COST 711

Operational applications of meteorology to agriculture, including horticulture

REPORT

Operational use of irrigation models using medium range weather forecast

edited by

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Annex
1. Introduction

Within the frame of COST action 711 a working group on irrigation was constituted in 1995. It was the aim to look out for irrigation schemes in the EU-member countries, to make them available to interested countries and to test them under the use of numerical weather forecasts. The interest in this issue was greater in the beginning of the action than in the end. This mainly concerns the handing-over of executable files for irrigation models and the interest of member countries to test the models in their area.

During the following months the ambitious workplan had to be reduced to a more collective contribution, including a kind of "data bank" for irrigation formulas, crop coefficients and irrigation models which follows.

2. Requirements and prerequisites for an operational use of irrigation models

Irrigation presents a usual means in agriculture of many countries in Europe. According to the weather, the soil and the cultures water is given to the fields since a long time. It is beyond the scope of our thematics to go into details about the technical methods of irrigation. Rather the agrometeorological requirements for irrigation recommendations to farmers are to be presented.

The following prerequisites for an irrigation management system are to be found:

1. the need for irrigation due to climate and/or soil type and/or crop type has to exist.
2. and this is not obvious, the need for a good irrigation advice has to be accepted by the farmer, generally for economic reasons.
3. an agrometeorological advisory office together with a meteorological network with a functioning dataflow has to exist.
4. an adequate irrigation scheme i.e. a suitable evapotranspiration model or formula for the regional or national scale has to be available.
5. it is essential to use meteorological forecast data, too, for the model in order to receive forecast evapotranspiration rates and precipitation amounts.
6. actual results have to be transferred quickly and at the right time to the users.

Looking at the evaluation of a questionnaire (see tables 1 and 2 in annex 2) for most COST countries these conditions are met, but not in every case for the above mentioned points 4 to 6. DOBESCH et al. (1993) report on the combined use of a hydrometeorological model and the weather forecast. The existence and availability of good quality numerical forecasts seems to be unknown or underestimated in part of the agrometeorological services in some or other country. For this reason some background about numerical forecast models is presented here for agrometeorological users.
3. Overview about the characteristics of European numerical weather prediction models concerning irrigation advices

In many European countries sophisticated numerical weather prediction (NWP) models are routinely used. Here information was available on the systems run in France, Germany, Great Britain, Scandinavia, Ireland, the Netherlands and Spain as well as the ECMWF (European Centre for Medium Range Weather Forecast) model calculated at Reading/UK. Table 1 gives a rough overview about the European NWP models.

<table>
<thead>
<tr>
<th>country</th>
<th>FRANCE</th>
<th>United Kingdom</th>
<th>Germany</th>
<th>Scand. + IRL + NL + Spain</th>
<th>ECMWF</th>
</tr>
</thead>
<tbody>
<tr>
<td>names</td>
<td>ARPEGE</td>
<td>UM-G</td>
<td>GLOBAL EUROPA</td>
<td>HIRLAM (GRV + DKV)</td>
<td>T213/L31</td>
</tr>
<tr>
<td></td>
<td>ALADIN</td>
<td>UM-R</td>
<td>DEUTSCHLAND</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALADIN-FRANCE</td>
<td>UM-M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>global</td>
<td>global</td>
<td>global</td>
<td>regional grid point</td>
<td>global</td>
</tr>
<tr>
<td></td>
<td>spectral,</td>
<td>regional and</td>
<td>spectral,</td>
<td>point models</td>
<td>spectral</td>
</tr>
<tr>
<td></td>
<td>regional</td>
<td>mesoscale grid</td>
<td>regional</td>
<td></td>
<td>model</td>
</tr>
<tr>
<td>grid size</td>
<td>300 to 50 km</td>
<td>135 km</td>
<td>200 km</td>
<td>46 km</td>
<td>60 km</td>
</tr>
<tr>
<td></td>
<td>25 km</td>
<td>50 km</td>
<td>55 km</td>
<td>23 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12 km</td>
<td>16 km</td>
<td>14 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>layers</td>
<td>27</td>
<td>19</td>
<td>19</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>19</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>regional model area</td>
<td>North Atlantic &amp; W. Europe</td>
<td>North Atlantic &amp; Europe, Brit. Isles</td>
<td>North Atlantic &amp; Europe, middle Europe</td>
<td>North America &amp; Europe, Europe &amp; seas</td>
<td>-</td>
</tr>
</tbody>
</table>

Practically all NWP models are quasi-deterministic and based on the Navier-Stokes equations. The coverage is from global to regional (meso-scale). All models are driven by high-velocity computers at least daily to cope with the immense number of mathematical operations for the numerical simulation. In Reading/UK at the ECMWF e.g. the "Cray T3D" works at 10000 Mflops speed (1 Mflops = 10^6 floating point operations per second). Differences between the models can be found in the way of parameterization of the physics, in the numerics (e.g. grid size, number of layers, time step), in the data assimilation, forecasting length. As they are routinely used without problems, the output of all of them will be of comparable quality and usable for agrometeorological models, especially for irrigation purposes. In Germany a nested model chain of the "Global", "Europa" and "Deutschland" model is routinely run (3 times a day) by the German Weather Service at Offenbach for some years with increasing complexity and forecasting accuracy. A comparison of their characteristics is given in table 2.
### TABLE 2: Intercomparison of the German NWP model chain

<table>
<thead>
<tr>
<th>model</th>
<th>GLOBAL</th>
<th>EUROPA</th>
<th>DEUTSCHLAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>characteristic</td>
<td>global spectral model derived from ECMWF</td>
<td>hydrostatic mesoscale grid point model for Europe and North Atlantic</td>
<td>Germany and its surroundings</td>
</tr>
<tr>
<td>diagnostic variables</td>
<td>geopotential, vertical velocity</td>
<td>temperature, water vapour, cloud water content, geopotential, vertical velocity</td>
<td></td>
</tr>
<tr>
<td>predicted variables</td>
<td>surface pressure, temperature, spec. humidity, rel. velocity, horiz. divergence</td>
<td>surface pressure, total heat, total water content, horiz. wind components</td>
<td></td>
</tr>
<tr>
<td>numerics</td>
<td>spectral horizontal Gaussian grid: 1.125°/~125 km</td>
<td>rotated spherical grid, mesh size: 0.5°/~55 km</td>
<td>0.125°/~14 km, 20 vert. layers, 30 vert. layers</td>
</tr>
<tr>
<td></td>
<td>semi-implicit time integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 min time step</td>
<td>5 min time step</td>
<td>4 min time step</td>
</tr>
<tr>
<td></td>
<td>fourth-order linear diffusion, slope correction for diffusion of temperature</td>
<td>slope correction for diffusion of total heat</td>
<td></td>
</tr>
<tr>
<td>parameterization</td>
<td>(see MAJEWSKI, 1995)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>topographic data</td>
<td>mean orography, land/sea mask and roughness length from 10°*10’ NCAR/NAVY data set</td>
<td>FAO vegetation cover and root depth, potential vegetation cover (2.5°*2.5° resolution)</td>
<td></td>
</tr>
<tr>
<td>operation</td>
<td>since 1991</td>
<td>since 1991</td>
<td>since 1993</td>
</tr>
<tr>
<td></td>
<td>initial hours: 00, 12 and 18 UTC</td>
<td>78 h</td>
<td>48 h</td>
</tr>
<tr>
<td></td>
<td>assimilation cycle 00, 06, 12 and 18 UTC with integration up to 6 hours</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some more points mainly of the Global model (GM) may be compared with the ECMWF model, a global spectral model which was the basis for the Europa model. The ECMWF horizontal resolution is about 60 km (comparable to the 55 km mesh size of the Europa model) whereas the vertical resolution comprises 31 layers. Orography in GM is treated as a mean, the ECMWF model uses the envelope method. The radiation part in GM is solved by the RITTER & GELEYN (1992) method whereas ECMWF uses the MORCRETTE (1990) solution. The soil model within GM contains 2, the ECMWF 4 prognostic layers. For sea surface temperature analysis a NMC analysis (National Meteorological Centre) before a model start is made in both, the GM and ECMWF model, whereas GM additionnally uses ship and ice edge data. Data cut-off is after 3h 30min in GM and after 7h 30min in ECMWF.
Prediction grid point data of the GM (and other nested models) and ECMWF may be supplied from and via the German Weather Service in Offenbach. The following output data interesting for agrometeorological purposes are available on an hourly basis: short and long-wave radiation, photosynthetically active radiation, albedo, total cloud cover, 2m-temperature and specific humidity, rain amount and 10m-windspeed.

The average forecast quality can be estimated for example from the correlation coefficient between forecast and measured surface air pressure: about 0.97 for 24 hours and about 0.85 for a 96 hours forecast. On an average the output of the Europa model seems to be comparable to ECMWF results. The quality changes with the season and forecasting length and is not consistent with time.

Although there has been a constant trend to faster computers, smaller mesh size and to better longer-ranged forecasts, the quality of NWP output is more and more dependent on good quality basic data, sound data assimilation and still better interpretation and parameterization of the physics.

4. Evapotranspiration formulas

4.1 Fundamentals

The estimation of evapotranspiration is no new problem of the last decades, but dates back as early as e.g. DALTON (1801) with his equation $ET_c = f(u)(e_2-e_1)$, which means a product of a wind function $f(u)$ (to be defined) and the difference of the actual vapour pressure in two heights. During the last years the FAO publication of DOORENBOS & PRUITT (1977) has become a widespread and useful help for evapotranspiration estimation, crop water requirements and irrigation scheduling. New excellent treatments on this issue were published by SMITH et al. (1992, 1996).

In the following a lot of evapotranspiration formulas are described briefly, which lateron reappear in the subchapter 4.2 within the program VERDU. Here, any modifications of equations are set just behind the alphabetically ordered author.

Notice: for all formula holds, that when put in an computer program, care should be taken for a limitation of daily evapotranspiration above 0 mm.

4.1.1 Albrecht formula

ALBRECHT (1950) developed an equation for the calculation of monthly 'possible' evapotranspiration, which is (after SCHRÖDTER (1985)) comparable with the potential evapotranspiration of modern understanding. Recalculated for daily values of $ET_o$ this equation reads:

$$ETP = F \cdot [E(T_m) - e_m]$$

with $ETP$ in mm/d, $E$ saturation vapour pressure in hPa, $T_m$ daily mean air temperature (2m) in degrees C and $e_m$ daily mean of vapour pressure (2m) in hPa. The prefactor $F$ equals 0.4 for
the units used here and is only valid for windspeeds \( u > 1 \text{ m/s} \) in 2m height. After UHLIG (1954) \( F \) becomes for lower windspeeds (adjusted to \( u \) in m/s): \( F = 0.1 + 0.3 \cdot u \).

4.1.2 Antal formula

The Antal-method used in Hungary (MÜLLER et al., 1990; WENDLING et al., 1991)

\[
ETP = 0.736 \cdot [E(T_m) - e]^{0.7} \cdot (1 + T_m / 273)^{4.8}
\]

calculates the potential daily evapotranspiration \( ETP \) according to the equation

with \( ETP \) in mm/d, \( E \) saturation vapour pressure in hPa, \( T_m \) daily mean air temperature (2m) in degrees C and \( e_m \) daily mean vapour pressure (2m) in hPa.

4.1.3 Blaney-Criddle formula

a  Middle European version after DOORENBOOS & PRUITT (1977)

BLANEY & CRIDDLE (1950) developed a formula for the west of the USA in order to calculate the plant specific potential monthly evapotranspiration, which only needs the daily mean temperature and daylength as input variables besides special plant factors. DOORENBOOS & PRUITT (1977) made an adjustment to the equation for other climatic regions. From this follows under middle European conditions for the daily evapotranspiration

\[
ETP = a + b \cdot p \cdot (8.128 + 0.457 \cdot T_m)
\]

(SCHRÖDTER, 1985):

with \( ETP \) in mm/d and \( T_m \) daily mean air temperature (2m height) in EC. The factor \( p \) denominates the daily astronomical maximum possible sunshine duration as percentage of the yearly sunshine duration. The constants are given as:

\[
a = -1.55, \quad b = 0.96.
\]

b  Extended version after DOORENBOOS & PRUITT (1977)

DOORENBOOS & PRUITT (1977) enhanced the formula given above by replacing \( a \) and \( b \) by factors, which result from the minimum air humidity at noon in 2m height (\( RF_{min} \), in %), from the daily mean windspeed in 2m height (\( UB \), in Beaufort) and the quotient \( q \) of real and astronomical maximum possible daily sunshine duration. In the publication of SCHRÖDTER

\[
a = 0.0043 \cdot RF_{14} + q - 1.41
\]

\[
b = 1.21 + 0.0545 \cdot UB + 0.6q - 0.01 \cdot RF_{14}
\]

(1985) \( a \) und \( b \) read as follows, where \( RF_{14} \) is the 14 h-value of the relative humidity:

\( UB \) may be obtained from the widely measured 10m height windspeed (\( u_{10} \)) by the approximation
4.1.4 Haude formula

a  The original formula
HAUDE (1952) developed an empirically based approach, rather similar to the formula of ALBRECHT (1959), for the calculation of the plant specific potential daily evapotranspiration \( ETP \), with \( ETP \) in mm/d, \( E \) saturation vapour pressure in hPa, \( T_{14} \) air temperature (2 m) in \( ^\circ \text{C} \) and \( e_{14} \) vapour pressure (2 m) in hPa at 14 h local time. The Haude factor \( f \) mainly describes the dependence of the evapotranspiration from the energy supply (daylength) as well as plant species and plant condition. For all typical and important agricultural crops empirical monthly \( f \) values exist.

b  Haude formula 'hourly'
The basic approach of the Haude calculation for the daily evapotranspiration is used here for the hourly estimation, too. But it requires the empirical deduction of new \( f \) values. HEGER (1978) presented such hourly Haude factors.

c  Haude formula modified by LÖPMEIER (1994)
Also the soil evaporation has to be regarded besides the plant transpiration when the canopy has not been closed as it is the case in early development stages. Therefore LÖPMEIER (1987) modified the factor \( f \) in the original Haude approach as follows:

\[
f = f_1 \cdot a_{PF} + f_2 \cdot a_B
\]

with \( f_1 = 1 - f_2 \) and \( f_2 = 0.7 \cdot \text{LAI} \) (LAI: leaf area index). The plant factor \( a_{PF} \) corresponds to the Haude factor \( f \), as it is valid for a closed canopy, where soil evaporation can be neglected. For the soil factor \( a_B \) he gives (with \( a_{BF} \) Haude factor for humid soil (dependent on soil type), \( N \) number of uninterrupted days without precipitation and \( b \) a soil dependent empirical constant):

\[
a_B = a_{BF} \left( 1 - b \cdot N \right)
\]

d  Haude evapotranspiration under equilibrium conditions
Assuming sufficient water supply, as it is predefined for the potential evapotranspiration of a closed canopy, often the so-called equilibrium evapotranspiration (PRIESTLEY & TAYLOR, 1972) can be regarded. In this case the theoretically based Penman-Monteith equation (MONTEITH, 1973) can be transformed approximately into an equation, formally identical to the original Haude approach, where

\[
UB = \left( \frac{u_{10}}{0.87} \right)^{1/1.44}
\]
\[ f = 1.8 \times \frac{n}{r_{s,\text{min}}}, \]

with \( n \) number of real daily hours of sunshine and \( r_{s,\text{min}} \) the so-called minimum surface resistance (in s/m).

