Worked Example of Potential Evaporation Calculations

Use equations in the class notes to compute *Reference Crop Evaporation Rate* [in mm day^{-1}] on April 15, for a site which is at latitude 30 °N and elevation 1000 m, and where the crop has an albedo of 0.23. On this day there are 6 hours of bright sunshine, max. and min. temperatures are 15 ° C and 5 ° C respectively, and average relative humidity and average wind speed are 80 % and 3 m s^{-1} respectively.

We will assume we can neglect the daily total soil heat flux since it largely averages out over a day, and also assume the average atmospheric pressure, P (in kPa), can be used in the calculations since they are comparatively insensitive to day-to-day variations. At elevation Z (in m) the average pressure can be estimated by:

$$P = 101.3\left(\frac{293 - 0.0065.Z}{293}\right)^{5.256}$$

We will also assume that the psychrometric "constant" , γ, can be estimated by:

$$\gamma = 0.0016286\frac{P}{\lambda}$$

and set the Stefan-Boltzmann constant equal to 4.903 x 10^{-9} MJ m^{-2} day^{-1}.]

First we calculate the values of the several meteorological inputs to the evaporation estimation equations and "constants" as follows.

Mean temperature, T , at this site on this day is

$$T = \frac{T_{\max} + T_{\min}}{2} = \frac{15+5}{2} = 10 \quad [\text{in } °\text{C}]$$

Latent heat, λ , at this temperature is given by

$$\lambda = 2.501 - 0.002361\ \mathrm{T} = 2.477 \quad [\mathrm{MJ\ kg^{-1}}]$$

Mean saturated vapor pressure is given by

$$e_{sat} = \left[\frac{e_{sat}(T_{\max}) + e_{sat}(T_{\min})}{2}\right] = \frac{0.873 + 1.706}{2} = 1.289$$

Mean vapor pressure is given by

$$e = \left[\frac{e_{sat}(T_{\max}) + e_{sat}(T_{\min})}{2}\right]\frac{RH}{100} = 1.289 \text{ x } 0.8 \ = 1.03 \qquad (\text{in kPa})$$

Mean vapor pressure deficit is given by

$$D = \left[\frac{e_{sat}(T_{\max}) + e_{sat}(T_{\min})}{2}\right]\frac{(100 - RH)}{100} = 1.289 \text{ x } 0.2 = 0.258 \quad \text{(in kPa)}$$

Rate of change of saturated vapor pressure with temperature, at the mean temperature is given by

$$\Delta \;=\; \frac{4098\; e_{sat}}{(237.3 + T)^2} = 0.086$$

Air pressure for a site with elevation 1000m is estimated using the formulae given is

$$P = 101.3\left(\frac{293 - 0.0065.\,Z}{293}\right)^{5.256} = 90 \qquad \text{(in kPa)}$$

Psychrometric "constant" is estimated as

$$\gamma = 0.0016286\;.\frac{P}{\lambda} = 0.0016286\;.\frac{90}{2.477} = 0.059$$

The "Modified" psychrometric "constant" (used in calculating Reference Crop Evaporation) is estimated as

$$\gamma^* = \gamma.(1{+}0.33\text{ U}) = 0.059\;.(1{+}0.33\text{x}3) = 0.118$$

Solar declination on April 15 (Julian day, J=105) is given by

$$\delta = 0.4093\sin\left(\frac{2\pi}{365}J - 1.405\right) = 0.1603 \qquad \text{[radians]}$$

Sunset hour angle on this date at latitude is 30 ° N is given by

$$\omega_s = \arccos\;(-\tan\phi\tan\delta)$$

$$= \arccos\;[-\tan(0.52)\;\tan(0.1603)]$$

$$= 1.66\;\;\text{[radians]}$$

Maximum possible daylight hours is given by

$$N \;=\; \frac{24}{\pi}\,\omega_s \;=\; 12.7 \;\;\text{hours}$$

Relative distance between earth and sun is given by

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) = 0.9922$$

Extraterrestrial Solar Radiation is given (in mm/ day) by

$$I_s^D = 15.392\, d_r\, (\omega_s \sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \sin\omega_s) = 15.0\ \ [\text{ mm day}^{-1}\ ]$$

Solar radiation (at the ground) is given by

$$I_{sc}^D = \left(0.25 + 0.5\frac{n}{N}\right) I_s^D = \left(0.25 + 0.5\frac{6}{12.68}\right).\ 15.0 = 7.3\ \ [\text{mm day}^{-1}\ ]$$

Net Solar Radiation is given by

$$S_n = I_{sc}^D(1-a) = 7.3 \text{ x } 0.77 = 5.62 \qquad [\text{mm day}^{-1}\ ]$$

Effective emissivity for net longwave radiation is given by

$$\varepsilon' = 0.34 - 0.14\sqrt{e_d} = 0.34 - 0.14\ .\sqrt{1.03} = 0.198$$

Cloud Factor for Longwave Radiation (in this humid climate) is given by

$$f = \left(\frac{I_{sc}^D}{I_s^D}\right) = \frac{7.29}{15.0} = 0.486$$

Net longwave radiation is then given (in mm / day) by

$$\begin{aligned} L_n &= -\left(f\varepsilon'\sigma \mathrm{T}^4/\lambda\right) \\ &= [-\ 0.486 \text{ x } 0.198 \text{ x } 4.903 \text{ x } 10^{-9} \text{ x } (273.15+10)^4\,]/\,2.477 \\ &= [-\ 0.4718 \text{x } 10^{-9} \text{ x } 6.428 \text{ x } 10^{9}\,]/\,2.477 \\ &= -\ 3.03/2.477 \\ &= -1.22 \quad [\text{mm day}^{1}] \end{aligned}$$

Net radiation is given by

$$R_n = (S_n + L_n) = 5.62 - 1.22 = 4.4 \quad (\text{mm day}^{-1})$$

Reference Crop Evaporation can now be calculated from:

$$E_{RC} = \left(\frac{\Delta}{\Delta+\gamma^*}\right)(R_n - G) + \left(\frac{\gamma}{\Delta+\gamma^*}\right)\left(\frac{900}{T+275}\right) U\, D$$

with $G = 0$, and substituting values from above, this gives

$$E_{RC} = 2.39 \quad (\text{mm day}^{-1})$$