GEOG415  Lecture 4: Evaporation

Why study open-water evaporation?
- water supply reservoirs
- salinity
- aquatic habitat quality
- energy balance

How many m³ of water is lost in a day?

City of Calgary water use:

5 mm d⁻¹

5 km²

L d⁻¹ person⁻¹
Factors affecting evaporation
- radiation

- wind and humidity

- area of the lake

- salinity

Evaporation measurement: Water balance method
Conservation principle (mass balance principle)

Storage change = Inflow - Outflow

Inflow:

Outflow:

Challenges are usually in estimating groundwater flow.
Example → page 4-5
Evaporation pan

Standard size - Class A pan (diameter 1.2 m, depth 25 cm, filled with water to 20 cm.)

Boundary effects

Monitoring methods
- automatic recorder
- point gauge

Pan coefficients

Required to compensate for the boundary effects.

Varies with meteorological conditions, but 0.7-0.75 is assumed in most practical studies.
Lake evaporation map

Based on Class-A pan measurement. A pan coefficient of 0.7 is used.

Annual lake evaporation (mm)
St. Denis Wildlife Area, 40-km east of Saskatoon

(a) Two-hour precipitation.
(b) Water level in the pond.
(c) Water level in a submerged evaporation pan and the estimated water loss by groundwater outflow (residual).

Energy balance of a lake

- net radiation \((Q_n J m^{-2})\)

- sensible heat \((Q_h)\)

- latent heat \((Q_e)\)

- net energy advected into the lake by flows of water \((Q_v)\)

\[
= \frac{\rho c V_{in} (T_{in} - T_b) - \rho c V_{out} (T_{out} - T_b)}{A} = \frac{\rho c V_{in} T_{in} - \rho c V_{out} T_{out}}{A}
\]

\(T_{in}, \ T_{out}\): temperature of inflow and outflow waters (°C)

\(T_b\): reference temperature (= 0 °C)

\(\rho\): density of water (kg m\(^{-3}\)) \quad c: \text{ specific heat (J kg}^{-1} \text{ °C}^{-1})

\(V_{in}, \ V_{out}\): flow volumes (m\(^3\)) \quad A: \text{ lake area (m}^2\))

- energy advected out of the lake by evaporating water \((Q_{ve})\)

**Note:** This term is usually insignificant.

- storage change \((Q_\theta)\)

\[
= \frac{\rho c V_{lake} \Delta T_{lake}}{A}
\]

\(V_{lake}\): lake volume

\(\Delta T_{lake}\): change in the average lake temperature
Energy balance equation

\[ Q_{\theta} = Q_n - Q_h - Q_e + Q_v - Q_{ve} \]  

The objective is to estimate evaporation \( E_0 \) (m) from \( Q_e \) by knowing other terms.

Relationship between \( Q_e \) and \( E_0 \)?

\[ L: \text{latent heat of vaporization (J kg}^{-1}\text{)} \]

Bowen ratio

It is difficult to measure \( Q_e \) and \( Q_h \) separately, but reasonably easy to measure the ratio \( Q_h/Q_e \). Why?

Each parcel contains numerous molecules. Parcels near the water surface contain more water vapor than the ones far from the surface.

Random motion of the parcels lead to the *net upward* transfer of water vapor.
The same principle applies to sensible heat transfer. If the water surface is warmer than the air, random motion of the parcels lead to the net upward transfer of warm air parcels.

Under a given wind condition,

\[ Q_h \propto T_s - T_a \quad Q_e \propto e_s - e_a \]

- \( T_s \): water surface temperature
- \( T_a \): air temperature at a specified height, usually 2 m
- \( e_s \): vapor pressure at the water surface (mb)
- \( e_a \): vapor pressure in the air at a specified height (mb)

Bowen ratio \( (R) \)

\[ R = \frac{Q_h}{Q_e} = \frac{T_s - T_a}{e_s - e_a} \quad \text{where} \quad \gamma = 0.00065p \]

- \( \gamma \): psychrometric constant (mb °C\(^{-1}\))
- \( p \): atmospheric pressure (mb)

Using \( R \), we can now estimate \( E_0 \).

\[ E_0 = \]
Net radiation

Net radiation data is available from only a limited number of meteorological stations (e.g. Edmonton, Lethbridge).

Approximate estimates of $Q_n$

$$Q_n = Q_s - Q_{rs} - Q_{lw} = Q_s (1 - \alpha) - Q_{lw}$$

- $Q_s$: incoming shortwave (solar) radiation
- $Q_{rs}$: reflected shortwave radiation
- $Q_{lw}$: net longwave radiation
- $\alpha$: albedo (assumed 0.06 for water)

$Q_s$ can be estimated from the solar radiation at the top of the atmosphere $I_0$ and average cloudiness $C$ (DL, p.107), or directly from “average insolation” on the NASA web site.

