Appendix 2.1

Optional implementations of reference evapotranspiration and the PM-models

1 Makkink-implementations

In total, five implemetations of the Makkink equation are available. They are very similar. The overall equation (Makkink, 1957) is

$$E_{r,M} = \beta_0 + \beta_1 \frac{\Delta}{\Delta + \gamma} \frac{S_i}{\lambda} \tag{1.1}$$

Where

$E_{r,M}$ = reference evapotranspiration [mm day^{-1}], calibrated to a certain location

β_0 = empirical constant [mm day^{-1}] calibrated to a certain location

β_1 = empirical constant []

S_i = global radiation [MJ m^{-2} day^{-1}]

Δ = slope of vapour pressure curve [Pa K^{-1}],

λ = latent heat of vaporization [MJ kg^{-1}] and

γ = psychrometric constant [Pa K^{-1}]

The last three parameters are defined according to eq. [2.5], eq. [2.6 and eq. [2.7] in Chapter 2.

The available Makkink applications are listed in Table 1.

The old “makkink” process description is an earlier version of the AslyngHansen parameterization, with different descriptions for Δ, γ and λ:

$$\Delta = 5362.7 / T_a^2 * \exp(26.042 - 5362.7 / T_a$$

γ = 66.7 [Pa K^{-1}]

λ = 2.4 [MJ kg^{-1}]

Table 1. Makkink implementations available in the Daisy code.

Process name	parameters	Source, Comments
Makkink	The user specifies the values of β_0 and β_1.	
AslyngHansen82	β_0 = 0 mm d^{-1}, β_1 = 0.7 []	(Aslyng and Hansen, 1982), (Hansen, 1984)
Makkink57	β_0 = -0.12 mm d^{-1}, β_1 = 0.61 []	(Makkink, 1957)
deBruin	β_0 = 0 mm d^{-1}, β_1 = 0.65 []	(de Bruin, 1987) Described in Chapter 2.3.4. Presently default.
makkink	As AslyngHansen82	Old implementation of AslyngHansen, using a different parameterization of Δ, λ and γ, see above. This version used to be default.

2 An additional Penman-Monteith implementation

This equation attempts to take the actual vegetation on the field into account. It thus estimates potential evapotranspiration rather than a reference evapotranspiration as such. Thus, some variables and parameters used in the FAO Penman Monteith-solution are adjusted.

The PM reference evapotranspiration calculation distinguishes between periods with a LAI-value above 0 and bare soil and for wet or dry conditions.

The model calculates hourly values, either based on hourly input data or distributing global radiation according to the fraction of extra-terrestrial radiation occurring that particular hour and, if T_{min}/T_{max} is specified, the temperature distribution described in Chapter 2 (2.3.4).

2.1 Net radiation

For calculation of the short-wave radiation balance for a specific crop, an albedo is required.

The albedo for standard crops (α_{crop}) is by default 0.20 (hardcoded). The albedo for litter (α_{litter}) is by default 0.2 and for dry and wet surface soil (α_{soil}), it is 0.15 and 0.08, respectively [in Daisy albedo_dry and albedo_wet].

α_{soil} is related to soil moisture in the following way: If the soil is dryer than pF 3, the dry albedo is used. If it is wetter than pF 1.7, the wet albedo is used. In between, the albedo is interpolated according to water content.

The effective albedo (α_e) for the field is calculates as follows:

$$\alpha_e = \alpha_{crop} \cdot A_C + \alpha_{ls} \cdot \left(1 - A_C\right) \tag{1.2}$$

$$\alpha_{ls} = \alpha_{litter} \cdot A_M + \alpha_{surface} \left(1 - A_M\right) \tag{1.3}$$

Where A_c and A_M are the fractions of surface covered with crop and litter/mulch, respectively. These factors are dynamic and described in Chapter 3.

While the FAO Penman Monteith implementation always use the Brunt equation for calculation of net longwave radiation, this implementation allows the use of other models if they are specified in the bio-climate module. These models will be used when LAI is above 0. If the soil is bare, the balance is calculated using the Brunt equation. The models that may be selected are: Swinbank (1963), Idso and Jackson (1969), Brutsaert (1975), Satterlund (1979) and Prata (1996), see Appendix 2.3.

