influencing Rainfall:**
  - Cyclones, monsoons, thunderstorms, depressions.

1.8 Human Impacts on the Hydrologic Cycle

- **Urbanization:**
  - Reduces infiltration, increases runoff.
  - Alters natural drainage patterns.
- **Deforestation:**
  - Reduces transpiration, increases erosion.
  - Affects groundwater recharge.
- **Climate Change:**
  - Alters precipitation patterns.
  - Increases intensity and frequency of extreme events.
- **Water Extraction and Land Use Change:**

  - Depletion of groundwater.
  - Impacts on surface water flows and water quality.

1.9 Mathematical Modeling of Hydrologic Cycle

- **Purpose of Modeling:**
  - To simulate and predict hydrologic behavior.
  - Useful in design and decision-making.
- **Types of Models:**
  - **Deterministic vs. Stochastic**
  - **Lumped vs. Distributed**
  - **Empirical vs. Conceptual vs. Physically-Based**
- **Examples:**
  - SWAT (Soil and Water Assessment Tool)
  - HEC-HMS (Hydrologic Modeling System)
  - MIKE SHE, etc.