### 4.1.5 Linacre formula

LINACRE (1992) simplified the Penman-Monteith equation (MONTEITH, 1973), that the calculation of the daily potential evapotranspiration \( ETP \) (in mm/d) only requires the geographical latitude \( B \) (in degrees), elevation \( z \) (m) above mean sea level, daily mean of air temperature \( T_m \) (°C), dewpoint \( T_{dm} \) (°C) and windspeed \( u_m \) (m/s) in 2m height \( u_m \) may be estimated

\[
ETP = (0.015 + 4 \times 10^{-4} \times T_m + 10^{-6}z) \times \left[ \frac{380 \times (T + 0.006z)}{(84 - |B|)} - 40 + 4u_m \times (T - T_{dm}) \right]
\]

by division by 1.3 from the 10 m-windspeed):

Negative \( ETP \) values have to excluded as implausible.

Due to the parameterization of radiation the Linacre formula is only applicable within a range of \(-60 \leq B \leq +60 \) degrees.

### 4.1.6 Makkink formula

#### a Original formula of Makkink

MAKKINK (1957) simplified combination formula of PENMAN (1948) by neglecting the ventilation part, by replacing the radiation balance by the daily sum \( Rs \) of global radiation and by correcting the resulting error by comparative measurements. Finally the daily potential evapotranspiration \( ETP \) (mm/d) resulted in:

\[
ETP = a + b \times \frac{s}{(s + \gamma)} \times Rs,
\]

with \( Rs \) in mm/d (1 mm/d = 0.004 J/m²), \( s \) slope of vapour pressure curve (in hPa/K) at air temperature in 2 m height (daily mean), \( \gamma \) the psychrometric constant (0.67 hPa/K) as well as the coefficients \( a = -0.12 \) und \( b = 0.61 \). Negative \( ETP \) values are to be excluded as implausible.

#### b Makkink formula modified by DOORENBOS & PRUITT (1977)

As with the formula of Blaney & Criddle (see paragraph 4.1.3 a and b) DOORENBOS & PRUITT (1977) tried to estimate more closely the empirical coefficients \( a \) und \( b \) in the Makkink formula, too. It results (SCHRÖDTER, 1985)\n
\[ a = -0.3, \] when
with $UB$ daily mean of windspeed in Beaufort (for calculation from the measured 10 m-windspeed see paragraph 4.1.3. b) and mean relative humidity $RF_m$ (in %). Negative $ETP$ value have to be excluded as implausible.

c  Makkink formula after FEDDES (1987)

Opposite to DOORENBOS & PRUITT (1977) FEDDES (1987) at first simplified the Makkink formula by defining $a = 0$. Then, from comparative experiments he found the coefficient $b$ for a number of different cultures. For the reference crop grass a coefficient $b = 0.65$ resulted.

4.1.7 Meyer formula

MEYER (1926) developed a formula for the calculation of the monthly potential evapotranspiration very early, the core of it being the vapour pressure difference, as found lateron in the ALBRECHT (1950) and HAUDE (1952) publications (see paragraphs 4.1.1 and 4.1.4. a). Here a modifying factor is added, which depends from the mean windspeed. After SCHRÖDTER (1985) the formula reads (recalculated on daily basis, but prefactor reduced from 0.5 to 0.375 in order to consider the pressure unit hPa instead of Torr):

\[
ETP = 0.375 \cdot (E(T_m) - e_m) \cdot (1 + 0.224 \cdot u_m)
\]

with $ETP$ in mm/d, $E$ saturation vapour pressure in hPa, $T_m$ daily mean air temperature (2m) in degrees C, $e_m$ daily mean vapour pressure (2m) in hPa and $u_m$ mean windspeed in 2m height, which can be deduced by division by 1.3 from routine 10 m-wind data.

4.1.8 Naumann formula

The monthly based formula of NAUMANN (1987) calculates the plant specific potential daily evapotranspiration from the vapour pressure deficit and the relative humidity at noon after division of the prefactor by 30 (days). While NAUMANN (1987) used 13.00 h-values, here the more often taken 14.00 h-data (local time) for irrigation recommendations are inserted:

\[
ETP = 0.018 \cdot n_{max} \cdot (E(T_{14}) - e_{14})
\]

with $ETP$ in mm/d, $n_{max}$ astronomical maximum possible daily sunshine duration, $E$ saturation vapour pressure in hPa, $T_{14}$ air temperature (2m) in degrees C and $e_{14}$ vapour pressure (2m) in hPa at 14 h (local time). According to WENDLING et al. (1991) the Naumann evapotranspiration rather closely corresponds to the Haude evapotranspiration of grass.
4.1.9 Penman formula modified by DOORENBOS & PRUITT (1977)
This formula calculates the daily potential evapotranspiration after a modification by DOORENBOS & PRUITT (1977) of the original equation of PENMAN (1948), which follows

\[
ETP = c \times \left[ \left( s \times Rn + \gamma \times f(u) \times (E - e) \right) / (s + \gamma) \right]
\]
within the brackets:

with \( ETP \) in mm/d, \( s \) the slope of saturation vapour pressure (in hPa/K) at air temperature in 2 m, \( Rn \) radiation balance in mm/d (1 mm/d = 0.004 J/m\(^2\)), \( \gamma \) the psychrometric constant (0.67 hPa/K), \( f(u) \) the wind function of PENMAN (1948), \( E \) saturation vapour pressure in hPa and \( e \) the vapour pressure (2 m height) in hPa.

DOORENBOS & PRUITT (1977) have given:
\[
c = 0.79 - 0.034 \times UB + 0.028 \times Rs,
\]
where \( UB \) is the windspeed in 2 m height in Beaufort (see paragraph 4.1.3 b), and \( Rs \) stands for the daily sum of global radiation in mm/d (1 mm/d = 0.004 J/m\(^2\)). Negative \( ETP \)-values have to be excluded as implausible.

4.1.10 Schendel formula
Here a formula deducted on a monthly basis has been developed by SCHENDEL (1968) for the calculation of daily values of \( ETP \) in dependence on air temperature and air humidity. The prefactor 480 was replaced by 16 by SCHENDEL in order to consider the time scale,

\[
ETP = 16 \times Tm / RFm
\]
shortened from a month to a day:

with \( ETP \) in mm/d, \( Tm \) daily mean of air temperature in 2 m (in °C) and \( RFm \) daily mean of air humidity (in %) in 2 m.

Notice the similarity of this equation to the equation of SMITH & STOPP (1978) in paragraph 11 and to the equation of THORNTHWAITE (1948) with the linearization given by MINTZ & WALKER (1993) (see paragraph 12). Negative \( ETP \)-values have to be excluded as implausible.

4.1.11 formula of SMITH & STOPP
This formula calculating the daily value of the potential evapotranspiration \( ETP \) in dependence on air temperature has been developed by SMITH & STOPP (1978, cited of

\[
ETP = 0.16 \times Tm
\]

MINTZ & WALKER, 1993):
with \( ETP \) in \( \text{mm/d} \) and \( T_m \) daily mean air temperature in 2m (in EC). MINTZ & WALKER (1993) have stressed, that SMITH & STOPP give no derivation for their formula. But it is supported by its similarity to the linearized form (by MINTZ & WALKER, 1993) of THORNTHWAITE (1948) (see paragraph 12) and to the formula of SCHENDEL (1968). Negative \( ETP \)-values have to be excluded as implausible.

### 4.1.12 a  Thornthwaite formula modified by SIEGERT & SCHRÖDTER

This formula calculates the daily value \( ETP \) of potential evapotranspiration after the monthly

\[
ETP = 0.533 \times \left( \frac{n_{\text{max}}}{12} \right) \times \left( 10 \times \frac{T_m}{WI} \right)^A
\]

formula of THORNTHWAITE (1948), modified by SIEGERT & SCHRÖDTER (1975):

with \( ETP \) in \( \text{mm/d} \), \( n_{\text{max}} \) the astronomical maximum possible daily sunshine duration (in h) and \( T_m \) daily mean of air temperature in 2 m height (in EC). The heat index \( WI \) and the dependent exponent \( A \) were given by SCHRÖDTER (1985) as 33.617 resp. 1.033 for Braunschweig (central Germany).

In the approach above instead of the factor 'f' the quotient of astronomical maximum possible daily sunshine duration \( n_{\text{max}} \) and a 'mean' daily sunshine duration of 12 hours was used, a slight deviation from the original form of SIEGERT & SCHRÖDTER (1975). The reason is to come to a smoother transition of the daily evapotranspiration at the change of a month. Negative \( ETP \)-values again have to be excluded as implausible.

### b  Linearized Thornthwaite formula

MINTZ & WALKER (1993) by linearization eliminated the dependence of the Thornthwaite

\[
ETP = 0.17 \times \left( \frac{n_{\text{max}}}{12} \right) \times T_m
\]

formula on the heat index \( WI \), and they received:

The meaning of symbols is like in paragraph 4.1.12 a. Negative values of \( ETP \) are to be excluded as implausible.

### 4.1.13  Turc formula

TURC (1961) developed a formula for the calculation of daily potential evapotranspiration in dependence on air temperature, relative humidity and global radiation. The Turc formula

\[
ETP = 0.0133 \times \left( \frac{T_m}{T_m + 15} \right) \times (0.239 \times R_s + 50) \times \left( 1 + \frac{50 - RF}{70} \right)
\]

reads after adjustment of the units:
with $ETP$ in mm/d, $T_m$ the daily mean of air temperature in 2 m (in EC) and $Rs$ the daily sum of global radiation (in J/cm$^2$). $RF$ represents a relative humidity (in %) with $RF = 100 \cdot \frac{e_m}{E(T_m)}$, where $E$ is the saturation vapour pressure (in hPa) and $e_m$ the daily mean of vapour pressure in 2 m height (in hPa). For $RF > 50\%$ the value $RF$ is set to 50%. The expression in parentheses with $RF$ makes this formula complicated, as at least hourly measurements are needed for the estimation of $e_m$. But this drawback does not weigh too much, as under middle European humidity conditions the expression in parentheses may be normally set to 1.

The data basis used by TURC (1961) consists of temperatures well above the freezing point. For this reason this formula should be applied to a minimum value of $T_m = 0$.

### 4.1.14 Wendling formula

WENDLING et al. (1991) and WENDLING (1995) simplified the Penman-Monteith equation (MONTEITH, 1973) with the aim to calculate the daily value of the potential evapotranspiration $ETP$ (in mm/d) only from the daily mean of air temperature in 2 m height and the daily sum of global radiation ($Rs$, in J/cm$^2$):

$$ETP = (Rs + 93 \cdot K) \cdot \frac{(T_m + 22)}{(150 \cdot (T_m + 123))}$$

($T_m$, in EC) and the daily sum of global radiation ($Rs$, in J/cm$^2$):

with $ETP \geq 0.1$ mm/d. The factor $K$ considers the distance from the coast (beginning with $K=0.5$ at the coast and reaching 1 at distances of 50 km and more from the coast). The coefficients used here originate from a newer version of the formula.

### 4.2 FORTRAN listings of 25 European evapotranspiration formulas

The different evapotranspiration formulas of chapter have been put into a FORTRAN routine in Braunschweig (Agrometeorological Research, Deutscher Wetterdienst). The description of this module VERDU (from the German word for evapotranspiration) can be found as annex 3. The user has the possibility to choose the evapotranspiration method and to determine it in the input file $VERDU.STA$ together with other starting variables concerning soil data, plant species and irrigation data. A separate input file for phenological and biometrical plant data is described. On page 3 of annex 3 a table shows the meteorological variables (files) needed for the different evapotranspiration formulas.

The FORTRAN source code of this module VERDU is added in annex 4.

Earlier comparisons of the results from different evapotranspiration formulas are published in JENSEN et al. (1990), where the Penman-Monteith equation behaved best at humid and arid
sites in the United States. Also CHOISNEL (1992) found this approach to be the best in an European study.

4.3 Regional crop coefficients

The crop coefficient $k_c$ is defined as $ET_c / ET_o$ (DOORENBOS & PRUITT, 1977).

FAO recommends to replace the term potential evapotranspiration $ETP$ by reference evapotranspiration $ET_o$ (ALLEN et al., 1992). They give the following definition:

The reference evapotranspiration ($ET_o$) is defined as the rate of evapotranspiration from a hypothetic crop with an assumed crop height (12 cm) and a fixed canopy resistance (70) [s m$^{-1}$], and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

Consequently they prefer the term crop evapotranspiration $ET_c$ instead of actual evapotranspiration $ETA$. ALLEN et al. (1996) give a treatise about the dependence of the $k_c$-value on various factors. PEREIRA et al. split the crop coefficient into two factors $\alpha_o$ (=function of climatic and aerodynamic resistances) and $\alpha_c$ (=function of surface and aerodynamic resistances) both for the crop and reference crop.