2.2 Wind

Because the method is expected to be used for a specific field crop, it is also expected that the wind speed is measured in the field, at a height specified as ScreenHeight. The values are used to calculate the aerodynamic resistance as described below.

2.3 Aerodynamic and stomata resistance value of field crop

The stomata resistance value is calculated as the minimum transpiration resistance [rs_min] with a default value of 100 s m^{-1}, divided by LAI.

The aerodynamic resistance is calculated as:

$$r_a = \frac{\ln\left[\frac{z_m - d}{z_{om}}\right]\ln\left[\frac{z_h - d}{z_{oh}}\right]}{k^2 u_z} \qquad (1.4)$$

Where

r_a = aerodynamic resistance in s m^{-1}

z_m = height of wind measurements [m] [ScreenHeight]

z_h = height of humidity measurement [m] [in Daisy also ScreenHeight]

d =zero plane displacement height = $0.66*CropHeight$ [m]

z_{om} = roughness length governing momentum transfer [m] = $0.123*CropHeight$ [m]

z_{oh} = roughness length governing transfer of heat and vapour [m] = $=0.0123*CropHeight$ [m]

K = von Karman's constant = 0.41 []

u_z = wind speed at height z [m s^{-1}]

If $u_z = 0$; $u_z = 0.1$

If $CropHeight = 0$; $Z_{om} = 0.01$ *and* $Z_{oh} = 0.001$

2.4 Calculation options

2.4.1 LAI>0, dry conditions

For LAI above 0 and dry conditions it calculates a reference evapotranspiration according to equation 2.1 in the main document, but using the adjusted albedo, the choice of longwave radiation model, the aerodynamic and atmospheric resistances calculated above.

2.4.2 LAI>0, wet conditions

For wet conditions (wet=true) with positive LAI, the calculation is as above but r_c is exchanged with a rb-value of 20 s m^{-1}.

2.4.3 LAI<0

When no plants are present it uses the normal FAO-Penman Monteith equation with reference albedo for dry conditions and the same equation with rb of default 20 s m^{-1} for wet conditions.

NB: Using the "Wet Conditions"-options will give significantly higher potential evapotranspiration especially when feed with daily weather data.

3 References

Aslyng, H.C., Hansen, S., 1982. Water balance and crop production simulation. Royal Veterinary and Agricultural University., Hydrotechnical Lab., Royal Vet. and Agric. Univ., Copenhagen, Denmark.

Brutsaert, W., 1975. On a derivable formula for long-wave radiation from clear skies. Water Resources Research 11, 742–744. https://doi.org/10.1029/WR011i005p00742

de Bruin, H., 1987. From Penman to Makkink, in: Hoogarth, J. (Ed.), Evaporation and Weather: Technical Meeting. pp. 5–31.

Hansen, S., 1984. Estimation of Potential and Actual Evapotranspiration: Paper presented at the Nordic Hydrological Conference (Nyborg, Denmark, August - 1984). Hydrology Research 15, 205–212. https://doi.org/10.2166/nh.1984.0017

Idso, S.B., Jackson, R.D., 1969. Thermal radiation from the atmosphere. Journal of Geophysical Research (1896-1977) 74, 5397–5403. https://doi.org/10.1029/JC074i023p05397

Makkink, G.F., 1957. Ekzameno de la formulo de Penman. Net. J. Agr. Sci. 5, 290–305. https://doi.org/10.18174/njas.v5i4.17731

Prata, A.J., 1996. A new long-wave formula for estimating downward clear-sky radiation at the surface. Quarterly Journal of the Royal Meteorological Society 122, 1127–1151. https://doi.org/10.1002/qj.49712253306

Satterlund, D.R., 1979. An improved equation for estimating long-wave radiation from the atmosphere. Water Resources Research 15, 1649–1650. https://doi.org/10.1029/WR015i006p01649

Swinbank, W.C., 1963. Long-wave radiation from clear skies. Quarterly Journal of the Royal Meteorological Society 89, 339–348. https://doi.org/10.1002/qj.49708938105