Methods of Estimating Evaporation:

1. Mass Transfer Methods (Myers Formula)
2. Energy Budget Methods
3. Combined Methods (Penman Equation)
4. Water Budget Method (Pan Evaporation Method)

1. Mass transfer method

Evaporation driven by

–Vapor pressure gradient

–Wind speed

$$E = f(u)\,(e_s - e_a)$$
$$= (a + bu)\,(e_s - e_a)$$

e_s: saturation vapor pressure at temperature T of the water surface

e_a: vapor pressure at some fixed level above the water surface

u : wind speed at some level above surface

a,b : empirical constants

Some formulas use a zero value for the constant “a”in the formula due to the small local air movements with velocities insufficient to remove excess vapor from a above a pan surface. Harbeck and Meyers (1970) present the following equation.

$$\mathbf{E = bu_2 * (e_s - e_2)}$$

Where:

E=Evaporation (cm/day)

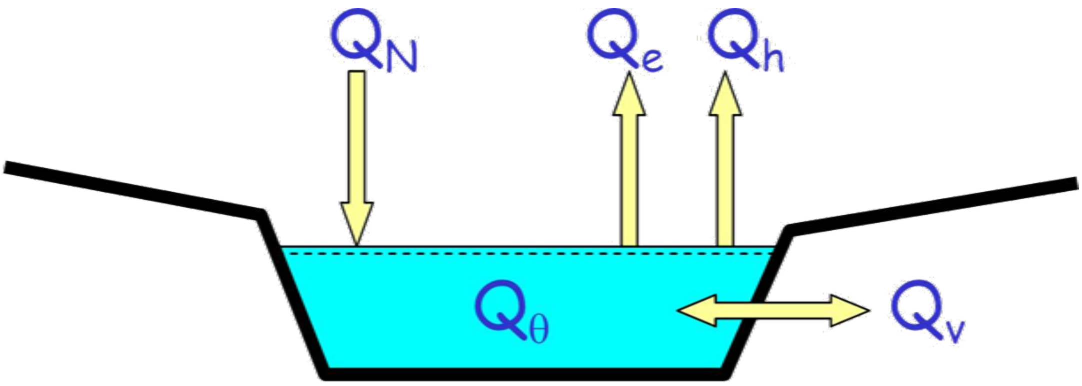
b=0.012 for Lake Hefner, 0.018 for Lake Mead

es=vapor pressure at water surface (mb)

e_2=vapor pressure 2 m above water surface (mb)

u_2=wind speed 2 m above water surface (m/s)

2. Energy budget method



The overall energy budget for a lake can be written as

$$\mathbf{Q_N = Q_e + Q_h - Q_v + Q_\theta}$$

Q_N: net radiation absorbed by water body [cal/cm2-day]

(solar radiation –reflection –radiation from lake)

Q_e: evaporation energy

Q_h: sensible heat transfer (conduction and convection to the atmosphere)

Q_v: advected energy of inflow and outflow

Q_θ: change in stored energy in the water body the overall energy budget

Sensible heat transfer difficult to measure

$Q_h \approx R \times Q_e$

$$\mathbf{R = \gamma \frac{T_s - T_a}{e_s - e_a}}$$

T_a: air temperature [°C]

T_s: water surface temperature [°C]

e_a: vapor pressure of the air [mb]

e_s: saturation vapor pressure at water surface temp. [mb]

γ: psychrometric constant = 0.66 (P/1000), P: atmospheric pressure in mb

Daily evaporation depth: $\mathbf{E = \gamma \frac{Q_e}{\rho L_e}}$ cm/day

Energy balance $\mathbf{Q_N = Q_e + Q_h - Q_v + Q_\theta}$

$\mathbf{Q_h = R * Q_e}$

$\mathbf{Q_N = Q_e *(1+R) - Q_v + Q_\theta}$

$\mathbf{Q_N = E\rho L_e (1+R) - Q_v + Q_\theta}$

$$\mathbf{E = \frac{Q_N + Q_v - Q_\theta}{\rho L_e (1+R)}} \quad \text{cm/day}$$

with

Q in [cal/cm^2-day]

L_e in [cal/g]: the latent heat of vaporization

ρ in [g/cm^3]: mass density of evaporated water

•Most accurate method

3. Combined method (Penman, 1948)

Combined 'mass transfer' and 'energy budget':

$$\mathbf{E \rho L_e = \frac{\Delta}{\Delta+\gamma} Q_N + \frac{\gamma}{\Delta+\gamma} E_a}$$

L_e = 597.3 - 0.57 (T-0 C^0)

Δ: slope of e_s vs t curve or

$$\Delta = \frac{de_s}{d_T} = \frac{2.7489*10^8*4278.6}{(T+242.79)^2} e^{\left(\frac{-4278.6}{T+242.79}\right)}$$

Q_N = is net absorbed radiation

E_a: drying power from equation

$\gamma = 0.66 * \left(\frac{P}{1000}\right)$

$\mathbf{E_a = \rho L_e (a+bu) (e_{sa} - e_a)}$ cal/cm^2-day

where

a,b : empirical constants

e_{sa}: saturation vapor pressure at air temp.

e_a: actual vapor pressure

Example :

Assume Meyer's formula applies to a lake:

$E = 0.0106\ (1+0.1\ u)(e_s-e_a)$ [cm/day]

u in mi/h, e in mb

Given:

$T_a = 32.2°C$

u = 32 km/h = 20 mi/h

RH = 30%

QN= 400 cal/cm2-day

Estimate daily evaporation using Penman's formula.

Solution

$$\Delta = \frac{\mathbf{2.7489x10^8x4278.6}}{(\boldsymbol{T} + \mathbf{242.79})^2} \exp\left\{-\frac{\mathbf{4278.6}}{(\boldsymbol{T} + \mathbf{242.79})}\right\}$$

with T = 32.2^oc , $\Delta = 2.72\ \text{mb}/{}^oc$

Actual and saturation vapor pressure:

e_{sa} (T = 32.2^oc) = 48.1mb

e_a= RH x e_{sa} = 0.3 x 48.1 =14.4 mb

Latent heat of evaporation at air temperature:

Le = 597.3 – 0.57 x 32.2 = 579 cal/g

$E_a = \rho\ L_e\ 0.0106\ (1+0.1u)\ (e_{sa}-e_a)$

= 1 x 579 x 0.0106 (1+0.1x20) (48.1-14.4)

= 1590 cal/cm^2-day

Penman's equation:

$$\mathbf{E\ \rho L_e} = \frac{\Delta}{\Delta+\gamma}\mathbf{Q_N} + \frac{\gamma}{\Delta+\gamma}\ \mathbf{E_a}$$

$$= \frac{2.72}{2.72+0.66}\,400 + \frac{0.66}{2.72+0.66}\ 1590$$

$= 632\ \ cal/cm^2\text{-day}$

or

$E = \frac{632}{1\ x\ 579} = 1.1\ cm/day$

4: Water budget method

Applicable to lake evaporation

Δ storage = input – output

$\Delta S = (I+P)-(O+E+GW)$

Or

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

I : inflow [cm]

P : precipitation [cm]

O: outflow [cm]

E : Evaporation [cm]

GW: Groundwater seepage [cm]