Many crop factor tables have been developed and published during the last decades. A collection of crop factors, mainly for European crops can been found in annex 5, of course without the claim for completeness. The source is added to every table and may be looked up in exact citation in the references. Also the World Wide Web may be a source of further $k_c$-values. Some Internet addresses can be found in chapter 5.2.

5. Irrigation models

5.1 Models of COST member countries for testing

A listing of irrigation models used in the COST member countries is given in the table of annex 1 and 2. This is the result of two questionnaires to the delegates of COST 711. There has been the willingness of some member countries to contribute their evapotranspiration / irrigation model as an executable file (preferably as an English dialogue version) together with a user's manual. These were Belgium, France, Germany, Italy, Slovakia, Slovenia und Spain. At a later stage only fewer models were received, but additionally one from the Netherlands. As for the German model AMBAV both has been ready for interested member countries at the Toulouse MCM in 1996.

5.1.1 Model characteristics
The characteristics of the German, Italian, Dutch, Slovene, Slovak and former GDR irrigation model are comprehended in annex 6 in several tables. The fundamentals seem to be rather similar. Some models base on the Penman-Monteith equation for evapotranspiration and incorporate plant data and soil processes to come to crop evapotranspiration $ET_c$. All irrigation schemes give results for the soil water contents and the recommended irrigation amounts. The models can deal with a slightly different set of cultures. Judging from the information available on the soil water unit and the crop unit within the models they seem to be most advanced in the German AMBAV model and the Italian BIDRICO model, although for some points in the other models clear information misses. The time step ranges from 1h in the AMBAV model to 1 week in the Slovene SISETA model. All models can be run easily on each modern PC.

The contents and the format of the input files have to be taken from the tables in annex 6 and to be asked from the contact persons for the model (see next chapter). The English manual of the model AMBAV in attached as annex 7a. In the same annex place is reserved for the description of the other models.

5.1.2 Availability and contact persons
All the mentioned models of annex 6 should be available as an executable file as a test version for the COST 711 members. The contact persons for each irrigation model are listed in table 1 of annex 6 with address, institution, phone and fax number and e-mail adress. Besides the exe-file of the model the institution in question certainly will furnish data files for a first testing, too, before creating suitably formatted input files of the new region.

5.2 Sources of further evapotranspiration models
At this time here only one WWW adress is given, where more information can be load down about irrigation models, evapotranspiration or kc-values.

http://www.wiz.uni-kassel.de/kww/irrisoft_i.html
as an irrigation software database.

Further models, which were not collected within COST 711 members, can be found in annex 6, table 6, of course without the claim to completeness.

Special notice should be also given to the recent papers:

Proceedings 6th ASAE Conference on Computer Application in Irrigation.
Mexico, June 1996.
6. Perspectives for further improvements

Experiences may be collected by scientists using the one or other irrigation model made available to COST member countries. Ideas for improvements may be submitted to the contact person and implemented into the model concerned. In future the often more regional solutions for irrigation management schemes may be replaced by sophisticated models with a greater area of application.

The trend is towards evapotranspiration and soil water models at a one hour timestep which can incorporate important boundary conditions like soil type and plant data like development stage, height and leaf area index etc. The driving variables will be from crop climate calculations concerning air and soil temperature and relative humidity. The number of crops for which reliable irrigation advice can be given will thus rise. The availability of sufficiently mighty PCs in most advisory services will support this outlook.

So, there is a chance for all countries to improve their quality and efficiency of irrigation management by exchange of know-how, information, data and models.
7. References


Bussay, A.: personal communication, 1996


Clarke, D. & El-Askari, K.M.S.: Irrigation Scheduling - a Windows Equivalent to the FAO CROPWAT Program. Paper pres. at 6th ASAE Conf. on Computer Applications in Irrigation, Mexico, June 1996, p. ...


FAO: Early agrometeorological crop yield assessment. FAO Plant Production and Protection Paper no. 73, Rome 1986


Annex:

Contents:

annex 1 Evaluation of irrigation scheme questionnaire of 1994
annex 2 Evaluation of irrigation scheme questionnaire of 1996
annex 3 VERDU (different evapotranspiration formulas) description
annex 4 VERDU (different evapotranspiration formulas) source code
annex 5 Crop coefficients tables
annex 6 Availability and requirements of irrigation models
annex 7 Model descriptions and/or program manuals
   a AMBAV (German model)
   (b to f reserved for other models)
<table>
<thead>
<tr>
<th>Country, system</th>
<th>ET₀ (PET) formula</th>
<th>parameter</th>
<th>time resolution</th>
<th>farmer too?</th>
<th>water model type</th>
<th>crop model mod.</th>
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## IRRIGATION SCHEMES continued

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### ABBREVIATIONS:

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<th>Definition</th>
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<td>A-pan</td>
<td>class A-pan for evaporation</td>
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<td>ETₜ</td>
<td>crop evapotranspiration (~ETA)</td>
</tr>
<tr>
<td>ET₀</td>
<td>reference crop evapotranspiration (~PET)</td>
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<td>crop coefficient</td>
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<td>day, daily</td>
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<td>G</td>
<td>global radiation</td>
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<td>hour, hourly</td>
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<tr>
<td>min</td>
<td>minutes</td>
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<td>PET</td>
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<td>T</td>
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<td>VV</td>
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### IRRIGATION SCHEMES of COST member countries
(evaluation of autumn 1995 questionnaire to COST member countries)

#### part 1:

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<tr>
<th>country</th>
<th>name and place of replier</th>
<th>organization which operates the irrigation model</th>
<th>who are the users?</th>
<th>costs?</th>
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<td>AUSTRIA</td>
<td>H. Dobesch, Inst. for Met. &amp; Geodynamics, Vienna</td>
<td>planned for 1996 to start with German Weather Service</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
| BELGIUM | R. Oger, University of Gembloux | X. Dimitri of Hydraulique Agric., Univ. of Gembloux | farmers, vegetable | yes: 1000 /
|        | BEF/ha year | drauliq Agric., Gembloux | growers, factories of deep-frozen vegetables | / good |
| DENMARK | F. Plauborg, Danish Inst. Plant & Soil Science, Tjele | Centre, Aarhus: "MARKVAND*" | farmers, local advisors | yes: ~200 / well |
| FRANCE | V. Perarnaud/S. Paniagua Meteo France & agric. Meteo France, Tou | Institute: "IRRITEL", sors, agric. teachers | no longer in use | further models exist |
|        | Deutscher Wetterdienst "AMBAV*": region models | for fax | rather |
| HUNGARY | A. Bussay, Hungarian Meteorol. Service, Budapest Agric. Univ./Inst. at: Debrecen, Gödöllő & Szarvas; Hung. Met. | (not in the moment) | - |
| ITALY (1) | G. Zipoli, Institute of Agromet. & Env. Analys. for Agric., Florence Emilia-Romagna | regional agromet. services in Romagna & technicians | farmers (500 in E.-) | no, but |
|        | videotel term. 100000 LIT/year | of extension service | rent |
|        | good | / in general |
|        | good | (regional service, not at farm level) / good | |
SLOVAKIA
P. Nejedlik, Slovak HydroMet. Institute, Kosice
V. Cislak / A. Heldi Research Inst. Irrig. Management, Bratislava
~120 operators of irrigation systems / no

SLOVENIA
I. Matajc, Hydromet. Agricult. High School of Agromet., Ljubljana
Inst. of Slov., Dept. Racikan, Murska Sobota
26 farmers and advisory services, Agric. Institute / no
# part 2:

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<th>relevant sites?</th>
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<tr>
<td>DENMARK</td>
<td>no (only demo version)</td>
<td>2 stat.lysim.data</td>
<td>many files, daily all sites</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>[soil moist.?]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRANCE</td>
<td>yes, pc vers. (not longer used)</td>
<td>no</td>
<td>some files</td>
<td>maybe with from INRA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GERMANY</td>
<td>yes</td>
<td>20 stat. soil moist.</td>
<td>many files</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 station lysimetric data and energy bal. measurements</td>
<td>1 hour - 15 min, all sites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUNGARY</td>
<td>no</td>
<td>1 station soil moist.</td>
<td>1 station (driest) 3-4 years</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>ITALY (1)</td>
<td>yes</td>
<td>26 stat. soil moist. (1 probe per 2 months)</td>
<td>no</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>(Zipolli)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITALY (2)</td>
<td>no</td>
<td>soil moisture data</td>
<td>180 stations with hourly data</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>(Palchetti)</td>
<td></td>
<td>[number of sites?]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLOVAKIA</td>
<td>yes</td>
<td>10 stat. soil moist. (weekly)</td>
<td>many files all sites</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLOVENIA</td>
<td>yes</td>
<td>2 stations soil moist. (daily, as comp. files)</td>
<td>many files all sites</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>

---

NETHERLANDS, NORWAY and SWEDEN: no or no official irrigation service.
VERDU
(version of 12.11.96/11.55 h)
Deutscher Wetterdienst
Agrometeorological Research, Braunschweig

Short description
VERDU calculates the potential and real evapotranspiration for different crops as well as the soil moisture contents by different methods of potential evapotranspiration calculation. At this time this version has a choice of 24 methods.

input files

VERDU.STA

parameters:
1. line: LSTEU (I2)
2. line: INPUT DIRECTORY (max. A40)
3. line: OUTPUT DIRECTORY (max. A40)
4. line: YEAR (I4)
5. line: STATION; JDBEG; JDEND; METHO; IZWI; IPFLA; NWA; IOUT; NAUS; ISTBOF; INT; ISTBER ; JDBER; RRBER; GRENZNFK; NFKMAX
6. line: etc.

format: free (STATION, METHO as character variables)

meaning of parameters:

LSTEU = 0 ---> batch, >= 1 ---> dialogue
STATION = number / name of station
JDBEG, JDEND = julian day of begin and end of calculations
METHO = chooses method of evaporation calculation
HAU = Haude, original (monthly factors)
HAS = Haude, hourly (factors after Heger)
HAM = Haude, modified after Löpmeier (1987)
HAH = Haude, modified after Haenel
PE1 = Penman, (new radiation parameterization)
PE2 = Penman, original
PE3 = Penman, modified after Doorenbos & Pruitt (daily mean)
BLA = Blaney - Criddle, original
BL1 = Blaney - Criddle, modified after Doorenbos & Pruitt
TUR = Turc
THO = Thornthwaite, original
TH2 = Thornthwaite, modified after Mintz & Walker
LIN = Linacre
MAK = Makkink, original
MA1 = Makkink, modified after Doorenbos & Pruitt
MA2 = Makkink, modified (only radiation and temperature input)
ALB = Albrecht
WEN = Wendling
<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEY</td>
<td>Meyer</td>
</tr>
<tr>
<td>ANT</td>
<td>Antal</td>
</tr>
<tr>
<td>SCH</td>
<td>CZERATZKI-disk data (evaporative ceramic disk)</td>
</tr>
<tr>
<td>NAU</td>
<td>Nauman</td>
</tr>
<tr>
<td>SHE</td>
<td>Schendel</td>
</tr>
<tr>
<td>SMI</td>
<td>Smith</td>
</tr>
</tbody>
</table>

IZWI = regulates the input of start data

- 0 = reading from start data file ...BOD
- 1 = reading from interim file ...ZWI

IPFLA = name of crop for calculations (significant for methods HAU, HAS und HAM)
- 1 = winter wheat
- 2 = (summer cereals, not yet ready)
- 3 = grass
- 4 = maize
- else = set to -1

NWA = number of soil layers (for water content), each of 10 cm depth (NWA < 40)

IOUT = layer for seepage calculations (< NWA)

NAUS = output interval in days

ISTBOF = regulates the operation of a soil water model
- 1 = soil water model as in module AMBAV
- 2 = cascade model with reduction of ETP
- 3 = cascade model without reduction of ETP

INT = regulates interception evaporation
- 0 = without interception evaporation
- 1 = with interception (not yet meaningful at this time)

ISTBER = regulates irrigation
- 0 = without irrigation
- 1 = with irrigation (manual regulation, with JDBER and RRBER > 0)
- 2 = automatical irrigation (regulation by NFKMAX, GRENZNFK)

JDBER = julian day of irrigation

RRBER = amount of irrigated water (mm)

NFKMAX = maximum available water (%) after irrigation

GRENZNFK = available water (%) at which irrigation has to be started

---

**other input files**

**PFLA_ipfla.DAT (in main directory)**

This file contains plant parameters in lines for different evaporation calculation methods and may be changed by the user.

**parameters:**

1. line: crop, JD1, JD2, JD3, JD4, JD5, HMAX, HMIN, LAIMAX, LAIMIN, AL, DUWU, FAKP, PHI, RSMIN

2. line: FAK(1-12)

3. line: FAKS(1-12)

**meaning of parameters:**

- JD1, ..., JD5 = julian days of characteristic phenological stages
- HMAX, HMIN = maximum, minimum crop height
- LAIMAX, LAIMIN = maximum, minimum leaf area index
- AL = albedo
- DUWU = rooting depth (cm)
- FAKP = plant factor for modified Haude evapotranspiration
- PHI = crit. potential for reduction of ETP (for ISTBOF=2)
- RSMIN = minimum crop resistance
Remark: When choosing a negative rooting depth this parameter will not be calculated, but the preset rooting depth from the file *station_kultur.bod* will be held constant.

