Equations for Calculating Reference Crop ET from Hourly Weather Data

Jay M. Ham, Professor, Department of Agronomy, Kansas State University

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Reference Crop ET by the FAO-56 Method

Reference crop evapotranspiration (ET_0) can be estimated on an hourly basis using the Penman-Monteith equation (Allen, 2000)

$$ET_0 = \frac{0.408\Delta(R_n - G) + g\,\dfrac{37}{T + 273.2}\,u_2(e_s - e_a)}{\Delta + g(1 + 0.34u_2)} \qquad (1)$$

where

ET_0	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)
e_s	saturation vapor pressure at air temperature (kPa)
e_a	vapor pressure of air (kPa)
u_2	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 a albedo of 0.23 (Allen et al., 1998; Allen, 2000)

Supporting Calculations

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

$$e_s = 0.61078\exp\left(\frac{17.269T}{237.3 + T}\right) \qquad (2)$$

Actual vapor pressure of the air, e_a, in kPa, is the product of the e_s at air temperature and a simultaneous, collocated measurement of relative humidity (RH): $e_a = e_s RH$, where RH is between 0 and 1.

The slope of the saturation vapor pressure curve, Δ, in kPa K^{-1}, can be calculated as the partial derivative of Muray's Eq.

$$\Delta = e_s\left(\frac{17.269}{237.3+T}\right)\left(1-\frac{T}{237.3+T}\right) \quad (3)$$

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

$$P = 101.3\exp\left(\frac{-3.42x10^{-2}A}{T+273.15}\right) \quad (4a)$$

Pressure can be estimated solely from altitude as

$$P = 101.3\left(\frac{293-0.0065A}{293}\right)^{5.26} \quad (4b)$$

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

$$L = 2.5005x10^{6} - 2.359x10^{3}(T_a + 273.15) \quad (5)$$

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

$$c_p = 1004.7\left(\frac{0.522e_a}{P}+1\right) \quad (6)$$

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

$$g = \frac{1.61c_pP}{L} \quad (7)$$

References

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Murray, F.W. 1967. On the computation of saturation vapor pressure. J. Appl. Meteorol. 6:203-204.

Penman, H.L. 1948. Evaporation from open water, bare soil, and grass. Proc. Roy. Soc. London A193:120-146.

Example ET_o Calculations for the Konza Prairie Research Natural Area, Manhattan, KS

Example Input Data (hourly weather data)

Global Irradiance, Rs:	700 W m^{-2}
Air Temperature, T (1.5m):	30 C
Relative Humidity, RH (1.5 m):	0.4
Wind Speed, u (3 m):	5 m s^{-1}

1. Estimate R_n and G

For vegetated surfaces R_n, in MJ m^{-2} hr^{-1} can be estimated as

Rn = (0.0036)*[0.76*Rs – 38.5] {equation based on field measurements from KNRPA watershed 1D)

Rn = (0.0036)*(0.76*700-38.5)

Rn = 1.78 mm h^{-1}

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^{-1}

2. Estimate the vapor pressure deficit (e_s-e_a)

Calculate e_s first

From Eq. 2, e_s at 30 C is 4.24 kPa

then

e_s-e_a = e_s*(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_o=0.015m , h=0.08 m).

$u_2 = u_3*0.92$

u_2 = 5*0.92 = 4.6 ms^{-1}

4. Calculate Δ and γ

Given an air 30 C air temperature, the result from Eq. 3 is **Δ = 0.243 kPa C^{-1}**

Equation 7 is often simplified to the form

$\gamma = 0.665E-3*P$

Equation 4b yields P = 96.7 kPa (Assuming A= 400 m)

and

γ = 0.665E-3*96.7 = 0.064 kPa C^{-1}

5. Calculate ET

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

ET_0 = 0.615 mm h^{-1}