EVAPORATION
AND
TRANSPARATION

Instructor

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4. EVAPORATION AND EVAPOTRANSPIRATION

Introduction

- **Evaporation**: The process through which water is transferred from the surface of the Earth to the atmosphere.

- Evaporation is important in all areas of water resources
- Because it affects
  - the capacity of the reservoir,
  - the yield of river basin,
  - the consumptive use of water by plants …. etc.

- In this chapter,
  - **Evaporation**: the water vaporization from the open water surfaces.
  - **Transpiration**: the water loss from the plants, through the pores at the surface of their leaves.
  - **Evapotranspiration**: Evaporation + Transpiration
Overview

Factors Effecting Evaporation
- Meteorological factors
- The Nature of the Evaporating Surface

Measurement of Evaporation

Methods of Estimation of Evaporation
- Water Budget (Storage Equation) Approach
- Energy Budget Method
- Panman (Combination) Method

Estimation of Evapotranspiration
- Blaney Criddle Method
- Thornthwaite Method
Factors Effecting Evaporation

Meteorological Factors

- **Solar radiation:**
  - Evaporation is a process of energy exchange.
  - Solar radiation supply the energy necessary for the liquid water molecules to evaporate.

- **Relative humidity:**
  - As the humidity of air increase its ability to absorb more water vapor decreases, and the rate of evaporation becomes slower.

- **The temperature of air:**
  - Temperature increase saturation vapor pressure (increases saturation deficit),
  - High temperature implies that there is energy available for evaporation.
Factors Effecting Evaporation

Meteorological Factors

- Wind:
  - As the liquid water vaporizes from a water body, the air adjacent to this body will be saturated.
  - For the continuation of evaporation, this saturated air should be removed.
  - This is possible by wind.
  - 10% change in the wind speed $\rightarrow$ 1-3% change in evaporation.

- Atmospheric Pressure:
  - An increase in atmospheric pressure prevents the movement of molecules out of water.
Factors Effecting Evaporation

The Nature of the Evaporating Surface

Important factors affecting the evaporation from different surfaces:

- **Temperature of liquid water:**
  - (High liquid water temp.) → (High molecular motion in the water)
  - (The number of molecules leaving the water body will be high)

- **Salinity:**
  - Adversely affects evaporation.
  - 1% increase in salt concentration → 1% decrease in evaporation

- **Aerodynamic characteristics of the surface:**
  - Roughness, texture or size of the surface.

- **Reflection coefficient (albedo) of the surface:**
  - High albedo → Low evaporation from the surface
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4. EVAPORATION AND EVAPOTRANSPIRATION

Measurement of Evaporation

- Direct measurement of evaporation is possible using evaporation pan.
- The most widely used pan:
  - The standard U.S. Weather Bureau Class A pan.
  - Daily measurements: height of water & volume of water / day
  - Anemometer to measure the wind
  - Precipitation gauge nearby the pan.

Diameter: 122 cm (4 ft)
Pan depth: 25.4 cm (10 in)
Water depth: 20 cm (8 in)
Measurement of Evaporation

- Due to the heating of water by the walls of the pan, pan measurement should be corrected by a coefficient.

- The pan coefficient may change from time to time or from one location to another.

- In Turkey, it is constant (0.7).

http://commons.wikimedia.org/wiki/File:Evaporation_Pan.jpg
Measurement of Evaporation

- Installation of a pan
  - Sunken
  - Floating
  - Surface

- Other instruments:
  - Wild Evaporimeter
  - Livingston Atmometer
  - Pische Armometer

http://commons.wikimedia.org/wiki/File:Evaporation_Pan.jpg
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Methods of Estimation of Evaporation

The estimation of evaporation from free water surfaces is necessary for mainly two purposes:

- The determination of actual evaporation taking place from an existing reservoir for an optimum operation of the reservoir.
- The estimation of future evaporation from a reservoir to be constructed.

Methods to estimate evaporation:

- Water Budget (Storage Equation) Approach
- Energy Budget Method
- Mass Transfer Method
- Empirical Equations
- Penman Method
Methods of Estimation of Evaporation

Water Budget (Storage Equation) Approach

- Continuity Equation:

\[ E = (\Delta S + P + Q_s) - (Q_o + Q_{ss}) \]

where \( \Delta S \): change in storage \((S_2 - S_1)\)

- \( P \): precipitation
- \( Q_s \): surface inflow
- \( Q_o \): surface outflow
- \( Q_{ss} \): subsurface outflow (seepage)

\( \Delta t \): week, month or year.
Methods of Estimation of Evaporation

Energy Budget Method

\[ Q_N - Q_h - Q_e = Q_\theta - Q_v \]

where

- \( Q_N \): net radiation absorbed by the water body
- \( Q_h \): sensible heat transfer
- \( Q_e \): energy used for evaporation
- \( Q_\theta \): increase in energy stored in the water body
- \( Q_v \): advected energy of inflow and outflow

1 langley/day = 1 cal/cm²
Methods of Estimation of Evaporation

Energy Budget Method

\[ E = \frac{Q_N + Q_v - Q_\theta}{\rho L_e(1 + R)} \]

where \( \rho \): density of water (gr/cm\(^3\)).
\( L_e \): latent heat of vaporization (cal/gr)
\( R \): ratio of heat loss by conduction to that by evaporation
Methods of Estimation of Evaporation

Energy Budget Method

\[ R = \gamma \frac{T_s - T_a}{e_s - e_a} \]

where \( \gamma \) : Psychrometer constant = 0.66 mb/\(^\circ\)C.