The following meteorological data files are needed:

<table>
<thead>
<tr>
<th>Method</th>
<th>from METD</th>
<th>TL</th>
<th>RF</th>
<th>VV</th>
<th>RG</th>
<th>NG</th>
<th>RR</th>
<th>CZ</th>
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<tbody>
<tr>
<td>HAU</td>
<td>SAE&lt;sub&gt;14&lt;/sub&gt;</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>HAS</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>HAM</td>
<td>SAE&lt;sub&gt;14&lt;/sub&gt;</td>
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<tr>
<td>HAH</td>
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<td>X</td>
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<td>PE2</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>PE3</td>
<td>SO, TMI</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>BLA</td>
<td>TMI, SO</td>
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<tr>
<td>BL1</td>
<td>TMI, SO</td>
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<tr>
<td>TUR</td>
<td>TMI, RGSUM</td>
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<tr>
<td>THO</td>
<td>TMI</td>
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<tr>
<td>LIN</td>
<td>TMI</td>
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<tr>
<td>MA1</td>
<td>TMI, RGSUM</td>
<td></td>
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<tr>
<td>MAK</td>
<td>TMI, RGSUM</td>
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<tr>
<td>MA2</td>
<td>TMI, RGSUM</td>
<td></td>
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<tr>
<td>ALB</td>
<td>TMI</td>
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<tr>
<td>WEN</td>
<td>TMI, RGSUM</td>
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<tr>
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<td>TMI</td>
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</tr>
<tr>
<td>ANT</td>
<td>TMI</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCH</td>
<td>TMI</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>TH2</td>
<td>TMI, SO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAU</td>
<td>TL&lt;sub&gt;14&lt;/sub&gt; RF&lt;sub&gt;14&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SHE</td>
<td>TMI</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMI</td>
<td>TMI</td>
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</tr>
</tbody>
</table>

SAE = saturation deficit (14h)  SO = sunshine duration  TD = dew-point
RGSUM = daily sum of global radiation  TMI = daily mean air temperature  E = vapour pressure
File data abbreviation:  METD_... = daily meteorol. data
TL_... = hourly air temperature (2m)
RF_... = hourly relative humidity (2m)
VV_... = hourly wind velocity in m/s
RG_... = hourly global radiation in W/m²
NG_... = hourly octas of cloudiness
RR_... = hourly precipitation amount
CZ_... = daily data of CZERATZKI evaporative disk

**CZ_year.station**
This file contains the julian days and the disk evaporation amount with a format of I4,F6.1
and a record length of 10.

The following files are needed for the use of the soil water model by the variable ISTBOF=1:

**station_kultur.BOD**
This file contains the crop-specific starting and boundary conditions for the water model.

**station.PAR**
This file contains the soil-hydraulic data for the water model.

**Remarks for the files station.BOD and station.PAR.**
The files station.BOD and station.PAR have to be located in the main directory of AMBAV. Further information can be found in the manual for the AMBAV module.

******************************************************************

**Output files**

**VERDU.LSI**
Output of control data and sums of results.

output of the parameters:
  statio, JDBEG, JDEND, METHO, ISTBOF, IPFLANZ, Surr, SUETP, SUETA, SICKER, BEREg, NFK

meaning of parameters:
  see also file description of VERDU.STA above
Surr = sum of precipitation
SUETP = sum of potential evapotranspiration
SUETA = sum of real evapotranspiration
SICKER = sum of seepage water
BEREG = sum of irrigation water
NFK = available water (0-60 cm) on day JDEND
**VERDU.LS2**

Larger compilation of results concerning the soil water (for ISTBOF=1).

**VERDU_jahr.station**

parameters: \( JD, ETP, ETA, NFK \)

format: \( I4, 2F6.1 \)

meaning of parameters: 
- \( JD \) = julian day
- \( ETP \) = potential evapotranspiration
- \( ETA \) = real evapotranspiration
- \( NFK \) = available water (%)  

**WURZEL_ipfla.station**

Supporting programs for VERDU
There exist programs for creating the files METD_..., TL_... etc.  
A plot routine can be used for the presentation of results.

Helps for data processing
According to the choosen methods the data files needed have to be supplied.

Remarks
Detailed results may be read in the output file VERDU.LS2. The result of the water model are described in the manual of the AMBAV model.

State of verification
Due to the new design of the program taking account of the structure of the AMBER software package the possibility of technical errors cannot be excluded.
Annex 4

SUBROUTINE ALBRECHT( DT, TLT, UT, ETPT )
C Diese Subroutine berechnet eine sog. "moegliche" Verdunstung nach
C einem Ansatz von Albrecht (1950, zitiert nach Schroedter, 1985) in
C Abhaengigkeit von Lufttemperatur, Dampfdruck und Windgeschwindigkeit.
C Die im folgenden verwendete Formel fuer den Verdunstungs-Tageswert
C wurde aus Schroedter (1985) entnommen, wobei allerdings gleich eine
C Umrechnung aller Koeffizientenwerte auf SI-Einheiten erfolgte.
C Literatur:
C Variablenbedeutung und Einheiten:
C **** Input ****
C DT Tagesmittel des Dampfdruckes in 2m [hPa]
C TLT Tagesmittel der Lufttemperatur in 2m [Grad C]
C UT Tagesmittel der Windgeschwindigkeit in 2m [m/s]
C **** Output ****
C ETPT Tageswert der potentiellen Verdunstung [mm/d]
C SDADR Funktion: berechnet Saettigungsdampfdruck [hPa]
C **** Intern ****
C F Koeffizient, von der Windgeschwindigkeit UT abhaengig
C Umrechnung von 10 auf 2 meter
ut=ut/1.3
IF ( UT .GT. 1. ) THEN
  F = 0.4
ELSE
  F = 0.1 + 0.3 * UT
END IF
ETPT = F * ( SDADR( TLT ) - DT )
RETURN
END

*************************************
SUBROUTINE ANTAL( TLT, DT, ETPT )
C Diese Subroutine berechnet die potentielle Tagesverdunstung nach dem in
C Ungarn gebraeuchlichen ANTAL-Verfahren (Mueller et al., 1990; Wendling
C et al., 1991). Das ANTAL-Verfahren benoetigt als Input Informationen zu
C Lufttemperatur und Dampfdruck.
C Literatur:
C Variablenbedeutung und Einheiten:
C **** Input ****
C DT Tagesmittel des Dampfdruckes in 2m [hPa]
C TLT Tagesmittel der Lufttemperatur in 2m [Grad C]
C **** Output ****
C ETPT Tageswert der potentiellen Verdunstung [mm/d]
C **** Intern ****
C SDADR Funktion: berechnet Saettigungsdampfdruck [hPa]
C if(sdadr(tlt)-dt .gt.0)then
  ETPT = 0.736 * (SDADR( TLT ) - DT)**0.7 * (1. + TLT / 273.)**4.8
else
  etpt =0.
end if
RETURN
END
SUBROUTINE BLANEY2( J, TLT, RH14, UT10, S, ST, SJ, ETPT )
C Diese Subroutine berechnet den Tageswert der potentiellen
C Criddle (1952) in Abhaengigkeit von Lufttemperatur, Luftfeuchte,
C Windgeschwindigkeit und Sonnenscheindauer. Die im folgenden
C verwendete Formel ist Ergebnis einer leichten Bearbeitung durch
C ACHTUNG: Die Formel wurde hier sinnvollerweise ergaenzt durch den
C Ausschluss negativer ETPT-Werte.
C Literatur:
C Variablenbedeutung und Einheiten:
C **** Input ****
C J                          Jahrestag oder Julianisches Datum
C RH14  Relative Feuchte [%] in 2m zum Klimatermin II = 14:00 MOZ
C (gemeint ist damit das Tagesminimum der rel. Feuchte)
C SJ                Jahressumme der astronomisch maximal moeglichen Sonnen-
C (scheindauer [h]
C ST                taegliche astronomisch maximal moglichen Sonnen-
C (scheindauer [h]
C TLT               Tagesmittel der Lufttemperatur in 2m [Grad C]
C UT10              Tagesmittel der Windgeschwindigkeit in 10m [m/s]
C **** Output ****
C ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C **** Intern ****
C A  ) Koeffizienten, deren Formeln von Doorenbos & Pruitt (1977)
C B  ) stammen, und von Schroedter (1985) bearbeitet wurden
C PFAK            taegliche astronomisch maximal mogliche Sonnenscheindauer
C ( in Prozent der Jahres-Sonnenscheindauer
C UTB               Tagesmittel der Windgeschwindigkeit in 2m [Beaufort=BFT];
C Berechnung aus m/s in 10m Hoche mittels Invertierung einer
C gaengigen Formel {m/s = 0.87*BFT**1.44}. Man beachte, daa
C diese Formel allein schon deshalb nicht besonders gut zur
C Hilfstafel 6 bei Schroedter (1985) passen kann, da die dort
C angegebenen m/s-Werte lediglich jeweils die Untergrenze
C eines m/s-Bereiches darstellen, der einer jeden BFT-Stufe
C zugeordnet wird (DWD-Wetterstation-Unterlagen). Zwischen
C 10m-Wind und 2m-Wind wird im uebrigen die bei Schroedter
C (1985) benutzte Relation 1.3:1 verwendet.
C Ein gewisses, von Schroedter (1985) aber auch vernachlaes-
C sigtes Problem bei dieser Umrechnung von m/s in BFT stellt
C die Nichtlinearitaet der Beziehung dar (verfaelschte
C Mittelbildung ueber den Tag!).
dimension st(366)
  A = 0.0043 * RH14 - S / ST(J) - 1.41
  UTB = ( UT10 / 0.87 )**( 1. / 1.44 )
  B = 1.21 + 0.0545 * UTB + 0.6 * S / ST(J) - 0.01 * RH14
  PFAK = 100. * ST(J) / SJ
  ETPT = A + B * PFAK * ( 0.457 * TLT + 8.128 )
  IF ( ETPT .LT. 0. ) ETPT = 0.
RETURN
END
********************************************************
SUBROUTINE BLANEY( J, TLT, ST, SJ, ETPT )
C Diese Subroutine berechnet den Tageswert der potentiellen

Literatur:

Variablenbedeutung und Einheiten:
ETPT  Tageswert der potentiellen Verdunstung [mm/d]
J      Jahrestag oder Julianisches Datum
PFAK   tägliche astronomisch maximal mögliche Sonnenscheindauer in Prozent der Jahres-Sonnenscheindauer
SJ     Jahressumme der astronomisch maximal möglichen Sonnenscheindauer [h]
ST     tägliche astronomisch maximal möglichen Sonnenscheindauer [h]
TLT    Tagesmittel der Lufttemperatur in 2m [Grad C]

PFAK = 100. * ST(J) / SJ
ETPT  = - 1.55 + 0.96 * PFAK * ( 0.457 * TLT + 8.128 )
RETURN
END

********************************************************************************
C PROGRAMM ZUR BERECHNUNG DER VERDUNSTUNG NACH HAUDE
C HAU.MOD.FOR
SUBROUTINE HAUDE (SAE,monat,etp)
include 'bestan.inc'
ETP = HAUFAK(MONAT)*SAE
RETURN
END

*********************************************************************************
C PROGRAMM ZUR BERECHNUNG DER STUNDLICHEN HAUDE-VERDUNSTUNG
C HAUS.FOR
SUBROUTINE HAUS (SAE,monat,etp)
include 'bestan.inc'
ETP = HAUFAKS(MONAT)*SAE
RETURN
END

**********************************************************************************
C PROGRAMM ZUR BERECHNUNG DER MODIFIZIERTEN VERDUNSTUNG NACH HAUDE
C HAU.MOD.FOR
SUBROUTINE HAUMOD (LAI,SAE,jtorr,etp)
include 'verdu.inc'
include 'bestan.inc'
DIMENSION BODEN (5)
DATA BODEN/0.07,0.08,0.09,0.11,0.13/
DATA IDAU/18/
DATA IBODEN/4/, IDAU/18/
C IDAU = Dauer des erhöhten Wasserverbrauchs
C HIER WIRD ENDE DES BESTANDES DEFINIERT (VORLAUEFIG)
C IDAU DAUER des HOHEN WASSERBRAUCHS
C Bodenfaktoren von Lehm bis Sand
C HAUDE= HAUDEVERDUNSTUNG
C HAU = SAETTIGUNGSEDIFIZIT WIRD VON VER GELIEFERT
C F = HAUDEFAKTOR
C FAKB= BODENFAKTOR
C jj1 jahrestag Verdunstungsbeginn
C jj2 deutlicher Verdunstungsanstieg
C jj3 maximaler Wasserverbrauch
C jj4 Ernte, Achtung Reife entfällt hier
jj1=jauf
jj2=j1
jj3=j2
jj4=j4
C Ausnahme Zuckerrüben / Mais??

