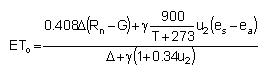
**Reference Evapotranspiration**

**1 - The Model:**

To calculate the evapotranspiration for each station we will use the model described by the Food and Agriculture Organization of the United States - FAO (at http://www.fao.org/docrep/x0490e/x0490e06.htm) also referred as an alternative ETo calculation procedure for situations where some weather variables are missing.

According to this author, even where the data set contains only maximum and minimum air temperature it is still possible to obtain reasonable estimates of ten-day or monthly ETo with the FAO Penman-Monteith equation. The radiation data can be derived from the air temperature difference, or, along with wind speed and humidity data, can be imported from a nearby weather station. Humidity data can also be estimated from daily minimum air temperature.

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed:



Where:

ETo reference evapotranspiration [mm day-1],

Rn net radiation at the crop surface [MJ m-2 day-1],

G soil heat flux density [MJ m-2 day-1],

T mean daily air temperature at 2 m height [°C],

u2 wind speed at 2 m height [m s-1],

es saturation vapour pressure [kPa],

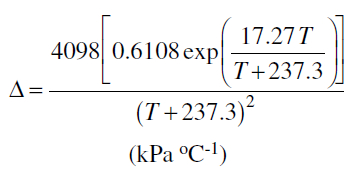
ea actual vapour pressure [kPa],

es - ea saturation vapour pressure deficit [kPa],

D slope vapour pressure curve [kPa °C-1],

g psychrometric constant [kPa °C-1].

**- Slope of saturation vapor pressure curve (Δ)**

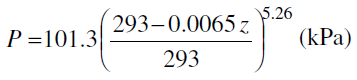


where T is the daily average temperature between Tmax and Tmin.

**- Psychrometric constant (g) obtained by the following equation:**

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where P is the atmospheric pressure obtained as a function of altitude using:



where z is the local altitude (m).

**- Actual vapor pressure (ea):**

In the absence of RHmax and RHmin, another equation can be used to estimate ea:

http://www.fao.org/docrep/x0490e/x0490e0m.gif

where RHmean is the mean relative humidity, defined as the average between RHmax and RHmin.

**- Mean saturation vapor pressure (es)**

As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by:

http://www.fao.org/docrep/x0490e/x0490e0g.gif

where

e°(T) saturation vapour pressure at the air temperature T [kPa],

T air temperature [°C],

exp[..] 2.7183 (base of natural logarithm) raised to the power [..].

Due to the non-linearity of the above equation, the mean saturation vapour pressure for a day, week, decade or month should be computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

http://www.fao.org/docrep/x0490e/x0490e0h.gif

**- Net radiation (Rn)**

The net radiation (Rn) is the difference between the incoming net shortwave radiation (Rns) and the outgoing net longwave radiation (Rnl):

Rn = Rns - Rnl

**- Net solar or net shortwave radiation (Rns)**

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

Rns = (1-a)Rs

where

Rns net solar or shortwave radiation [MJ m-2 day-1],

a albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless],

Rs the incoming solar radiation [MJ m-2 day-1].

**- Solar Radiation (Rs)**

This is calculated by Hargreaves’ equation

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where the coefficient kRs is an empirical adjustment coefficient that differs for ‘interior’ or ‘coastal’ regions. For ‘interior’ locations where land masses dominate and air masses are not strongly influenced by a large water body, oceans for example, kRs assumes a value close to 0.16, while for ‘coastal’ locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body such as an ocean, kRs assumes a value close to 0.19. Therefore the previous equation assumes the following formulation in this study:

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where Ra is the extraterrestrial radiation.

**- Extraterrestrial radiation for daily periods (Ra)**

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

http://www.fao.org/docrep/x0490e/x0490e0u.gif

where

Ra extraterrestrial radiation [MJ m-2 day-1],

Gsc solar constant = 0.0820 MJ m-2 min-1,

dr inverse relative distance Earth-Sun,

ωs sunset hour angle [rad],

φ latitude [rad],

δ solar decimation [rad].

The inverse relative distance Earth-Sun, dr, and the solar declination, d, are given by:

http://www.fao.org/docrep/x0490e/x0490e0w.gif

and:

http://www.fao.org/docrep/x0490e/x0490e0x.gif

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle, ωs*,* is given by:

ωs = arccos [-tan (φ)\* tan (δ)]

**- Clear-sky shortwave radiation (Rso).**

This parameter is used to calculate the net long wave radiation:

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in which z is altitude (m).

**- Net longwave radiation (Rnl)**

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. The net energy flux leaving the earth's surface is, however, less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. Water vapour, clouds, carbon dioxide and dust are absorbers and emitters of longwave radiation. Their concentrations should be known when assessing the net outgoing flux. As humidity and cloudiness play an important role, the Stefan-Boltzmann law is corrected by these two factors when estimating - the net outgoing flux of longwave radiation. It is thereby assumed that the concentrations of the other absorbers are constant:

http://www.fao.org/docrep/x0490e/x0490e18.gif

where

Rnl net outgoing longwave radiation [MJ m-2 day-1],

α Stefan-Boltzmann constant [4.903 10-9 MJ K-4 m-2 day-1],

Tmax, K^4 maximum absolute temperature during the 24-hour period [K *=* °C *+* 273.16],

Tmin, K^4 minimum absolute temperature during the 24-hour period [K = °C + 273.16],

ea actual vapour pressure [kPa],

Rs/Rso relative shortwave radiation (limited to £ 1.0),

Rs measured or calculated solar radiation [MJ m-2 day-1],

Rso calculated clear-sky radiation [MJ m-2 day-1].