Chapter 21: Evapotranspiration Equations: Penman and Blaney & Criddle Methods

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Introduction

Evapotranspiration (ET) is a fundamental process in the hydrological cycle that combines two components: **evaporation** from soil and water surfaces, and **transpiration** from plant surfaces. Estimating evapotranspiration accurately is crucial for water resource planning, irrigation scheduling, hydrological modeling, and assessing agricultural water demands.

Direct measurement of evapotranspiration is complex, time-consuming, and often impractical over large areas or long periods. Therefore, empirical and semi-empirical methods have been developed to estimate ET based on available climatic data. Among these, the **Penman Method** and the **Blaney & Criddle Method** are widely used and recommended in engineering applications.

21.1 Concept of Evapotranspiration

Evapotranspiration is the **total loss of water** from the soil through both **evaporation** and **transpiration** processes. It is influenced by several climatic and physiological factors, including:

- Solar radiation
- Air temperature
- Wind speed
- Relative humidity
- Type and condition of vegetation
- Soil moisture content

There are two main types:

- **Potential Evapotranspiration (PET):** The evapotranspiration that would occur if water is abundantly available.
- **Actual Evapotranspiration (AET):** The evapotranspiration that actually occurs, considering soil moisture limitations.

21.2 Penman Method

21.2.1 Introduction to Penman Equation

The Penman method, developed by H.L. Penman in 1948, is a **physically-based** method combining **energy balance** and **aerodynamic** principles. It estimates

potential evapotranspiration (PET) and is widely used in regions where detailed meteorological data are available.

The **Penman Equation** is expressed as:

$$ET_0 = \frac{\Delta R_n + \gamma f(u)(e_s - e_a)}{\Delta + \gamma}$$

Where:

- ET_0: Reference crop evapotranspiration (mm/day)
- R_n: Net radiation at the crop surface (MJ/m²/day)
- Δ: Slope of the saturation vapor pressure vs temperature curve (kPa/°C)
- γ: Psychrometric constant (kPa/°C)
- $f(u)$: Wind function based on wind speed
- e_s: Saturation vapor pressure (kPa)
- e_a: Actual vapor pressure (kPa)

21.2.2 Components of Penman Equation

a) Net Radiation (Rn) The net radiation is calculated as:

$$R_n = R_s(1 - \alpha) - R_{nl}$$

Where:

- R_s: Incoming solar radiation
- α: Albedo or reflectivity
- R_{nl}: Net outgoing longwave radiation

b) Aerodynamic Term The aerodynamic term considers wind speed and vapor pressure deficit:

$$f(u)(e_s - e_a) = (0.26)(1 + 0.54u_2)(e_s - e_a)$$

Where:

- u_2: Wind speed at 2 meters height (m/s)

c) Temperature and Vapor Pressure Parameters

- e_s is calculated from average air temperature using the saturation vapor pressure curve.
- e_a is derived from relative humidity or dew point data.

21.2.3 Advantages and Limitations of Penman Method

- **Advantages:**
  - Physically based and accurate under a wide range of conditions
  - Accounts for both energy and aerodynamic factors
- **Limitations:**
  - Requires detailed meteorological data (radiation, wind speed, humidity, temperature)
  - Not suitable in data-scarce regions

21.3 Blaney and Criddle Method

21.3.1 Introduction

The **Blaney and Criddle method** is an empirical approach developed in the U.S. and is widely used in regions with **limited climatic data**. It estimates seasonal or monthly consumptive use based on **temperature and daylight hours**.

21.3.2 Blaney and Criddle Equation

$$ET_c = k \cdot p \cdot T$$

Where:

- ET_c: Crop evapotranspiration (mm/month)
- k: Crop coefficient (dimensionless)
- T: Mean monthly temperature (°C)
- p: Monthly percentage of total annual daytime hours

The sum $p \cdot T$ over the growing season is used to estimate seasonal evapotranspiration.

21.3.3 Calculation of the p Factor

The p factor is calculated using the following formula:

$$p = \frac{\text{Monthly Daylight Hours} \times \text{Number of Days in Month}}{\text{Total Annual Daylight Hours}} \times 100$$

Values of p for different latitudes and months are usually taken from tables.

21.3.4 Crop Coefficient (k)

The **crop coefficient** k varies with:

- Type of crop
- Stage of growth
- Climatic zone

Typical values are available in standard tables provided by FAO or national irrigation manuals.

21.3.5 Limitations of Blaney and Criddle Method

- Does not consider humidity, wind speed, or radiation
- Less accurate than Penman in regions with high climatic variability
- Mainly applicable in arid and semi-arid regions for seasonal planning

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21.4 Comparison of Penman and Blaney & Criddle Methods

Aspect	Penman Method	Blaney & Criddle Method
Type of Model	Physically-based	Empirical
Data Requirements	High (temp, radiation, wind, humidity)	Low (temp, daylight hours)
Accuracy	High (with full data)	Moderate
Applicability	General purpose	Semi-arid and data-scarce regions
Evapotranspiration Type	Potential ET	Actual/Crop ET
Complexity	Moderate to high	Simple

21.5 Applications in Civil Engineering

- **Irrigation Scheduling:** Estimating water requirements for different crops.
- **Water Resource Planning:** Understanding water losses from reservoirs and basins.
- **Urban Hydrology:** Incorporating ET in green infrastructure planning.
- **Climate Impact Studies:** Assessing changes in ET due to climatic variations.
- **Drought Analysis and Monitoring**