IF ( JT .GE. Jj3+IDAU )THEN
IF((Jj4-(Jj3+IDAU)) .EQ. 0)Jj4=Jj4+1
FAKP= FAKP- FAKP*0.8* ( 
* (0.3*FLOAT((JT-(Jj3+IDAU))/FLOAT((Jj4-(Jj3+IDAU))))) + 
* (0.7*FLOAT((JT-(Jj3+IDAU))/FLOAT((Jj4-(Jj3+IDAU)))))**3. )
ENDIF

XBODEN=BODEN(IBODEN)
FAKB=0.22
FB=0.7**LAI
FAKB=FAKB *(1.- XBODEN*JTORR)
IF(FAKB .LT.0.)FAKB=0.
FAK=FB*FAKB + (1.-FB)*FAKP
ETP = FAK*SAE
RETURN
END

**************************************************************************
SUBROUTINE HAUDHAE( TL14, RH14, S, RSMIN, ETPT )
C "HAHA" = Haude/Haenel
C Diese Subroutine berechnet die pflanzenspezifisch potentielle Tagesver- 
C dunstung nach Haude (1952) aus dem Dampfdruckdefizit zum Klimatermin II 
C (14:00 h MOZ), wobei allerdings der sog. Haufaktor nach Haenel 
C (1995, unveroeffentlicht) in Abhaengigkeit von minimalem Bulkstomata-
C widerstand und tatsaechlicher taglicher Sonnenscheindauer parame-
C terisiert wird.
C Literatur: 
C Haude, W., 1952.
C Variablenbedeutung und Einheiten:
C **** Input ****
C RH14  Relative Feuchte [%] in 2m zum Klimatermin II = 14:00 MOZ 
C (gemeint ist damit das Tagesminimum der rel. Feuchte)
C RSMIN minimaler Bulkstomatawiderstand [s/m]
C S  tatsaechliche tagliche Sonnenscheindauer [h]
C TL14  Lufttemperatur [Grad C] in 2m zum Klimatermin II = 14:00 MOZ 
C (gemeint ist damit das Tagesminimum der rel. Feuchte)
C **** Output ****
C ETPT Tageswert der potentiellen Verdunstung [mm/d]
C **** Intern ****
C SDADR Funktion: berechnet Saettigungsdampfdruck [hPa]

C ***************************************************************
SUBROUTINE LINACRE( GEOB, ZNN, TLT, TDT, UT, ETPT )
C "LINA" = Linacre
C Diese Subroutine berechnet den Tageswert der potentiellen 
C Verdunstung nach einer Formel von Linacre (1992, S. 105/106)
C in Abhaengigkeit von geographischer Breite, Hohe ueber NN,
Lufttemperatur, Taupunkt und Windgeschwindigkeit. 
Die Anwendbarkeit beschränkt sich wegen der verwendeten 
Strahlungsparameterisierung (s. Linacre, 1992, S. 181/182) 
auf geogr. Breiten von -60 bis +60 Grad. 
Literatur:

Variablenbedeutung und Einheiten:
ETPT        Tageswert der potentiellen Verdunstung [mm/d]
GEOB        geographische Breite [Grad]
TLT         Tagesmittel der Lufttemperatur in 2m [Grad C]
TDT         Tagesmittel des Taupunkts [Grad C]
UT          Tagesmittel der Windgeschwindigkeit in 2 Meter [m/s]
ZNN         Höhe über Meeresniveau NN [m]

ut=ut/1.3
IF ( ABS( GEOB ) .LE. 60. ) THEN
      ETPT = ( 0.015 + 4.E-4 * TLT + 1.E-6 * ZNN ) *
            ( 380. * ( TLT + 0.006 * ZNN ) / ( 84. - ABS(GEOB) ) -
            40. + 4. * UT * ( TLT - TDT ) )
ELSE
      ETPT = -9.9
END IF
RETURN
END

SUBROUTINE MAKKINK ( TLT, RGTSU, ETPT )
Diese Subroutine berechnet den Tageswert der potentiellen
Verdunstung nach der Formel von Makkink (1957) in Abhängigkeit
von Lufttemperatur und Globalstrahlung.
Achtung: ergänzend wird ETPT nach unten durch Null begrenzt.
Literatur:
Makkink, G.F., 1957:

Variablenbedeutung und Einheiten:
**** Input ****
J            Jahrestag oder Julianisches Datum
RGTSU       Tagessumme der Globalstrahlung [J/cm²]
TLT         Tagesmittel der Lufttemperatur in 2m [Grad C]
**** Output ****
ETPT        Tageswert der potentiellen Verdunstung [mm/d]
**** Intern ****
DSDADR      Steigung des Sättigungsdampfdruckes mit der Temperatur
            [hPa/K], wird im vorliegenden Fall nicht analytisch be-
            rechnet, sondern als Differenzenquotient approximiert
            (unter Verwendung von FUNCTION SDADR)
PSYKO       Psychrometer-Konstante [hPa/K]
RGTM       RGTSU in mm-Aequivalent

DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
PSYKO = 0.67
RGTM = RGTSU / 250.
ETPT = -0.12 + 0.61 * RGTM * DSDADR / ( DSDADR + PSYKO )
IF ( ETPT .LT. 0. ) ETPT = 0.
RETURN
END

SUBROUTINE MAKKINK1 ( TLT, RGTSU, rht, ut, ETPT )
03.11.95 LETZTE AENDERUNG
Diese Subroutine berechnet den Tageswert der potentiellen
Verdunstung nach einer von Doorenbos & Pruitt (1977) modifizier-
ten Formel von Makkink (1957) in Abhängigkeit von Lufttemperatur,


Achtung: ergänzend wird ETPT nach unten durch Null begrenzt.

Literatur:
Doorenbos, J., and Pruitt, W.O., 1977
Makkink, G.F., 1957

Variablenbedeutung und Einheiten:

***** Input *****
J Jahrestag oder Julianisches Datum
RGTSU Tagessumme der Globalstrahlung [J/cm^2]
RGTMM Tagessumme der Globalstrahlung [mm Wasser, q.]
RHT Tagesmittel der Luftfeuchte [%]
TLT Tagesmittel der Lufttemperatur in 2m [Grad C]
UT Tagesmittel der Windgeschwindigkeit in 10m [m/s]

***** Output *****
ETPT Tageswert der potentiellen Verdunstung [mm/d]

***** Intern *****
B Koeffizient nach Doorenbos & Pruitt (1977)
DSDADR Steigung des Sättigungsdampfdruckes mit der Temperatur [hPa/K], wird im vorliegenden Fall nicht analytisch be-rechnet, sondern als Differenzengquotient approximiert
PSYKO Psychrometer-Konstante [hPa/K]
UTB Tagesmittel der Windgeschwindigkeit in 2m [Beaufort=BFT]; Berechnung aus m/s in 10m Hoche mittels Invertierung einer gaengigen Formel (m/s = 0.87*BFT**1.44). Man beachte, daa diese Formel allein schon deshalb nicht besonders gut zur Hilfstafel 6 bei Schroedter (1985) passen kann, da die dort angegebenen m/s-Werte lediglich jeweils die Untergrenze eines m/s-Bereiches darstellen, der einer jeden BFT-Stufe zugeordnet wird (DWD-Wetterstation-Unterlagen). Zwischen 10m-Wind und 2m-Wind wird im uebrigen die bei Schroedter (1985) benutzte Relation 1.3:1 verwendet.
Ein gewisses, von Schroedter (1985) aber auch vernachlas-sigtes Problem bei dieser Umrechnung von m/s in BFT stellt die Nichtlinearitaet der Beziehung dar (verfaelschte Mittelbildung ueber den Tag!).

DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
UTB = ( UT / 0.87 )**(1. / 1.44)
B = 1.165 + 0.043 * UTB - 0.00575 * RHT
RGTMM=RGTSU/250.
ETPT = - 0.3 + B * RGTMM * DSDADR / ( DSDADR + PSYKO )
RETURN
END

SUBROUTINE MAKKINK2( TLT, RGTSU, ETPT )
Literatur:
Makkink, G.F., 1957

Variablenbedeutung und Einheiten:

**** Input ****
RGTSU Tagessumme der Globalstrahlung [J/cm²]
TLT Tagesmittel der Lufttemperatur in 2m [Grad C]

**** Output ****
ETPT Tageswert der potentiellen Verdunstung [mm/d]

**** Intern ****
DSDADR Steigung des Saftigungsdampfdruckes mit der Temperatur
[Pa/K], wird im vorliegenden Fall nicht analytisch berechnet, sondern als Differenzenquotient approximiert
(unter Verwendung von FUNCTION SADDR)
PSYKO Psychrometer-Konstante [Pa/K]
RGTMM RGTSU in mm-Equivalent

DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
PSYKO = 0.67
RGTMM = RGTSU / 250.
ETPT = 0.65 * RGTMM * DSDADR / ( DSDADR + PSYKO )
IF ( ETPT .LT. 0. ) ETPT = 0.
RETURN
END

SUBROUTINE MEYER( DT, TLT, UT, ETPT )
Diese Subroutine berechnet eine die potentielle Verdunstung nach
einem Ansatz von Meyer (1926, zitiert nach Schroedter, 1985) in
Abhaengigkeit von Lufttemperatur, Dampfdruck und Windgeschwindigkeit.
Die im folgenden verwendete Formel fuer den Verdunstungs-Tageswert
wurde aus Schroedter (1985) entnommen.

Literatur:

Variablenbedeutung und Einheiten:
**** Input ****
DT Tagesmittel des Dampfdruckes in 2m [Pa]
TLT Tagesmittel der Lufttemperatur in 2m [Grad C]
UT Tagesmittel der Windgeschwindigkeit in 2m [m/s]

**** Output ****
ETPT Tageswert der potentiellen Verdunstung [mm/d]

SDADR Funktion: berechnet Saattigungsdampfdruck [Pa]

Umrechnung 10 Meterwind auf 2 Meter
UT=UT/1.3
ETPT = 0.5 * ( SDADR( TLT ) - DT )/1.33322 * ( 1. + 0.224 * UT )
c 1.333 Umrechnung Pa in Torr
RETURN
END

SUBROUTINE NAUMAN( J, TL14, RH14, ST, ETPT )
Diese Subroutine berechnet die pflanzenspezifisch potentielle Tagesver-
dunstung nach einer auf Monatsbasis entwickelten Formel von Naumann
Der originale Vorfaktor lautet bei Naumann (1987) 0.54 und wurde zur
Verwendung auf Tagesbasis durch 30 (Tage) dividiert) 0.54/30=0.018.
C Waehrend Naumann (1987) die 13:00-Uhr-Werte verwendet, kommen im
C folgenden die zum Klimatermin II (14:00 h MOZ) erfassten Daten zum
C Einsatz.
C Die Naumann-Formel "stimmt faktisch uberein" mit dem Haude-Ansatz,
C wie Wendling et al. (1991) feststellen. Nach ihrer Tabelle I
C entspricht die hier programmierte "Naumann-Verdunstung" der
C Haude-Verdunstung uber Gras.
C Die unten programmierte Naumann-Formel erhalt man direkt auch, wenn
C in der Haude/Haenel-Formel in Subr. ETP_HAHA.FOR das RSMIN mit dem
C von der FAO empfohlenen Wert von 69 s/m und die tatsaechliche Sonnen-
C scheidauer S mit ca 70% von ST eingesetzt wird.
C
C Literatur:
C Haude, W., 1952.
C Wendling, U., Schellin, H.-G.
C
C Variablenbedeutung und Einheiten:
C **** Input ****
C J Jahrrestag oder julianisches Datum
C RH14 Relative Feuchte [%] in 2m zum Klimatermin II = 14:00 MOZ
C (gemeint ist damit das Tagesminimum der rel. Feuchte)
C ST astronom. maximal moegliche taegliche Sonnenscheindauer [h]
C TL14 Lufttemperatur [Grad C] in 2m zum Klimatermin II = 14:00 MOZ
C (gemeint ist damit das Tagesminimum der rel. Feuchte)
C **** Output ****
C ETPT Tageswert der potentiellen Verdunstung [mm/d]
C **** Intern ****
C HF "Haude-Faktor"
C SDADR Funktion: berechnet Saetigungsdampfdruck [hPa]
C
C Dimension ST(366)
C HF = 0.018 * ST(J)
C ETPT = HF * SDADR( TL14 ) * ( 1. - RH14 / 100. )
C RETURN
C END
C
C SUBROUTINE PENman2(J, TLT, DT, UT10, RGTSU, S, ST, ETPT)
C Diese Subroutine berechnet den Tageswert der potentiellen
C Verdunstung nach der von Doorenbos & Pruitt (1977) modifizier-
C ten "Ur"-Formel von Penman (1948) in Abhaengigkeit von Lufttemperatur,
C Luftfeuchte, Windgeschwindigkeit und Strahlungsbilanz. Hierbei
C wurden die Modifikationen nach Schroedter (1985) zitiert.
C Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C Literatur:
C Doorenbos, J., and Pruitt, W.O., 1977
C Penman, H.L., 1948.
C Variablenbedeutung und Einheiten:
C **** Input ****
C J Jahrrestag oder Julianisches Datum
C DT Tagesmittel des Dampfdruckes in 2m [hPa]
C RGTSU Tagessumme der Globalstrahlung [J/cm^2]
C TLT Tagesmittel der Lufttemperatur in 2m [Grad C]
C UT10 Tagesmittel der Windgeschwindigkeit in 10m [m/s]
C S gemessene Tages-Sonnenscheindauer [h]
C ST taegliche astronomisch maximal moegliche Sonnen-
C scheindauer [h]
C **** Output ****
C ETPT Tageswert der potentiellen Verdunstung [mm/d]
C **** Intern ****
C C Koeffizient nach Doorenbos & Pruitt (1977)
C F1  ) Funktionen zur Berechnung des langwelligen Anteiles
C F2  ) der Stahlungsbilanz aus Lufttemperatur, Dampfdruck
C F3  ) und Sonnenscheindauer (Gleichungen 5.4.2-6 bis -8 bei
C   ) Schroedter, 1985)
C FW  Windwegfunktion nach Penman (1948)
C H   Hilfsgroesse
C DSDADR  Steigung des Saettigungsdampfdruckes mit der Temperatur
C [hPa/K], wird im vorliegenden Fall nicht analytisch be-
C rechnet, sondern als Differenzenquotient approximiert
C (unter Verwendung von FUNCTION SDADR)
C PSYKO Psychrometer-Konstante [hPa/K]
C RGTMM  RGTSU in mm-Aequivalent
C RNTMM  Tages-Strahlungsbilanz in mm-Aequivalent
C UTB  Tagesmittel der Windgeschwindigkeit in 2m [Beaufort=BFT];
C Berechnung aus m/s in 10m Hohe mittels Invertierung einer
C gaengigen Formel \( m/s = 0.87 \times BFT^{1.44} \). Man beachte, daá
C diese Formel allein schon deshalb nicht besonders gut zur
C Hilfstafel 6 bei Schroedter (1985) passen kann, da die dort
C angegebenen m/s-Werte lediglich jeweils die Untergrenze
C eines m/s-Bereiches darstellen, der einer jeden BFT-Stufe
C zugeordnet wird (DWD-Wetterstation-Unterlagen). Zwischen
C 10m-Wind und 2m-Wind wird im uebrigen die bei Schroedter
C (1985) benutzte Relation 1.3:1 verwendet.
C Ein gewisses, von Schroedter (1985) aber auch vernachlaes-
C sigtes Problem bei dieser Umrechnung von m/s in BFT stellt
C die Nichtlinearitaet der Beziehung dar (verfaelschte
C Mittelbildung ueber den Tag!).
C WIWEG  Tages-Windweg in 2m [km/Tag]. Zu berechnen aus UT10. Zwi-
C schen 10m-Wind und 2m-Wind wird die bei Schroedter
C (1985) benutzte Relation 1.3:1 verwendet.
C
C ----------------------------------------------------------------
C dimension ST(366)
C DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
C PSYKO  = 0.67
C H     = DSDADR / ( DSDADR + PSYKO )
C RGTMM = RGTSU / 250.
C F1    = 1.98E-9 * ( 273. + TLT )**4
C F2    = 0.34 - 0.044 * SQRT( DT )
C F3    = 0.1 + 0.9 * S / ST(J)
C RNTMM = 0.75 * RGTMM - F1 * F2 * F3
C UTB   = ( UT10 / 0.87 )**( 1. / 1.44 )
C WIWEG = 86.4 * ( UT10 / 1.3 )
C FW    = 0.27 * ( 1. + WIWEG / 100. )
C C = 0.79 - 0.034 * UTB + 0.028 * RGTMM
C ETPT  = C *( H * RNTMM + (1. - H) * (SDADR( TLT ) - DT) * FW )
C IF ( ETPT .LT. 0. ) ETPT = 0.
C RETURN
C END

