Watershed Engineering

Estimating Potential Evapotranspiration (*PET*)

I. Pan Evaporation

If a nearby meteorological station has pan evaporation data (E_{pan}), a reasonable estimate of *PET* is:

$$PET = 0.7(E_{pan}) \qquad \text{[depth/day]} \qquad (1)$$

II. Priestly-Taylor (1972)

A relatively mechanistic equation is was introduced by Preistly and Taylor (1972) as a simplified version of the more robust Penman (1948) and Penman-Monteith (1965) equations:

$$PET = \left(\frac{1.3}{\lambda_v \rho_w}\right)\frac{\Delta}{\Delta + \gamma} R_n \qquad \text{[m]} \qquad (2)$$

Where γ is the the psychrometric constant[1] [4.95x10-4 kg m^{-3} $^{o}C^{-1}$], Δ is the slope of the saturation vapor density curve from the psychrometric chart (kg $^{o}C^{-1}$), λ_v is the latent heat of vaporization [2500 kJ kg^{-1}], ρ_w is the density of water [1000 kg m^{-3}], and R_n is the net radiation at the surface (kJ m^{-2}). The constant 1.3 is a generally used value although some researchers have found this value to vary geographically. The slope of the saturation vapor density curve can be estimated over the range of most environmental temperatures with the following equation (based on data from Campbell, 1977):

$$\Delta = 0.3221 \exp\left(0.0803 T^{0.8876}\right) \qquad 0 < T < 30^{o}C \qquad (3a)$$

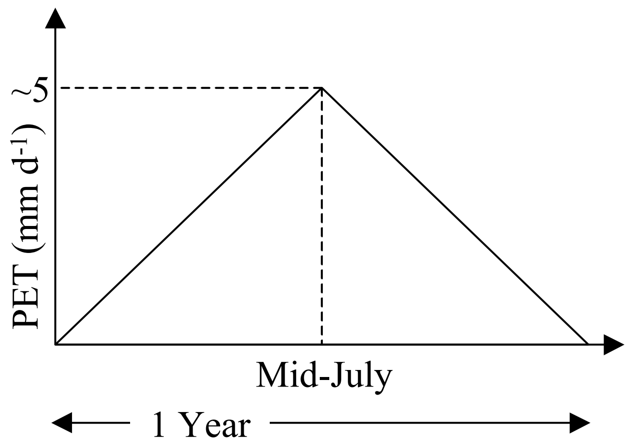
$$\Delta = 0.3405 \exp\left(0.0642 T\right) \qquad ? < T < 0^{o}C \qquad (3b)$$

Eq. 2 is generally used to find daily *PET* but can be used to estimate *PET* from shorter periods if the appropriate R_n data are available. Net radiation is available at some meteorological stations or can be estimated on a daily basis from latitude, day of the year, and max and min air temperatures. See last page.

III. Generalized Annual *PET* Trend

PET follows similar patterns from year to year and almost never exceeds 7 mm d^{-1}. In fact, 5 – 3 mm d^{-1} is a reliable estimate of maximum daily *PET* during the summer. The following graph is a crude, but reasonable estimate of *PET* above ~30^{o} N-latitude.

[1] The psychrometric constant is the ratio of the heat capacity of air to the latent heat of vaporization.



The minimum (winter) *PET* is generally 0°C in cold-region latitudes. You can etimate the minimum PET for humid areas by noting that the annual precipitation volume should equal the annual stream discharge plus the annual volume of $ET \approx PET$, i.e., the area of the triangle times the watershed area. Because *PET* is typically greater than *ET* (never less than *ET*), this approximation of minimum *PET* will probably be low. Note that mid-latitudes have two peaks in their annual *PET* trend.

IV. **Penman Equation (Penman, 1948)** & estimates of parameters

$$PET = \frac{\gamma f(u)\left(\rho_v^o - \rho_v\right) + \Delta R_n}{\gamma + \Delta}\left(\frac{1}{\lambda_v \rho_w}\right) \qquad [\mathrm{m\ d^{-1}}] \qquad (4)$$

ρ^o_v = saturated vapor density of the air [kg m^{-3}]

$$= \exp\left(\frac{.16.78T - 116.8}{T + 273.3}\right)\left[\frac{1}{(273.15 + T)R}\right]$$ T = average daily temp [°C]

ρ_v = vapor density of the air [kg m^{-3}]

$$= \exp\left(\frac{.16.78T_n - 116.8}{T_n + 273.3}\right)\left[\frac{1}{(273.15 + T_n)R}\right]$$ T = minimum daily temp [°C]

$f(u)$ = an empirical wind function

~ $5.3(1+u)$ when u, the average daily windspeed, is in m/s and measured at 2 m height.

