**Equations for Calculating Reference Crop ET from Hourly Weather Data**

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**Reference Crop ET by the FAO-56 Method**

Reference crop evapotranspiration (ET₀) can be estimated on an hourly basis using the Penman-Monteith equation (Allen, 2000)

\[
ET₀ = \frac{0.408\Delta(R_n - G) + \frac{37}{T + 273.2}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}
\]  

(1)

where

- ET₀: Reference evapotranspiration (mm h⁻¹)
- Rₙ: Net radiation (MJ m⁻² h⁻¹)
- G: Soil heat flux (MJ m⁻² h⁻¹)
- T: Air temperature (C)
- eₛ: saturation vapor pressure at air temperature (kPa)
- eₐ: vapor pressure of air (kPa)
- u₂: Wind speed at 2 m (m s⁻¹)
- Δ: slope of saturation vapor pressure curve at air temperature (kPa C⁻¹)
- γ: psychrometer constant (kPa C⁻¹)

Equation 1 is an estimate of ET from a hypothetical short grass with a height of 0.12 m, a surface resistance of 70 s m⁻¹, and an albedo of 0.23 (Allen et al., 1998; Allen, 2000)

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**Supporting Calculations**

Saturation vapor pressure, eₛ, in kPa can be approximated at temperature, T, in C, using the equation of Murray (1967)

\[
e_s = 0.61078 \exp\left(\frac{17.269T}{237.3 + T}\right)
\]  

(2)

Actual vapor pressure of the air, eₐ, in kPa, is the product of the eₛ at air temperature and a simultaneous, collocated measurement of relative humidity (RH): eₐ = eₛ RH, where RH is between 0 and 1.
The slope of the saturation vapor pressure curve, $\Delta$, in kPa K$^{-1}$, can be calculated as the partial derivative of Muray's Eq.

$$\Delta = e_s \left( \frac{17.269}{237.3 + T} \right) \left( 1 - \frac{T}{237.3 + T} \right)$$

(3)

noting that $e_s$ is the result from equation 2.

Atmospheric pressure, $P$, in kPa, can be approximated from altitude, $A$, in m, and air temperature, $T$, in C, as

$$P = 101.3 \exp \left( -\frac{3.42 \times 10^{-2} A}{T + 273.15} \right)$$

(4a)

Pressure can be estimated solely from altitude as

$$P = 101.3 \left( \frac{293 - 0.0065 A}{293} \right)^{5.26}$$

(4b)

The latent heat of vaporization, $L$, in J kg$^{-1}$, can be approximated as

$$L = 2.5005 \times 10^6 - 2.359 \times 10^3 (T_a + 273.15)$$

(5)

Heat capacity of air, $c_p$, in J kg K$^{-1}$, can be expressed as

$$c_p = 1004.7 \left( \frac{0.522 e_a}{P} + 1 \right)$$

(6)

where $R_d$ is the gas constant (287.04 J kg K$^{-1}$). The psychrometric constant, $\gamma$, in kPa K$^{-1}$, can be approximated as

$$\gamma = \frac{1.61 c_p P}{L}$$

(7)

References


Example ET<sub>0</sub> Calculations for the Konza Prairie Research Natural Area, Manhattan, KS

Example Input Data (hourly weather data)
- Global Irradiance, Rs: 700 W m<sup>-2</sup>
- Air Temperature, T (1.5m): 30 C
- Relative Humidity, RH (1.5 m): 0.4
- Wind Speed, u (3 m): 5 m s<sup>-1</sup>

1. Estimate R<sub>n</sub> and G
For vegetated surfaces R<sub>n</sub>, in MJ m<sup>-2</sup> hr<sup>-1</sup> can be estimated as
R<sub>n</sub> = (0.0036)*[0.76*Rs – 38.5]  
(equation based on field measurements from KNRPA watershed 1D)
R<sub>n</sub> = (0.0036)*(0.76*700-38.5)
R<sub>n</sub> = 1.78 mm h<sup>-1</sup>
G is assumed to be 0.1*Rn during the day and 0.5*Rn during the night
If computing with software, use an if-then statement,
If Rs>0 then G=0.1*Rn else G=0.5*Rn
G = 0.1*1.78 = 0.178 mm h<sup>-1</sup>

2. Estimate the vapor pressure deficit (e<sub>s</sub>-e<sub>a</sub>)
Calculate e<sub>s</sub> first
From Eq. 2, e<sub>s</sub> at 30 C is 4.24 kPa
then
e<sub>s</sub>-e<sub>a</sub> = e<sub>s</sub>*(1-RH) = 4.24*(1-0.4) = 2.55 kPa

3. Estimate wind speed at 2 m
Most weather stations measure wind speed at 3 m. Winds speed at 2 m can be estimated by assuming a logarithmic wind profile (surface similarity theory, z<sub>0</sub>=0.015m, h=0.08 m).

u<sub>2</sub> = u<sub>3</sub>*0.92
u<sub>2</sub> = 5*0.92 = 4.6 ms<sup>-1</sup>

4. Calculate Δ and γ
Given an air 30 C air temperature, the result from Eq. 3 is Δ = 0.243 kPa C<sup>-1</sup>
Equation 7 is often simplified to the form
γ = 0.665E-3*P
Equation 4b yields P = 96.7 kPa (Assuming A= 400 m)
and
γ = 0.665E-3*96.7 = 0.064 kPa C<sup>-1</sup>

5. Calculate ET
Substituting the above-stated results into Eq. 1, yields

ET<sub>0</sub> = 0.615 mm h<sup>-1</sup>