**************************************************************************
SUBROUTINE PENsub (T,rf,N,FFf,gln,EVAP,evapen)
REAL LE,n
data al/0.22/,xm/10./,p/0.29/
C
C BERECHNUNG DER POTENTIELLEN VERDUNSTUNG NACH PENMAN AUS SYNOP-DATEN
C GRUNDLAGE: VERoeffENTLICHERUNGEN VON PENMAN, FAO IRRIGATION
C AND DRAINAGE PAPER NO.24 (CROP WATER REQUIREMENTS),
C REVISED 1977, ROM, S.15FF, ANNALEN D.MET. NR.15 (DT.MET.-
C TAGUNG 1980),
C
C LISTE DER ABKUERZUNGEN UND DIMENSIONEN:
C
C\T\ = LUFTTEMPERATUR \quad (K)\\
C\FF\ = WINDGESCHWINDIGKEIT IN 10 M \quad (M/S)\\
C\N\ = BEDECKUNGSGRAD \quad (ACHTTEL)\\
C\GLN\ = GLOBALSTRAHLUNG BEI N=1...8 \quad (W/M**2)\\
C\BZW.\ = (J/H*CM**2)\\
C\XM\ = MESSHOEHE FUER WIND \quad (M)\\
C\WIND\ = WINDGESCHWINDIGKEIT UMGERECHN.AUF 2 M \quad (M/S)\\
C\SRA\ = RELATIVE SONNENSCHEINDAUER \quad (DIM.LOS)\\
C\SVP\ = SAETTIGUNGSDAMPFDRUCK \quad (MBAR)\\
C\VAP\ = DAMPFDRUCK \quad (MBAR)\\
C\EAED\ = SAETTIGUNGSDEFIZIT \quad (MBAR)\\
C\FU\ = WINDFUNKTION\\
C\DELTA\ = NEIGUNG D.SAETTIGUNGSDAMPFDRUCKKURVE \quad (MBAR/K)\\
C\W\ = TEMPERATURABHAENG. WICHTUNGSFAKTOR \quad (DIM.LOS)\\
C\WI\ = AERODYNAM. TERM D. PENMAN-FORMEL \quad (MM/H)\\
C\LE\ = SPEZIF. VERDUNSTUNGSENTHALPIE \quad Z.UMRECHN. STRAHLG.-MM/D\\
C\FED\ = DAMPFDRUCKFUNKTION \quad ( -'-' - )\\
C\RNL\ = LANGWELL. ANTEIL D.STRAHLUNGSBILANZ \quad (MM/H)\\
C\AL\ = ALBEDO \quad (DIM.LOS)\\
C\LE\ = SPEZIF. VERDUNSTUNGSENTHALPIE \quad ZUR UMRECHNUNG \quad D. STRAHLUNGSSERIE \quad (MM/H)\\
C\XNET\ = NETTOSTRAHLUNG \quad (STRAHLUNGSBILANZ) \quad (MM/H)\\
C\EVAP\ = STUENDLICHE VERDUNSTUNG \quad (POTENTIELLE EVAPOTRANSPIRATION) \quad (MM/H)\\
C\WIND\ = FFF \times (2./XM)**P

C\ABFRAGE FUER ORIGINAL-PENMAN WICHTIG ABER SONST NICHT SINNVOLL
IF(N.GE.9)N=8
IF(N.EQ.8) GOTO 350
IF(N.GT.5) GOTO 300
SRA = 0.95 -(0.1*N)
GOTO 400
300 SRA = 0.45 -(0.15*(N-5.))
GOTO 400
350 SRA = 0.0

400 SVP = sdadr(t)
VAP = rfsv/th/100.
EAED = SVP-VAP
FU = 0.27 \times (1.+(WIND*3600.*24./1000.) /100.)
DELTA = 6.1078 \times (EXP(17.08085\times(T+1.) / (234.175+(T+1.))))-SVP
W = DELTA/(DELTA+0.67)
WI = EAED \times FU \times (1.-W)/24.
LE = (2501.- 2.36\times T) \times 0.1
FT = ((4.898E-7) / LE / 24.) \times (273.15+T)**4
FED = 0.56-0.092 \times VAP**0.5
RNLpen= FT * FED *(0.1+0.9*SRA)
C\PEN KENNZEICHNET ALLE ZEILEN WO NACHTRAEGLICH ORIGINAL -PENMAN
C\VERAENDERT WURDE
EPS=0.965
SIGMA=5.67E-8
CALL GEGEN(T,VAP,N,RH)
C\RH - HIMMELSTRAHLUNG DIE WAHL DER FORMEL WIRD IN LOE.P.GEGEN-
C\STRAHLUNG FESTGELEGT
C\RE = AUSSTRAHLUNG DES BODENS
RE=EPS\times SIGMA\times (T+273.1)**4
C\EVETUELL BESSERE PARAMETRSIERUNG DER BODENAUSSTRAHLUNG
CC\BRUIN UND HOLTSLAG
CC\RE=EPS\times SIGMA\times (T+273.1)**4 + 0.07\times (1.-AL)*GLN
RNL=-RE
C\UMRECHNUNG AUF JOULE PRO CM**2 UND STUNDE UND AUF MM /STUNDE
RNL=RNL*0.36 / LE
C\XNET = (1.-AL) \times (GLN/LE) -RNL
C\XNETPE=(1.-AL)*(GLN/LE)-RNLPEN
XNET  = (1.-AL) * (GLN*0.36/LE) - RNL
XNETPE=(1.-AL)*(GLN*0.36/LE)-RNLPEN
GOTO 500
C HIER KANN DEFINIERT WERDEN, DASS NACH SONNENUNTERGANG KEINE
C STRAHLUNGSBEDINGTE VERDUNSTUNG MEHR AUFTRITT. SONST KOMMEN
C IF(GL0 .LE.0.)EXNET=0.
C BEI NEGATIVEN WERTEN VON XNET INSBESONDERE IM WINTER HAUEFIG
C UNREALISTISCHE KONDENSATIOSNRATEN RAUS
500 EVAP  = XNET * W + WI
EVAPEN=XNETPE*W +WI
900 CONTINUE
1000 CONTINUE
C UMRECHNUNG VON MM/H IN WATT/M**2 ZUR UEBERPRUEFUNG
RNLPEN=RNLPEN*LE/0.36
RNL=RNL*LE/0.36
RETURN
C
C                       EVAP = W * XNET + (1-W) * FU * EAED
C
C                   UEBERARBEITET MAI 1981, ZAMF BRAUNSCHWEIG
C                                                (LOEPMEIER, FRIESLAND)
END
***********************************************************************************
SUBROUTINE SCHENDEL( TLT, RHT, ETPT )
C Diese Subroutine berechnet den Tageswert der potentiellen
C Verdunstung nach einer von Schendel (1968) auf Monatsbasis abge-
C leiteten Formel in Abhaengigkeit von Lufttemperatur und
C Luftfeuchte. Zur Beruecksichtigung der von Monat auf Tag ver-
C kuerzten Zeitskala wurde der von Schendel angegebene Faktor
C 480 durch den Wert 16 ersetzt. (Man beachte die Ahnlichkeit
C mit der Formel von Thornthwaite, 1948, in der von Mintz & Walker,
C 1993, angegebenen Linearisierung - s. Subr. ETP_THO2.FOR -
C oder auch mit der bei Mintz & Walker, 1993, zitierten Formel
C von Smith & Stopp, 1978, - s. Subr. ETP_SMIT.FOR.)
C Achtung: ergaenzzend wird ETPT nach unten durch Null begrenzt.
C Variablenbedeutung und Einheiten:
C **** Input ****
C RHT    Tagesmittel der Luftfeuchte [%]
C TLT    Tagesmittel der Lufttemperatur in 2m [Grad C]
C **** Output ****
C ETPT   Tageswert der potentiellen Verdunstung [mm/d]
C
ETPT = 16. * TLT / RHT
IF ( ETPT .LT. 0. ) ETPT = 0.
RETURN
END
***********************************************************************************
SUBROUTINE SMITH( TLT, ETPT )
C Diese Subroutine berechnet den Tageswert der potentiellen
C Verdunstung in Abhaengigkeit von der Lufttemperatur nach einer
C Mintz & Walker (1993) betonen, daá Smith & Stopp keinerlei Ablei-
C tung zu ihrer Formel angeben. "Gestuetzt" wird diese Formel aber
C durch ihre Verwandtschaft zu der von Mintz & Walker (1993) lineari-
C sierten Formel von Thornthwaite (1948) - s. Subr. ETP_THO2.FOR -
SUBROUTINE THORN(J, TLT, ST, ETPT)
C Diese Subroutine berechnet den Tageswert der potentiellen
C Verdunstung nach einer von Siegert & Schroedter (1975) modifi-
C zierten Formel fuer die monatliche potentielle Verdunstung von
C Thornthwaite (1948) in Abhaengigkeit von der Lufttemperatur sowie
C dem lokalen (= stationsbezogenen) Waermeindex WI.
C In geringfuegiger Abwandlung gegenueber Siegert & Schroedter (1975)
C wird anstelle des dortigen Faktors 'f' im folgenden das Verhaeltnis
C von taeglicher astronomisch moglicher Sonnenscheindauer zur
C "mittleren" maximalen Sonnenscheindauer von 12h verwendet.
C Grund: glatterer Uebergang der Tagesverdunstungswerte beim
C Monatswechsel (insbesondere, wenn meteorologische Bedingungen
C gleichbleibend).
C Ueberdies wird der Exponent A exakt mit den von Thornthwaite (1948)
C angegebenen Koeffizienten berechnet (geringfuegige Unterschiede zu Gl.
C 5.1.1-5 bei Schroedter, 1985).
C W1 ist der sogenannten Waermeindex
C fuer die Thornthwaite-Verdunstungsformel aus den langjahrigen
C Monatsmittelwerten der Lufttemperatur. Damit ist der Waermeindex
C fuer jede interessierende Station gesondert zu berechnen.
C Variablenbedeutung und Einheiten:
C TLM Monatsmitteltemperatur [Grad Celsius]
C WI Waermeindex
C dimension TLM(12),st(366)
data tlm /0.3,0.9,4.0,8.1,13.1,16.1,17.6,17.0,13.8,9.3
*4.7,1.7/
WI = 0.
DO 100 I=1,12
  WI = WI + ( 0.2 * TLM(I) )**1.514
100 CONTINUE
A = 1.E-5 *(0.06751 * WI**3 - 7.711 * WI**2 + 1792.1 * WI + 49239)
ETPT = 0.16 * TLT
IF ( ETPT.LT.0. ) ETPT = 0.
RETURN
END
if(tlt.gt.0) then
ETPT = 0.533 * ( ST(J) / 12. ) * ( 10. * TLT / WI )**A
else
etpt=0.
end if
RETURN
END

*********************************************************************
SUBROUTINE THORN2(j, TLT, ST, ETPT )
C     15.11.95    LETZTE AENDERUNG
C     Diese Subroutine berechnet den Tageswert der potentiellen
C    Verdunstung in Abhaengigkeit von Lufttemperatur und Sonnenschein-
C    dauer nach der von Mintz & Walker (1993) linearisierten Formel von
C    Thornthwaite (1948).
C     Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C     Literatur:
C    Thornthwaite, C.W., 1948.
C     Variablenbedeutung und Einheiten:
C     **** Input ****
C    ST  maximal moegliche Sonnenscheindauer [h]
C    TLT         Tagesmittel der Lufttemperatur in 2m [Grad C]
C     **** Output ****
C    ETPT        Tageswert der potentiellen Verdunstung [mm/d]
C     ----------------------------------------------------------------
dimension ST(366)
ETPT = 0.17 * TLT * ST(j) / 12.
IF ( ETPT .LT. 0. ) ETPT = 0.
RETURN
END

