Chapter 17: Evaporimeters and Analytical Methods of Evaporation Estimation

Introduction

Evaporation is a critical component of the hydrological cycle, representing the process by which water changes from liquid to vapor phase and is lost from open water bodies, soil surfaces, and plant leaves. In water resource engineering, accurate estimation of evaporation is essential for efficient reservoir design, irrigation scheduling, and water balance studies. Since direct measurement of evaporation over large surfaces is not feasible, several indirect and empirical methods, as well as various types of instruments called *evaporimeters*, are employed for its estimation.

This chapter provides an in-depth look into the **principles of evaporation**, **types of evaporimeters**, and the **analytical and empirical methods** used to estimate evaporation.

17.1 Definition and Importance of Evaporation in Hydrology

- **Evaporation** is defined as the process by which water changes from liquid to vapor due to solar radiation, wind, and vapor pressure deficit.
- It is a **major loss component** in the hydrologic budget of reservoirs, lakes, and ponds.
- Precise evaporation data is essential for:
  - Reservoir operation and planning
  - Irrigation project design
  - Flood routing
  - Water availability studies
  - Hydrological and climate modeling

17.2 Factors Affecting Evaporation

The rate of evaporation from water surfaces is influenced by:

1. **Solar Radiation (Insolation)** – More solar radiation increases evaporation.
2. **Air Temperature** – Higher temperatures enhance kinetic energy of water molecules.
3. **Relative Humidity** – High humidity lowers the evaporation rate.
4. **Wind Speed** – Promotes evaporation by removing saturated air near the water surface.
5. **Atmospheric Pressure** – Lower pressure encourages evaporation.
6. **Water Salinity** – Presence of salts decreases evaporation due to reduced vapor pressure.
7. **Water Surface Area and Depth** – Larger and shallower bodies evaporate more rapidly.

17.3 Evaporimeters (Evaporation Pans)

Evaporimeters are instruments used for direct measurement of evaporation. These are **standardized pans** filled with water and exposed to the atmosphere.

17.3.1 Class A Evaporation Pan

- **Most commonly used pan evaporimeter**
- Specifications:
  - Circular pan made of galvanized iron or stainless steel
  - Diameter: 1207 mm
  - Depth: 255 mm
  - Filled to 180 mm depth
  - Placed on a wooden platform 15 cm above ground
- **Measurement**:
  - Water loss is measured daily with a hook gauge or point gauge
- **Limitations**:
  - Evaporation from the pan is usually more than from a large water body
  - Hence, a **Pan Coefficient (K_p)** is applied (typically 0.7–0.8)

17.3.2 ISI Standard Pan Evaporimeter (India)

- Developed by the Indian Meteorological Department
- Rectangular in shape
- Made of copper or galvanized iron
- Enclosed in a screen to reduce wind effect
- Suitable for Indian climatic conditions

17.3.3 Floating Pan Evaporimeter

- Floats on the water surface of a reservoir or lake
- Mimics actual evaporation conditions better than land-based pans
- Requires anchoring to prevent drifting

17.3.4 Colorado Sunken Pan

- Sunken into the ground with rim at ground level
- Reduces error due to wind and temperature difference from surrounding ground
- Used in long-term hydrological studies

17.4 Analytical Methods of Estimating Evaporation

Due to limitations in using pans for large water bodies, analytical and empirical methods have been developed.

17.4.1 Energy Budget Method

- Based on **First Law of Thermodynamics**:

  $$Q_s - Q_r - Q_b = Q_e + Q_h + Q_s$$

  Where:

  - Q_s = Incoming solar radiation
  - Q_r = Reflected radiation
  - Q_b = Long-wave back radiation
  - Q_e = Energy used in evaporation
  - Q_h = Sensible heat transfer to air
  - Q_s = Heat storage in water

- **Evaporation (E)** is estimated from energy balance:

  $E = Q\_e / (L \times \rho)$

  Where:

  - L = Latent heat of vaporization
  - ρ = Density of water
- **Advantages**: Physically-based, accurate
- **Limitations**: Requires multiple difficult-to-measure parameters (solar radiation, back radiation, etc.)

17.4.2 Mass Transfer (Dalton's) Method

- Based on the principle that evaporation is proportional to vapor pressure deficit and wind speed:

  $E = C \times (e_s - e_a) \times u$

  Where:

  - C = Empirical constant
  - e_s = Saturation vapor pressure at water surface temperature
  - e_a = Actual vapor pressure of the air
  - u = Wind speed
- **Dalton's Law** forms the basis
- Simple and practical but sensitive to measurement errors

17.4.3 Combination Method (Penman Equation)

- Combines **energy budget** and **mass transfer** methods
- Penman's equation (1948):

  $E = (\Delta / (\Delta + \gamma)) \times E_n + (\gamma / (\Delta + \gamma)) \times E_a$

  Where:

  - Δ = Slope of saturation vapor pressure curve
  - γ = Psychrometric constant

- E_n = Net radiation-based evaporation
- E_a = Aerodynamic evaporation

- **Highly accurate** and considered a **standard** method
- Requires meteorological data (temperature, radiation, wind speed, humidity)

17.4.4 Empirical Formulas

Used when limited data is available. Examples include:

a) Meyer's Formula

$E = K (es - ea) (1 + u_9)$

- K = 0.36 for large deep waters, 0.50 for small shallow waters
- es, ea = saturation and actual vapor pressures
- u_9 = wind speed at 9 m height

b) Rohwer's Equation

$E = (0.771 + 0.06T) (es - ea) (1 + 0.1u)$

- T = air temperature in °C
- es, ea = vapor pressures
- u = wind velocity in km/hr

c) Blaney–Criddle Method

Used in irrigation engineering:

$E = p (0.46T + 8.13)$

- p = mean daily percentage of annual daytime hours
- T = mean monthly temperature in °C

17.4.5 Pan Evaporation Method

Although not strictly analytical, this method is commonly used for **field-scale evaporation estimation**.

- **$E_{waterbody} = K_p \times E_{pan}$**
- K_p varies depending on pan type, location, and surrounding environment.

17.4.6 Remote Sensing and GIS Techniques

- Use satellite-based thermal imagery and evapotranspiration models (like SEBAL, METRIC)
- GIS helps in spatial analysis and mapping of evaporation zones
- Suitable for regional-scale water resource assessments

17.4.7 Lysimeter Technique (for Evapotranspiration)

- Lysimeters measure **evapotranspiration (ET)** which includes evaporation and transpiration.
- Consist of soil-filled tanks with vegetation
- Water loss is recorded to estimate ET
- Mainly used in **agronomic and irrigation studies**

17.5 Selection Criteria for Evaporation Estimation Methods

- **Purpose of study** – research, planning, or operational
- **Availability of data** – meteorological stations, pan data, satellite access
- **Size and type of water body**
- **Accuracy required**
- **Budget and resource availability**