Chapter 23: Actual Evapotranspiration

Introduction

Evapotranspiration is a vital process in the hydrologic cycle that combines two distinct phenomena—**evaporation** and **transpiration**. While evaporation refers to the transformation of water into vapor from surfaces like soil and water bodies, transpiration is the release of water vapor from plants through stomata. The term **actual evapotranspiration (AET)** denotes the quantity of water actually removed from the soil-plant system due to both processes under prevailing conditions. It is influenced by several factors including soil moisture availability, atmospheric demand, plant characteristics, and climatic conditions.

In the context of **Hydrology and Water Resources Engineering**, accurately estimating actual evapotranspiration is essential for **irrigation planning, water balance studies, reservoir operation, groundwater recharge assessments**, and **crop water requirements**. This chapter delves into the methods, influencing factors, measurement techniques, and applications of actual evapotranspiration.

23.1 Concept of Actual Evapotranspiration

- **Potential vs. Actual Evapotranspiration:**
  - *Potential Evapotranspiration (PET)*: The evapotranspiration that would occur with unlimited water supply.
  - *Actual Evapotranspiration (AET)*: The real evapotranspiration that occurs given the actual moisture availability in the root zone.
- **Water-Limited vs. Energy-Limited Conditions:**
  - In *water-limited* conditions, AET < PET due to insufficient soil moisture.
  - In *energy-limited* conditions, AET ≈ PET as water is available but energy (e.g., solar radiation) limits evapotranspiration.

23.2 Factors Affecting Actual Evapotranspiration

1. **Climatic Factors:**

- Solar radiation
- Air temperature
- Wind speed
- Humidity
- Atmospheric pressure

2. **Soil Properties:**
   - Soil texture and structure
   - Hydraulic conductivity
   - Soil water retention characteristics
   - Depth of root zone
3. **Vegetative Characteristics:**
   - Leaf Area Index (LAI)
   - Stomatal conductance
   - Plant rooting depth and type
   - Crop growth stage
4. **Water Availability:**
   - Soil moisture content
   - Depth to water table
   - Irrigation frequency and amount

23.3 Estimation Methods of Actual Evapotranspiration

23.3.1 Soil Water Balance Method

This method estimates AET by computing the change in soil moisture over time using the water balance equation:

$$AET = P - R - D - \Delta S$$

Where:

- P: Precipitation
- R: Runoff
- D: Deep percolation
- ΔS: Change in soil moisture storage

This method is widely used in **watershed hydrology** and **agriculture**, especially when reliable soil moisture data are available.

23.3.2 Lysimeter Method

- Lysimeters are precision devices that simulate field conditions and directly measure evapotranspiration by recording the change in weight of a soil column.
- Two types: *Weighing* and *Non-weighing lysimeters*.
- Accurate but expensive and location-specific.

23.3.3 Remote Sensing and Satellite-Based Methods

- Use **NDVI (Normalized Difference Vegetation Index)** and **surface temperature data** from satellites.
- Algorithms such as **SEBAL (Surface Energy Balance Algorithm for Land)** or **METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration)** are applied.

Advantages:

- Large spatial coverage
- Useful for regional water resource management

23.3.4 Empirical Formulas and Crop Coefficients

- FAO Penman-Monteith equation is used to estimate **PET**, which is then multiplied by a crop coefficient (K_c) to estimate **AET**:

$$AET = K_c \times PET$$

- The crop coefficient accounts for the type, stage, and density of vegetation.

23.3.5 Eddy Covariance and Bowen Ratio Method

- These are **micrometeorological methods** that use turbulent fluxes of latent heat to determine evapotranspiration.
- Suitable for research and high-precision studies.

23.4 Measurement Techniques and Tools

- **Tensiometers** and **Neutron Probes** for soil moisture.
- **Thermal Infrared Cameras** and **Flux Towers** for micrometeorological data.
- **Satellite sensors** like MODIS, Landsat, and Sentinel for remote sensing.
- **Ground-based meteorological stations** for radiation, wind, and humidity.

23.5 Temporal and Spatial Variability of AET

- **Temporal Variation**: AET varies daily, seasonally, and annually with changes in weather and crop growth stages.
- **Spatial Variation**: Influenced by land cover type, topography, soil heterogeneity, and water management practices.

Mapping AET spatially helps in identifying water-stressed zones and planning irrigation schedules.

23.6 Applications of Actual Evapotranspiration Data

1. **Irrigation Water Management**: Estimating crop water requirements and scheduling irrigation.
2. **Hydrologic Modelling**: Water balance studies, flood forecasting, and drought assessment.
3. **Climate Change Studies**: Monitoring changes in ET patterns due to global warming.
4. **Groundwater Recharge Analysis**: Estimating percolation and recharge potential.
5. **Catchment Management**: Sustainable planning of land and water use in a basin.

23.7 Challenges in Estimating AET

- Limited access to high-resolution and ground-based data.
- Complexity in modeling due to heterogeneity in land cover.
- Uncertainty in parameter selection in remote sensing and empirical methods.
- Calibration and validation issues in large-scale models.

23.8 Recent Advances and Research Trends

- Integration of **AI and Machine Learning** for ET prediction.
- Improved **satellite data assimilation techniques**.
- Development of **open-source models and cloud platforms** for AET estimation (e.g., Google Earth Engine).
- Use of **Unmanned Aerial Vehicles (UAVs)** for field-level monitoring.