*********************************************************************
SUBROUTINE TURC( TLT, RGTSU, DT, ETPT )
C     Diese Subroutine berechnet den Tageswert der potentiellen
C    Verdunstung nach einer Formel von Turc (1961) in Abhaengigkeit
C    von Lufttemperatur, Taupunkt und Globalstrahlung. Letztere
C    wird als Tagesmittel in cal/(cm**2 * d) benoetigt und muss daher
C    aus der in J/cm**2 gegebenen Tages s u m m e  umgerechnet werden.
C    A c h t u n g: die von Turc (1961) vorgeschlagene Korrektur KFAK zur
C    Beruecksichtigung der Luftfeuchte wird im folgenden zu Testzwecken
C    beibehalten (vgl. auch Schroedter, 1985), auch wenn Turc (1961)
C    ausdruecklich darauf hinwies, dass KFAK nur auf monatlicher Basis
C    gelten soll. KFAK macht die Anwendung der TURC-Formel unhandlich, da
C    KFAK anders als der uebrige Formel-Input nicht aus tagesbezogenen
C    Daten bereitzustellen ist (sondern nur aus mindestens stuedlich
C    aufgelosten Daten). Da nach Turc (1961) KFAK ohnehin nur in
C    wuestenartigen Gegenden von merkbarer Bedeutung ist, wurde im nach-
C    folgenden Programm die Moeglichkeit zur Abschaltung von KFAK (d.h
C    zum Setzen von KFAK = 1) vorgesehen, indem DT mit -9.9 vorgegeben
C    wird.
C     Literatur:
C     Variablenbedeutung und Einheiten:
C    DT          Tagesmittel des Dampfdruckes [hPa]
C    ETPT        Tageswert der potentiellen Verdunstung [mm/d]
C    KFAK        Korrekturglied zur Beruecksichtigung der Luftfeuchte
C    RGT         Tagesmittel der Globalstrahlung [cal/cm**2 * d]
C    RGTSU       Tagessumme der Globalstrahlung [J/cm**2]
C    TLT         Tagesmittel der Lufttemperatur in 2m [Grad C]
C     ----------------------------------------------------------
REAL KFAK
RGT = RGTSU / 4.187
IF ( DT .NE. -9.9 ) THEN
   RF = DT / SDADR( TLT)*100.
   IF ( RF .GT. 50. ) RF = 50.
   KFAK = 1. + ( 50. - RF ) / 70.
ELSE
   KFAK = 1.
END IF
ETPT = KFAK * 0.0133 * ( RGT + 50. ) * TLT / ( TLT + 15. )
RETURN
END
*************************************************************************
SUBROUTINE WENDLING( XK, TLT, RGTSU, ETPT )
C Diese Subroutine berechnet den Tageswert der potentiellen
C Verdunstung nach einer von Wendling et al. (1991) aus der Penman-
C Monteth-Gleichung (fuer potentielle Verdunstung: r_c==0) abgelei-
C teten Formel in Abhaengigkeit von Lufttemperatur und Globalstrahlung.
C Hinweis 1:
C Bei dieser Formel handelt es sich um eine Formel vom gleichen Typ
C wie die von TURC (1961). Allerdings besitzt sie gegenueber der TURC-
C Formel den entscheidenden Vorteil, in der Regel (d.h. solange
C Lufttemp. TLT > -22 Grad C) auch im Winter anwendbar zu sein!
C Fuer tiefere Temperaturen tritt folgende Sonderregel in Kraft:
C entsprechend einer diesbezgl. Anmerkung in Wendling et al.
C (1991, S. 474 links oben) wird fuer die Tagesverdunstung ein Mindest-
C wert von 0.1 mm/d angesetzt.
C Literatur:
C -=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=]
C Achtung: keine der drei hier zitierten Wendling-Arbeiten stimmt mit
C einer der anderen beiden in allen Koeffizienten ueberein! Es
C wurden daher fuer den Programmm-Code die Koeffizienten
C der juengsten Arbeit (= Wendling & Mueller-Westermeier)
C verwendet.
C Variablenbedeutung und Einheiten:
C **** Input ****
C J  Jahrestag oder Julianisches Datum
C K  Korrektur zur Beruecksichtigung des Kuesteneinflusses
C (K=0.5 an der Kueste, ansteigend auf 1 bis zu einer
C Kuestenentfernung von 50 km)
C TLT  Tagesmittel der Lufttemperatur in 2m [Grad C]
C RGTSU  Tagessumme der Globalstrahlung [J/cm2]
C **** Output ****
C ETPT  Tageswert der potentiellen Verdunstung [mm/d]
C ----------------------------------------------------------
ETPT = ( RGTSU + 93. * XK ) * ( TLT + 22. ) / *
    ( 150. * ( TLT + 123. ) )
IF ( ETPT .LT. 0.1 ) ETPT = 0.1
RETURN
END
### kc values for Citrus (grown in predominantly dry areas with light to moderate wind)

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<tr>
<th></th>
<th>Jan</th>
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J. Doorenbos and W. O. Pruitt: Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper no. 24, Rome 1977
### kc values for full grown deciduous fruit and nut trees

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*kc values need to be increased if frequent rain occurs

J. Doorenbos and W. O. Pruitt: Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper no. 24, Rome 1977
Crop factors $f$ as related to Makkink reference - crop evapotranspiration (PET)

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Plant factors (f) acc. to HAUDE

HAUDE formula: $\text{PET} = f \times \text{SD14h}$  
( SD14h = saturation deficit at 14 h)

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Daily basal kc for dry surface soil conditions (arid region)
reference: well-watered alfalfa on lysimeter

### a kc according to time from planting to effective cover

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<th>30%</th>
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<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
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### b kc according to days after effective plant cover

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<th>60</th>
<th>70</th>
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<td>1.00</td>
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<td>0.91</td>
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<td>1.00</td>
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### Seasonal consumptive use coefficients, $k_c$, for irrigated crops in Western United States
(values for Blaney-Criddle formula)

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<td>Cereals</td>
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<tr>
<td>Grass</td>
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<tr>
<td>Potatoes</td>
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<tr>
<td>Rice</td>
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<tr>
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Crop coefficients (examples for Italy) for PET

### winter wheat

Crop coefficients for the period following winter dormancy:

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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.90</td>
<td>0.70</td>
</tr>
</tbody>
</table>

### spring wheat

Crop coefficients for a 150 day wheat variety from the emergence stage:

<table>
<thead>
<tr>
<th>decade=</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kc</td>
<td>0.30</td>
<td>0.30</td>
<td>0.40</td>
<td>0.70</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.90</td>
<td>0.80</td>
<td>0.70</td>
<td>0.50</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

### maize

Crop coefficients for growing cycles of different lengths:

| decade=  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |10  |11  |12  |13  |14  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|
| 100 days | 0.30| 0.60| 0.90|1.10 |1.20 |1.10 |1.0  |0.80 |0.70 |0.50|
| 120 days | 0.30| 0.60| 0.90|1.0  |1.10 |1.20 |1.20 |1.10 |0.80 |0.70 |0.50|
| 140 days | 0.30| 0.60| 0.80|0.90 |1.0  |1.10 |1.20 |1.20 |1.10 |1.0 |0.80 |0.70 |0.60|0.50|

### Preliminary crop coefficients for vegetables (Forschungsstelle Geisenheim)

**kc dependent on development stage, \((AET = PET(Penman) \times kc)\)**

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>cauliflower</td>
<td>from planting</td>
<td>diam. 30 cm</td>
<td>diam. 70 cm</td>
<td>height &gt; 60 cm</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>broccoli</td>
<td>from planting</td>
<td>&gt; 4th leaf</td>
<td>&gt; 8th leaf</td>
<td>&gt; 12th leaf</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>bush beans</td>
<td>from emergence</td>
<td>&gt; 6th leaf</td>
<td>from pod developm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>chinese cabbage</td>
<td>from planting</td>
<td>&gt; 5th leaf</td>
<td>canopy closed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>cucumbers</td>
<td>from emergence</td>
<td>begin of flowering</td>
<td>begin of harvest</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>endives</td>
<td>from planting</td>
<td>&gt; 6th leaf</td>
<td>&gt; 8th leaf</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>tomatoes</td>
<td>from planting</td>
<td>height &gt; 0,75 m</td>
<td>height &gt; 1,0 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>potatoes (early)</td>
<td>from planting</td>
<td>first shoots</td>
<td>main leaf developm.</td>
<td>canopy closed</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>green cabbage</td>
<td>from planting</td>
<td>&gt; 6th leaf</td>
<td>&gt; 10th leaf</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>grain-maize</td>
<td>from emergence</td>
<td>height &gt; 0,5 m</td>
<td>height &gt; 1,0 m</td>
<td>height &gt; 1,5 m</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>kohlrabi</td>
<td>from planting</td>
<td>&gt; 5th leaf</td>
<td>bulb daim. 2 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>headed cabbage</td>
<td>from planting</td>
<td>&gt; 7th leaf</td>
<td>&gt; 10th leaf</td>
<td>begin of bulb devel.</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>lettuce</td>
<td>from planting</td>
<td>diam. &gt; 15 cm</td>
<td>&gt; diam. 25 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>carrots</td>
<td>from emergence</td>
<td>&gt; 4th leaf</td>
<td>&gt; 7th leaf</td>
<td>canopy closed</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>leek</td>
<td>from planting</td>
<td>diam. shaft &gt; 1 cm</td>
<td>diam. shaft &gt; 1,6 cm</td>
<td>diam. shaft &gt;2 cm</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>broad beans</td>
<td>from emergence</td>
<td>height &gt; 10 cm</td>
<td>begin of flowering</td>
<td>pods visible</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>brussels sprouts</td>
<td>from planting</td>
<td>&gt; 5th leaf</td>
<td>canopy closed</td>
<td>sprout initials</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>beetroot</td>
<td>from emergence</td>
<td>&gt; 4th leaf</td>
<td>&gt; 8th leaf</td>
<td>canopy closed</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>asparagus</td>
<td>from end of cutting</td>
<td>from complete devel.</td>
<td>from September</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>celery</td>
<td>from planting</td>
<td>&gt; 6th leaf</td>
<td>begin of tuber devel.</td>
<td>canopy closed</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.8</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>spring cereals</td>
<td>from emergence</td>
<td>canopy closed</td>
<td>begin of hard dough</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>0.8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>onions (summer)</td>
<td>from emergence</td>
<td>&gt; 4th leaf</td>
<td>&gt; 6th leaf</td>
<td>from middle of</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.0</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>potatoes (late)</td>
<td>from planting</td>
<td>first shoots</td>
<td>main leaf developm.</td>
<td>canopy closed</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>0.6</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>spinach (spring)</td>
<td>from emergence</td>
<td>&gt; 3th true leaf</td>
<td>&gt; 6th leaf</td>
<td></td>
</tr>
</tbody>
</table>
Crop coefficient (kc) for field and vegetable crops for different stages of crop growth and prevailing climatic conditions

<table>
<thead>
<tr>
<th>Crop</th>
<th>Humidity</th>
<th>RHmin</th>
<th>&gt;70%</th>
<th>RHmin</th>
<th>&lt;20%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wind [m/s]</td>
<td>0 - 5</td>
<td>5 - 8</td>
<td>0 - 5</td>
<td>5 - 8</td>
</tr>
<tr>
<td></td>
<td>0.5 0.8 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.2 0.4 0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from emergence</td>
<td>&gt; 4th leaf canopy closed</td>
<td>&gt; 12 cm beet diam.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>acc. to Paschold &amp; Zengele, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

annex 5

J. Doorenbos and W. O. Pruitt: Guidelines for predicting crop water requirements. FAO
Irrigation and Drainage Paper no. 24, Rome 1977

Crop stages:
3 = mid season
4 = at harvest or maturity
### Annex 5

**Plant factors (f) for calculation of PET acc. to Penman**

#### Winter wheat:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Feb.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Mar.</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Apr.</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>Tillering</td>
<td>0.81</td>
<td>0.70</td>
</tr>
<tr>
<td>Stem elongation - heading</td>
<td>sin (0.81 - &gt; 1.30)</td>
<td>0.92 / 1.20</td>
</tr>
<tr>
<td>Heading - end of flowering</td>
<td>1.30</td>
<td>1.20 / 1.30</td>
</tr>
<tr>
<td>End of flowering - hard dough</td>
<td>sin (1.30 - &gt; 0.95)</td>
<td>1.10 / 0.95</td>
</tr>
<tr>
<td>Hard dough - harvest</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Harvest - Aug.</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Sep.</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>Oct.</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
</tbody>
</table>

#### Spring wheat:

<table>
<thead>
<tr>
<th>Time</th>
<th>Rötzer (1996) f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>0.30</td>
</tr>
<tr>
<td>Feb.</td>
<td>0.30</td>
</tr>
<tr>
<td>Mar. - emergence</td>
<td>0.35</td>
</tr>
<tr>
<td>Emergence - heading</td>
<td>sin (0.35 - &gt; 1.35)</td>
</tr>
<tr>
<td>Heading - end of flowering</td>
<td>1.35</td>
</tr>
<tr>
<td>End of flowering - hard dough</td>
<td>sin (1.35 - &gt; 0.95)</td>
</tr>
<tr>
<td>Hard dough - harvest</td>
<td>0.95</td>
</tr>
<tr>
<td>Harvest - begin of green manure</td>
<td>0.70</td>
</tr>
<tr>
<td>Begin of green manure - Aug.</td>
<td>1.15</td>
</tr>
<tr>
<td>Sep.</td>
<td>0.85</td>
</tr>
<tr>
<td>Oct.</td>
<td>0.70</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.40</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.40</td>
</tr>
</tbody>
</table>