- \( T_s \) : water surface temperature in \(^\circ\)C.
- \( T_a \) : air temperature in \(^\circ\)C.
- \( e_s \) : saturation vapor pressure at surface water temperature in mb.
- \( e_a \) : vapor pressure of the air in mb.

The ENERGY BUDGET METHOD is the most accurate method but requires collection of detailed atmospheric data.
Methods of Estimation of Evaporation

Penman (Combination) Method

Using energy budget and mass transport methods, Penman (1956) proposed a new equation which gives a good estimation of evaporation from lakes for daily to monthly periods:

\[ E_0 = \frac{\Delta Q_n + \gamma E_a}{\gamma + \Delta} \]

where \( E_0 \): evaporation from open water surface (mm/day)
\( Q_n \): net amount of radiation remaining at the free water surface (g.cal/cm\(^2\)/day = 59 mm/day)
\( E_a \): evaporation due to mass transfer of vapor, (mm/day)
\( \Delta \): gradient of saturation vapor pressure at air temperature \( t \) (°C).
\( \gamma \): Psychrometer constant (=0.66 mb/°C or 0.49 mm Hg / °C)
Methods of Estimation of Evaporation

Panman (Combination) Method

\[ \Delta = \tan \alpha = \frac{e_{s2} - e_{s1}}{t_2 - t_1} \]
Panman (Combination) Method

The values of \( Q_n \) and \( E_a \) are determined from the following equations:

\[
Q_n = R_I - R_B = R_C (1-r) - R_B
\]

\[
R_C = R_A (0.20 + 0.48 \text{ n/D})
\]

\[
R_B = \sigma T_a^4 (0.47 + 0.077 \sqrt{e}) (0.20 + 0.80 \text{ n/D})
\]

\[
E_a = 0.35 (e_s - e) (0.5 + 0.54 U_2)
\]
Methods of Estimation of Evaporation

Panman (Combination) Method

The definition of the terms are as follows:

\( R_I \) : Net amount of energy absorbed at the surface.
\( R_B \) : Net long wave radiation of the Earth.
\( R_C \) : Actual short wave radiation from the sun and sky, at the Earth’s surface.
\( R_A \) : Angot’s value of solar radiation arriving at the outer limit of the atmosphere in g.cal/cm\(^2\)/day. It is given in Table 1 as a function of the latitude of the place and the month of the year.
\( r \) : Albedo (reflection coefficient) of the surface (equal to 0.06 for free water surfaces).
\( n/D \) : Ratio of actual hours of sunshine to possible hours of sunshine. Possible hours of sunshine, D, are given in Table 2 for the latitude of the place and the time of the year.
\( \sigma \) : Lummer and Pringsheim constant, equal to 117.74 \( \times 10^{-9} \) gr.cal/cm\(^2\)/day.
\( T_a \) : Absolute Earth temperature in °K (= t °C + 273).
\( e \) : Actual vapor pressure of air in mm Hg at t °C.
\( e_s \) : Saturation vapor pressure of air in mm Hg at t °C.
\( U_2 \) : Wind velocity at 2 m. height in m/s.
### Methods of Estimation of Evaporation

**Panman (Combination) Method**

**Table 1** $R_A$, Angot's value of short wave radiation flux $R_A$ at the outer limit of the atmosphere in (gr.cm$^2$/day) as a function of the month of the year and the latitude (Brunt, 1944)

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Methods of Estimation of Evaporation

Panman (Combination) Method

Table 2 D, Possible hours of sunshine (northern N, southern S hemisphere) (Criddle, 1958)

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</table>
4. EVAPORATION AND EVAPOTRANSPIRATION

Methods of Estimation of Evaporation

Panman (Combination) Method

Penman’s Method requires:
- Mean air temperature,
- Relative humidity,
- Wind velocity, and
- Duration of sunshine.

Penman’s method commonly used in the world and in Turkey and it gives reasonably good results.
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Estimation of Evapotranspiration

Consumptive Use

Evapotranspiration
Water used in the plants for their growth

- Consumptive use is a function of:
  - climate,
  - soil moisture,
  - soil type,
  - land management method and
  - the type of vegetation.