All other parameters are as discussed earlier.

References:

Campbell, G.S. 1977. *An introduction to environmental biophysics*. Springer-Verlag, New York, New York. pp.159.

Monteith, J.L. 1965. Evaporation and environment. *19th Sym. of the Soc. for Exper. Bio.* University Press, Cambridge. 19:205-234.

Penman, H.L. 1948. Natural Evaporation from open water, bare soil, and grass. *Proc. R. Soc*. A194:220.

Priestly, C.H.B. and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. *Mon. Weather. Rev*. 100:81-92.

Appendix A: Estimating Net Radiation (R_n)

$$R_n = S + L_a - L_t \tag{A.1}$$

Where S is the net incident solar radiation (kJ m^{-2}), L_a is the atmospheric long wave radiation (kJ m^{-2}), L_t is the terrestrial long wave radiation (kJ m^{-2}).

Solar Radiation: The solar radiation incident on a local slope can be calculated from:

$$S = (1 - A)T_t S_o \tag{A.2}$$

Where A is the surface albedo [~0.25 for vegetation, 0.05 for water], T_t is the atmospheric transmissivity, and S_o is the potential extraterrestrial solar radiation (kJ m^{-2}). The potential extraterrestial solar radiation on a horizontal plane is:

$$S_o = \frac{S'}{\pi}\left\{\cos^{-1}(-\tan\delta\tan\phi)\sin\phi\sin\delta + \cos\phi\cos\delta\sin\left[\cos^{-1}(-\tan\delta\tan\phi)\right]\right\} \tag{A.3}$$

Where, S' is the solar constant [117.5 x 10^3 KJ m^{-2} day^{-1}], ϕ is the latitude (radians), and δ is the solar declination (radians), which can be calculated by (Rosenberg, 1974):

$$\delta = 0.4102\sin\left(\frac{2\pi}{365}(J - 80)\right) \tag{A.4}$$

Where J is the day of the year (e.g. J=1 on January 1, J=2 on January 2,...etc.).

The solar transmissivity, T_t, can be calculated with an equation originally proposed by Bristow and Campbell (1984) and later modified by Campbell (Ndlovu, 1994):

$$T_t = 0.75\left[1 - \exp\left(-\frac{B}{S_{o30}}(T_x - T_n)^2\right)\right] \tag{A.5}$$

where B is an empirical coefficient, S_{o30} is the potential extraterrestrial solar radiation 30 days previous to the simulation day (MJ m^{-2}) (Eq. 2), and T_x and T_n are the daily maximum and minimum temperatures, respectively (°C). Ndlovu (1994) showed that B is seasonally and geographically dependent and developed some general correlations between summer and winter B values and latitude; summer encompasses the 90 days preceding and 90 days following the summer solstice and winter is the rest of the year:

$$B = 0.282\phi^{-0.431} \text{ for summer} \tag{A.6a}$$

$$B = 0.170\phi^{-0.979} \text{ for winter} \tag{A.6b}$$

Atmospheric Long Wave Radiation: Long wave radiation is calculated with the Stefan-Boltzmann equation:

$$L_a = \varepsilon_a \sigma T_K{}^4 \tag{A.7}$$

Where ε_a is the atmospheric emissivity, σ is the Stefan-Boltzmann constant (4.89×10^{-11} kJ m^{-2} K^{-4} day^{-1}), and T_K is the temperature of the air (°K), generally approximated by the average air temperature, T_a. One estimate for atmospheric long wave emissivity, ε_a, is (Campbell and Norman 1998):

$$\varepsilon_a = (0.72 + 0.005T_a)(1 - 0.84C) + 0.84C \tag{A.8}$$

Where T_a is the average air temperature (°C) and C is the fraction of cloud cover. For simplicity we grossly estimated C as 100% cloud cover on rainy days (P>0.5 cm) and 0% on other days.

Terrestrial Long Wave Radiation:

$$L_t = \varepsilon_t \sigma T_K{}^4 \tag{A.9}$$

Where T_K is the temperature of the ground (°K), crudely approximated by the average air temperature, T_a, and ε_t is the terrestrial emissivity (~0.97 for vegetation).