$Q_{lw}$ depends on surface temperature ($T_s$), the temperature ($T_a$) and vapor pressure ($e_a$) of the overlying air, and cloudiness. Why?

Several formulas for estimating $Q_{lw}$ from $T_s$, and $T_a$ and $e_a$ measured at 2 m are listed in DL, p.108-109.
NASA Surface meteorology and Solar Energy Data Set

Latitude 50 / Longitude -114 was chosen.

Parameters for Solar Cooking:

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insolation (kWh/m²/day)</td>
<td>0.95</td>
<td>1.90</td>
<td>3.20</td>
<td>4.88</td>
<td>5.60</td>
<td>6.02</td>
<td>6.45</td>
<td>4.98</td>
<td>3.90</td>
<td>2.50</td>
<td>1.20</td>
<td>0.81</td>
</tr>
<tr>
<td>10 Year Average</td>
<td>0.95</td>
<td>1.90</td>
<td>3.20</td>
<td>4.88</td>
<td>5.60</td>
<td>6.02</td>
<td>6.45</td>
<td>4.98</td>
<td>3.90</td>
<td>2.50</td>
<td>1.20</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Find a different location

- Click on a desired map location
- Enter latitude and longitude

Additional information about the SSE data set

- Accuracy
- Methodology
- Parameters (Units & Definition)

Back to SSE Data Set
Home Page
Questions?

Responsible NASA Official: Richard McGinnis
Site Administration: NASA Langley ASDC User Services
Site URL: http://eosweb.larc.nasa.gov/sse/
Document generated on Mon Feb 4 16:56:16 EST 2002
Mass transfer method

Evaporation is controlled by humidity and wind speed.

How?

\[ E_0 = f(u) (e_s - e_a) \]

The difference \( e_s - e_a \) called the vapor pressure deficit.

\( f(u) \) is called the wind function, where \( u \) is the wind speed (m s\(^{-1}\) or km d\(^{-1}\)) measured at a specified height.

Note: Eq. (4-15) in DL, p.110 is misleading.

Common forms of the wind functions:

\[ f(u) = a + bu \]

\( a, b \): arbitrary constants

\[ f(u) = Nu_2 \]

\( u_2 \): wind speed measured at 2 m.

\( N \): mass-transfer coefficient (DL, p.110)

The water-balance method is commonly used to “calibrate” the constants in the wind function. What about the troublesome groundwater seepage loss?

\[ \Delta h = E_0 + S \]

\( \Delta h \): water-level drop in a specified interval (e.g. 1 day)

\( S \): seepage loss
Assumption: $E_0 = 0$ when $u_2 = 0$. Is this valid??

This diagram shows the evaporation measured by a submerged Class-A pan in a prairie pond. Note that there should not be any seepage in this case.

Why is this not zero?
Scale effects

Pan $\rightarrow$ Puddle $\rightarrow$ Pond $\rightarrow$ Lake

Note that $e_s$ is based on the temperature of the water surface, and $e_a$ is measured on the land.

What does $e_s - e_a$ really mean?

In general, the value of $N$ decreases as the size of water body increases.

Dunne and Leopold (1978, Fig. 4-7)
Combination method

The energy-balance and mass-transfer methods have a serious drawback in terms of practical application.

Penman method eliminates this problem by combining the two methods.

\[
E_0 = \frac{100Q_n}{\Delta + E_a \gamma} - \frac{\rho L}{\Delta + \gamma}
\]

Eq.[4-20] in DL

where \( \gamma = 0.66 \text{ [mb ºC}^{-1} \text{]}, \) called psychrometric constant.
\( \Delta = \) slope of the \( e_s - T_a \) curve (see DL, Fig. 4-8)
\( \rho = \) density of liquid water (kg m\(^{-3}\))
\( L = \) latent heat of vaporization (J kg\(^{-1}\))
\( E_a = \) aerodynamic evaporation (cm d\(^{-1}\)), see below.

Note that \( Q_n \) is now given in J m\(^{-2}\) d\(^{-1}\), and “100” converts the unit of evaporation from m d\(^{-1}\) to cm d\(^{-1}\).

The first term on the numerator represents the effects of energy input, and the second term represents the effects of mass transfer.

\[
E_a = (0.013 + 0.00016u_2)(e_{sa} - e_a)
\]

\( u_2 : \) wind speed (km d\(^{-1}\)) measured at 2 m
\( e_{sa}: \) saturation vapor pressure at \( T_a \) (see DL, Fig. 4-8)

Penman method is widely used by hydrologists.
Summary

What are the factors controlling “open-water” evaporation?

Scale effects?

Methods of evaporation measurement.
- water balance
- pan
- energy balance
- mass transfer
- combination

Advantage/disadvantage of each method? Data requirement?