- **Climate factor:** temperature, precipitation, humidity, wind and latitude of the area, that all affect the length of growing season.
4. EVAPORATION AND EVAPOTRANSPIRATION

Estimation of Evapotranspiration

Evapotranspiration Measurement

- The actual measurement is almost impossible,

- Using large tanks (Ø 5 m or bigger) filled with the same type of soil and vegetation with the surrounding area.

- It is called evapotranspirometer (lysimeters).

Potential Evapotranspiration:

- Blaney Criddle Method
- Panman Method, and
- Thornthwaite Method
Estimation of Evapotranspiration

Blaney Criddle Method

- Gives good estimation of Potential Evapotranspiration in arid and semi-arid zones
- Consumptive Use

\[ U = 25.4 \, k \, f \]

where \( U \): Potential Evapotranspiration (mm/month)
\( k \): \( k_1 \times k_2 \) monthly crop coefficient
\( k_1 \): Seasonal coefficient
\( k_2 \): Monthly coefficient as % of \( k_1 \)
\( f \): Climatic factor

\[ f = \frac{1.8t + 32}{100} \, p \]

\( t \): mean monthly temperature (°C)
\( p \): monthly daytime hours as a percentage of the annual value
### Estimation of Evapotranspiration

#### Table 3: \( k_1 \) and \( k_2 \) values to be used in Blaney-Criddle formula (Blaney, 1959)

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<th>Crop</th>
<th>Grow. Seas. (mo)</th>
<th>( k_1 )</th>
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<th>May</th>
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<td>3</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>3.4</td>
<td>1.10</td>
<td>30</td>
<td>125</td>
<td>133</td>
<td>131</td>
<td>135</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Estimation of Evapotranspiration

Table 4 P values to be used in Blaney-Criddle formula (Criddle, 1958)

<table>
<thead>
<tr>
<th>Mon</th>
<th>24°</th>
<th>26°</th>
<th>28°</th>
<th>30°</th>
<th>32°</th>
<th>34°</th>
<th>36°</th>
<th>38°</th>
<th>40°</th>
<th>42°</th>
<th>44°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb.</td>
<td>7.17</td>
<td>7.12</td>
<td>7.07</td>
<td>7.03</td>
<td>6.97</td>
<td>6.91</td>
<td>6.86</td>
<td>6.76</td>
<td>6.73</td>
<td>6.65</td>
<td>6.58</td>
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<tr>
<td>Mar.</td>
<td>8.40</td>
<td>8.40</td>
<td>8.39</td>
<td>8.38</td>
<td>8.37</td>
<td>8.36</td>
<td>8.35</td>
<td>8.34</td>
<td>8.33</td>
<td>8.31</td>
<td>8.30</td>
</tr>
<tr>
<td>Apr.</td>
<td>8.60</td>
<td>8.64</td>
<td>9.68</td>
<td>8.72</td>
<td>8.75</td>
<td>8.80</td>
<td>8.85</td>
<td>8.90</td>
<td>8.95</td>
<td>9.00</td>
<td>9.05</td>
</tr>
<tr>
<td>Sep.</td>
<td>8.31</td>
<td>8.31</td>
<td>8.32</td>
<td>8.34</td>
<td>8.34</td>
<td>8.36</td>
<td>8.36</td>
<td>8.38</td>
<td>8.38</td>
<td>8.40</td>
<td>8.41</td>
</tr>
<tr>
<td>Oct.</td>
<td>8.09</td>
<td>8.06</td>
<td>8.02</td>
<td>7.99</td>
<td>7.93</td>
<td>7.90</td>
<td>7.85</td>
<td>7.80</td>
<td>7.75</td>
<td>7.70</td>
<td>7.63</td>
</tr>
<tr>
<td>Nov.</td>
<td>7.43</td>
<td>7.36</td>
<td>7.27</td>
<td>7.19</td>
<td>7.11</td>
<td>7.02</td>
<td>6.92</td>
<td>6.82</td>
<td>6.72</td>
<td>6.62</td>
<td>6.49</td>
</tr>
<tr>
<td>Dec.</td>
<td>7.46</td>
<td>7.35</td>
<td>7.27</td>
<td>7.14</td>
<td>7.05</td>
<td>6.92</td>
<td>6.79</td>
<td>6.66</td>
<td>6.52</td>
<td>6.38</td>
<td>6.22</td>
</tr>
</tbody>
</table>
Estimation of Evapotranspiration

**Thornthwaite Method**

- Monthly Evapotranspiration (cm)

\[
ET = 1.6 \left( \frac{10t}{TE} \right)^a
\]

where \( t \): Mean monthly temperature (°C)

\( TE \): Thornthwaite’s temperature efficiency index

\[
TE = \sum_{i=1}^{12} \left( \frac{t_i}{5} \right)^{1.514}
\]

\( a \): coefficient

\( a = 0.49239 + 0.01792 \, TE \)