Chapter 18: Reservoir Evaporation and Methods for Its Reduction

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Introduction

Reservoirs are integral to water resource systems, serving purposes like irrigation, hydroelectric power generation, flood control, and drinking water supply. However, one of the major inefficiencies in reservoir operations is **water loss due to evaporation**. This becomes especially critical in **arid and semi-arid regions**, where high temperatures and low humidity result in significant evaporation losses.

Evaporation from reservoirs not only reduces water availability but also affects project economics, alters downstream flow regimes, and impacts water quality. Hence, understanding the **process of reservoir evaporation**, accurately estimating it, and developing **strategies to minimize** this loss is essential for sustainable water resource management.

18.1 Nature and Magnitude of Reservoir Evaporation

18.1.1 Definition

- **Reservoir evaporation** refers to the **loss of water** from the free surface of a reservoir into the atmosphere due to the processes of **evaporation and vapor transport**.
- This evaporation occurs continuously and varies **diurnally** and **seasonally**.

18.1.2 Factors Influencing Reservoir Evaporation

1. **Climatic Factors**
    - Solar radiation
    - Ambient temperature
    - Relative humidity
    - Wind speed
    - Cloud cover
2. **Reservoir Characteristics**
    - Surface area: Larger reservoirs experience more evaporation.
    - Depth: Shallow reservoirs warm up faster, increasing evaporation.
    - Surface configuration: Irregular shorelines can create microclimates.
    - Storage operation pattern: Fluctuating levels affect surface area.
3. **Geographical and Environmental Factors**

- Latitude and altitude
- Surrounding vegetation
- Soil and air moisture conditions

18.1.3 Quantification of Reservoir Evaporation

- Typically estimated using:
  - **Pan evaporation data** adjusted using pan coefficient
  - **Penman** or **energy budget methods**
- Annual evaporation from reservoirs in India can range between **1.0 to 2.5 m/year**, depending on climatic conditions.

18.2 Methods of Estimating Reservoir Evaporation

Reservoir evaporation estimation methods are often adapted from standard evaporation estimation techniques, but with adjustments for scale, topography, and meteorological variability.

18.2.1 Pan Evaporation Method

- Most widely used in field conditions.
- **Formula**:

$$E_r = K_p \times E_p$$

- Where: E_r = Estimated evaporation from reservoir K_p = Pan coefficient (typically 0.6–0.8) E_p = Measured pan evaporation
- Requires careful site selection for the pan to ensure representativeness.

18.2.2 Water Budget Method

- Based on **mass balance**:

$$E = I + P - O - \Delta S$$

- Where: E = Evaporation loss I = Inflow P = Precipitation O = Outflow ΔS = Change in storage
- Works well over long durations.
- Requires accurate measurement of all components.

18.2.3 Energy Budget Method

- Based on heat fluxes across the reservoir:

$$Q_n = Q_e + Q_h + Q_s$$

- Where: Q_n = Net radiation Q_e = Energy used in evaporation Q_h = Sensible heat loss Q_s = Heat stored in water
- Evaporation is obtained using:

$$E = \frac{Q_e}{L \times \rho}$$

- Where: L = Latent heat of vaporization ρ = Water density
- Accurate but data-intensive.

18.2.4 Combination Method (Penman Method)

- Integrates both **energy and aerodynamic** factors.
- Requires data on net radiation, temperature, humidity, and wind speed.
- Suitable for reservoirs with meteorological station access.

18.2.5 Remote Sensing and GIS-Based Estimation

- Uses satellite-derived variables (e.g., land surface temperature, NDVI, albedo)
- Combined with models like **SEBAL**, **METRIC**, or **Penman-Monteith**
- Enables **spatially distributed** evaporation mapping
- Highly useful for **large reservoirs** or **basin-scale studies**

18.3 Impacts of Reservoir Evaporation

1. **Water Resource Loss**
   - Reduces usable water for irrigation, power, and urban needs.
2. **Altered Storage Planning**
   - Requires over-designing reservoir capacity to account for evaporation.
3. **Economic Implications**
   - Losses translate to increased project costs and reduced returns.
4. **Environmental Effects**
   - Affects microclimate and water temperature.
   - Increases concentration of salts and nutrients, degrading water quality.

18.4 Methods for Reducing Reservoir Evaporation

Due to the high magnitude of losses, several **engineering and environmental strategies** have been developed to minimize reservoir evaporation.

18.4.1 Surface Cover Methods

a) Floating Covers (Monomolecular Films)

- Chemicals like **hexadecanol**, **octadecanol**, or **cetyl alcohol** are sprayed over the surface.
- Form a one-molecule-thick film that resists vapor escape.
- **Advantages**:
  - Easy to apply
  - Reduces evaporation by 20–40%
- **Limitations**:
  - Effectiveness reduced by wind and water turbulence
  - Requires frequent reapplication
  - Environmental toxicity concerns

b) Floating Plastic Modules

- Plastic spheres or tiles that float and interlock to cover surface.
- Reduce exposure to air and sunlight.
- Durable but costly for large-scale application.

18.4.2 Wind Breaks and Shelterbelts

- Vegetative or structural barriers around reservoirs reduce **wind velocity**, thus minimizing evaporation.
- Trees like **Eucalyptus** or **Casuarina** are planted in **strategic alignment**.
- **Limitations**:
  - Require land space and long-term maintenance
  - Might increase transpiration losses if water-intensive species are used

18.4.3 Deepening of Reservoirs

- **Reduces surface-area-to-volume ratio**, lowering exposure.
- Involves **desilting** or modifying design contours.
- Technically effective but often **cost-prohibitive**.

18.4.4 Use of Underground Reservoirs (Subsurface Storage)

- Artificial recharge structures like **percolation tanks**, **infiltration galleries**, and **subsurface dams**.
- Store water below the surface, preventing direct evaporation.
- Useful in **arid zones** with permeable soil profiles.

18.4.5 Operational Adjustments

- **Water level management**: Maintaining lower water levels during high evaporation seasons.
- **Zoning of reservoir use**: Limit evaporation-exposed zones to non-critical uses.
- **Seasonal scheduling** of storage and releases based on evaporation forecasts.

18.4.6 Use of Shade Covers and Floating PV Panels

- Use of **solar panels** on floating structures:
  - Dual benefit: evaporation control + power generation
  - Increasingly adopted in India and other countries
- Shading covers also help reduce **algal growth** and **water warming**

18.5 Comparative Evaluation of Evaporation Reduction Methods

Method	Effectiveness	Cost	Environmental Impact	Applicability
Monomolecular Films	Moderate	Low–Med	Possible toxicity	Small/medium tanks
Windbreaks	Moderate	Low	Positive (if native)	Small to medium
Deepening Reservoirs	High	High	Neutral	Large reservoirs
Floating Plastic Covers	High	High	Neutral	Urban water bodies
Floating PV Panels	High	High	Positive (green tech)	Multi-purpose use
Underground Storage	Very High	Moderate	Positive	Arid/semi-arid

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18.6 Case Studies and Practical Implementations

1. **Indira Sagar Reservoir (Madhya Pradesh)**
   - Estimated annual evaporation: ~2.3 m
   - Used meteorological stations and Penman method for estimation
   - Suggested windbreak and floating PV strategies
2. **Pilot Study on Floating Covers – Maharashtra**
   - Monomolecular film trials showed ~35% evaporation reduction
   - Faced operational issues due to wind drift
3. **NTPC Simhadri Floating Solar Project**
   - 25 MW floating solar project over reservoir
   - Significantly reduced evaporation while generating renewable energy

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