#### Silage maize:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Feb.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Mar.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Apr. - emergence</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Emergence - flag leaf em.</td>
<td>sin (0.4 - &gt; 1.05)</td>
<td>0.55 / 0.70 / 0.85</td>
</tr>
<tr>
<td>Flag leaf em. - end of flowering</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>End of flowering - harvest</td>
<td>sin (1.05 - &gt; 0.70)</td>
<td>0.90 / 0.70</td>
</tr>
<tr>
<td>Harvest - Oct.</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.30</td>
<td>0.30</td>
</tr>
</tbody>
</table>
H. Ernstberger: Einfluß der Landnutzung auf Verdunstung und Wasserbilanz, 1987
<table>
<thead>
<tr>
<th>Model / Vers. no. (country)</th>
<th>AMBAV / 7.96 (Germany)</th>
<th>IRRFIB-1 / 1.0 (Slovenia)</th>
<th>SISETA / - (Slovakia)</th>
<th>BIDRICO 2 / 2.0 (Italy)</th>
<th>Beregeningsplanner / 2.0 (Netherlands)</th>
<th>BEREST / 90.4 (Germany)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Franz.-Josef Löpmeier</td>
<td>Iztok Matasc</td>
<td>V. Sláma</td>
<td>Danuso/Giovanardi 1)</td>
<td>Opticrop B. V.</td>
<td>FZB Müncheberg (GDR), now ZALF Müncheberg</td>
</tr>
<tr>
<td>Institution</td>
<td>German Weather Service Agromet. Research Station</td>
<td>Hydrometeorological Institute of Slovenia</td>
<td>Research Institute of Irrigation</td>
<td>Dipart. di Prod. Veget. 2) ERSA F.V. G 1)</td>
<td>Opticrop B. V.</td>
<td>FZB Müncheberg (GDR), now ZALF Müncheberg</td>
</tr>
<tr>
<td>Address</td>
<td>Bundesallee 50 38116 Braunschweig Germany</td>
<td>Vojkova 1/b 1000 Ljubljana Slovenia</td>
<td>Vrakunšká 29 825 63 Bratislava Slovakia</td>
<td>Via delle Scienze 208 33100 Udine Italy</td>
<td>P.O. Box 34 2140 AA Vyhuizen Netherlands</td>
<td>Eberswalder Str. 84 15374 Müncheberg Germany</td>
</tr>
<tr>
<td>Contact person</td>
<td>Franz.-Josef Löpmeier</td>
<td>Iztok Matasc</td>
<td>Vincent Cislák</td>
<td>Danuso</td>
<td>Wim Nugteren</td>
<td>Karl-Otto Wenkel Wilfried Mirschel</td>
</tr>
<tr>
<td>Programming language</td>
<td>FORTRAN 77</td>
<td>DELPHI</td>
<td>Excel + Visual Basic</td>
<td>TURBOBASIC</td>
<td>QBasic (DOS) Visual Basic (Windows)</td>
<td>Turbo-Pascal</td>
</tr>
<tr>
<td>Documentation or manual language (pages)</td>
<td>German or English (12 p.)</td>
<td>Slovene or English (5p.)</td>
<td>Slovak (10p.)</td>
<td>Italian or English (~150p)</td>
<td>Dutch (45p.) German (54 p.)</td>
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</tr>
<tr>
<td>Availability</td>
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<td>no/yes</td>
<td>no/yes</td>
<td>no/yes</td>
<td>no / yes</td>
<td>no/yes</td>
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<tr>
<td>Hardware requirements</td>
<td>PC 386 at least</td>
<td>PC 386 at least</td>
<td>PC AT/Pentium</td>
<td>PC 80286 or higher</td>
<td>PC 286 at least</td>
<td>PC 286 at least</td>
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<tr>
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<td>WINDOWS 3.x</td>
<td>WINDOWS 95 WINDOWS NT</td>
<td>DOS</td>
<td>DOS/WINDOWS 3.11 WINDOWS 95</td>
<td>DOS</td>
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<td>Minimum RAM</td>
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<td>512 KB</td>
<td>640 KB</td>
<td>480 KB</td>
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<td>Disc space required</td>
<td>8 MB</td>
<td>2 MB</td>
<td>?</td>
<td>5 MB</td>
<td>2 MB</td>
<td>720 KB</td>
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<td>Recommended user</td>
<td>local met. advisory service / farmers</td>
<td>local met. advisory service / farmers</td>
<td>? central or local met. advisory service / farmers</td>
<td>local met. advisory service / farmers</td>
<td>local met. advisory service / farmers</td>
<td>local met. advisory service / farmers</td>
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</table>
Table 2: Characteristic of fundamental meteorological processes and meteorological input requirements of available irrigation models within the COST 711 member countries

<table>
<thead>
<tr>
<th>Model /Vers. no. (country)</th>
<th>AMBAV / 7.96 (Germany)</th>
<th>IRRFIB-1 / 1.0 (Slovenia)</th>
<th>SISETA / - (Slovakia)</th>
<th>BIDRICO 2 / 2.0 (Italy)</th>
<th>Beregeningsplanner /2.0 (Netherlands)</th>
<th>BEREST / 90.4 (Germany)</th>
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<tr>
<td>fundamentals</td>
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<td></td>
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<tr>
<td>process method</td>
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<td></td>
<td></td>
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<tr>
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<td>ETPcrop</td>
<td>actual ETcrop</td>
<td>actual ETcrop</td>
<td>actual ETcrop</td>
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<td>ASCII</td>
<td>ASCII</td>
<td>ASCII</td>
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<td>ASCII</td>
</tr>
<tr>
<td>variable / unit / time resolution / type</td>
<td>air temperature / °C 1h / average</td>
<td>air temperature dry / °C 1 day / average 7, 14, 21 o’clock</td>
<td>air temperature / °C 1 week / diurnal average</td>
<td>min. air temp. dry / °C 1 day / minimum</td>
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<td></td>
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<tr>
<td></td>
<td>rel. humidity / % 1h / average</td>
<td>rel. air humidity / % 1 day / average 7, 14, 21 o’clock</td>
<td>saturation deficit / ? 1 week / diurnal average</td>
<td>reference ET0 / mm 1 day / daily sum</td>
<td>evaporation / mm 1 day / daily sum ET0 / mm 1 day / daily sum</td>
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</tr>
<tr>
<td></td>
<td>global radiation / W m⁻² 1h / sum</td>
<td>sunshine duration / h 1 day / daily sum</td>
<td>wind velocity / m s⁻¹ 1 h / average</td>
<td>wind velocity / m s⁻¹ 1 day / average 7, 14, 21 o’clock</td>
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<tr>
<td></td>
<td>precipitation / mm 1h / sum</td>
<td>precipitation / mm 1 day / daily sum at 7 o’clock</td>
<td>precipitation / mm 1 week / diurnal average</td>
<td>precipitation / mm 1 day / daily sum</td>
<td>precipitation / mm 1 day / daily sum</td>
<td>precipitation / mm 1 day / daily sum</td>
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<td>cloud cover / octas 1h / moment observation</td>
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<tr>
<td>use of weather forecast data</td>
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<td>possible up to 7 days</td>
<td>?</td>
<td>not possible</td>
<td>possible up to 5 days</td>
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<td>AMBAV / 7.96 (Germany)</td>
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<td>SISETA / - (Slovakia)</td>
<td>BIDRICO 2 / 2.0 (Italy)</td>
<td>Beregeningsplanner /2.0 (Netherlands)</td>
<td>BEREST / 90.4 (Germany)</td>
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<tr>
<td>process method</td>
<td>water balance / water fluxes</td>
<td>water balance capacity approach</td>
<td>water balance capacity approach</td>
<td>water balance capacity approach</td>
<td>water balance potential approach (?)</td>
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<td>driving variables</td>
<td>Richard’s equation</td>
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<td>ETPcrop, precipitation</td>
<td>ETPcrop, precipitation, irrigation</td>
<td>ET, precipitation, irrigation, groundwater level</td>
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<td>parameters</td>
<td>pF-curves, hydraulic conductivity</td>
<td>field capacity, wilting point, saturation percentage of available water, irrigation amounts</td>
<td>available water capacity percentage of available water, irrigation amounts</td>
<td>field capacity, wilting point, water table soil moisture, easily avail. water (EAW), water deficit, EAW depletion time, runoff, percolation, capillary rise, irrigation amounts and schedule</td>
<td>pF-curves, hydraulic conductivity ?</td>
<td></td>
</tr>
<tr>
<td>final output</td>
<td>water balance / water fluxes</td>
<td>ETPcrop, precipitation</td>
<td>ETPcrop, precipitation</td>
<td>ETA, soil water contents, water fluxes, irrigation amounts and schedule</td>
<td>ETA, soil water contents, water fluxes, irrigation amounts</td>
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<td>variable / unit</td>
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<td>light-middle-heavy soil/ -</td>
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<td>2 m / ? initial input</td>
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</tr>
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<td>initial input</td>
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<td>initial input</td>
<td>initial input</td>
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</tr>
<tr>
<td>water cont. / %</td>
<td>field capacity / vol %</td>
<td>field capacity / g g⁻¹</td>
<td>max. explor.depth / 2 l. initial input</td>
<td>field capacity / mm</td>
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<td>2 m 21 layers</td>
<td>root depth / 1 layer</td>
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<td>initial input</td>
<td>2 m / ? initial input</td>
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<td>initial/permanent inp.</td>
<td>initial input</td>
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<td>initial input</td>
<td>initial input</td>
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<tr>
<td>root distribution / %</td>
<td>bulk density / g cm⁻³</td>
<td>gravel content / g g⁻¹</td>
<td>max. explor.depth / 2 l. initial input</td>
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<td>initial input</td>
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<tr>
<td>2 m 21 layers</td>
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<td>max. explor.depth / 2 l. initial input</td>
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<td>% soil evaporation of ET</td>
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<td>soil classification acc. to &quot;Starinfg reeks&quot;</td>
<td>soil classification acc. to &quot;regional site type&quot;</td>
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<td>standing water at soil surface initial value</td>
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<td>water table/cm below gr. periodic, every 14 days</td>
<td>water table/dm bel. gr initial input</td>
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<td>crop specific ET</td>
<td>crop specific ET</td>
<td>root depth / crop yield response, crop spec. ET yield</td>
<td>plant development / root depth/water requirements standard dev. stages/ max. effective root depth opt. and max. pF</td>
<td>root depth / crop spec. ET water requirements stand. curves ontogenesis, soil cover,crop spec. coeff ontogenesis, draught sensitivity, soil cover rooting depth, irrigation demand</td>
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<td>plant specific coeff</td>
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<td>emergence date</td>
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<td>day - month</td>
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<td>soil coverage</td>
<td>development stages</td>
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<td>development stages</td>
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<td>elapsed time</td>
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<td>initial input</td>
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</tr>
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<td>max. rooting depth</td>
<td>initial input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>crops covered</strong></td>
<td>sugar beet, maize, wheat, w. barley, rye, oats, potatoes, pasture, fruit trees, coniferous forest, deciduous forest</td>
<td>sugar beet, maize, potatoes, pasture, alfalfa, apples, peaches, pears, apricots, cherries, plums, kiwi, strawberries, cabbage, tomatoes, salads, endives, cucumber, cauliflower, beets, onions</td>
<td>sugar beet, maize, wheat, barley, rye, pasture, alfalfa, soybean, sunflower, rape, hop, peas, beans, lentil, apples, grape, cabbage, tomatoes, pepper</td>
<td>sugar beet, maize, wheat, potatoes, soybean, sunflower, grape</td>
<td>all crops (grass, arable and vegetable)?</td>
<td>9 cereals, 10 legume crops, 10 oil crops, 39 vegetables, 9 root crops, 26 fodder crops, 7 medical and herb crops, 2 fibre crops, 8 fruit trees, 6 grasland types, 10 field gras crops</td>
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</tbody>
</table>
Table 5: Accessability on parameter sets and reference of irrigation models within the COST 711 member countries

*(means the possibility of a user to make local adjustments of parameter sets)*

<table>
<thead>
<tr>
<th>Model / Vers. no.</th>
<th>AMBAV / 7.96 (Germany)</th>
<th>IRRFIB-1 / 1.0 (Slovenia)</th>
<th>SISETA / - (Slovakia)</th>
<th>BIDRICO 2 / 2.0 (Italy)</th>
<th>Beregeningsplanner / 2.0 (Netherlands)</th>
<th>BEREST / 90.4 (Germany)</th>
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<tr>
<td>included in program code (fixed)</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>input by dialogue</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
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</tr>
<tr>
<td>included in program code (fixed)</td>
<td>-</td>
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<td>?</td>
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<td>-</td>
<td>+</td>
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<tr>
<td>input by dialogue</td>
<td>+</td>
<td>-</td>
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<td>+</td>
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<td>-</td>
</tr>
<tr>
<td>separate parameter file (file format)</td>
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<td>ASCII</td>
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</tr>
<tr>
<td>included in program code (fixed)</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>-</td>
<td>-</td>
<td>+ (default)</td>
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<tr>
<td>input by dialogue</td>
<td>+</td>
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<td>+</td>
<td>+</td>
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</tr>
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Table 6: Sources of other evapotranspiration models

<table>
<thead>
<tr>
<th>Model</th>
<th>Contact person</th>
<th>Adress</th>
<th>Availability/ price</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>BIGSIM</td>
<td>J. E. Ayars</td>
<td>Water Management Research Lab., 2021 South Peach Ave., Fresno CA 93727-5951 / USA</td>
<td>free of charge</td>
<td>Ayars &amp; Schoneman (1986)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phone: +1 209 453-3100 FAX : +1 209 453-3122 e-mail: <a href="mailto:JAyars@asrr.arsusda.gov">JAyars@asrr.arsusda.gov</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>phone: +39 6 52253818 FAX: +39 6 52256275 e-mail: <a href="mailto:Martin.Smith@fao.org">Martin.Smith@fao.org</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWR - VB</td>
<td>D. Clarke</td>
<td>Inst. of Irrigation Studies, Univ. of Southampton, Southampton SO17 1BJ / UK</td>
<td>exe file on request</td>
<td>Clarke &amp; El-Askari (1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phone: +44 1703 593728 FAX : +44 1703 677519 e-mail : <a href="mailto:DC@soton.ac.uk">DC@soton.ac.uk</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMS</td>
<td>T. Hess</td>
<td>Dept. of Water Management Cranfield Univ., Silsoe College Silsoe, Bedford, MK45 4DT / UK</td>
<td>exe file £ 150.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>phone: +44 1525 863292 FAX : +44 1525 863300 e-mail: <a href="mailto:T.Hess@cranfield.ac.uk">T.Hess@cranfield.ac.uk</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citrus Irrigation Scheduling</td>
<td>D. Ayers</td>
<td>Univ. of Florida, PO Box 110340 Gainesvile, FL 32611-0340 / USA</td>
<td>exe file 35.00 US$</td>
<td>Zazuata (1995)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phone: +1 904 392 7853 FAX: +1 904 392 3856 e-mail: <a href="mailto:softsub@gnv.ifas.ufl.edu">softsub@gnv.ifas.ufl.edu</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWBACROS</td>
<td>C. Babajimopoulos</td>
<td>Dept. of Hydraulics, Soil Sci. &amp; Agric. Engineering, School of Agriculture, Aristotle University Thessaloniki 540 06 / Greece FAX: +30 31 998767 e-mail: <a href="mailto:babajim@olymp.ccf.auth.gr">babajim@olymp.ccf.auth.gr</a></td>
<td>exe file for qualified users for cost of reproduction, manual, shipping and handling</td>
<td>Babajimopoulos et al. (1995)</td>
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</tbody>
</table>
AMBAV
version 28.12.00

Short model description
The program AMBAV (engl. version: AMBAVE.EXE) calculates the potential and real evapotranspiration as well as the soil water contents of single soil layers for 13 different cultures. Basis of this scheme is the Penman-Monteith equation. This actual version is additionally meant for irrigation recommendations. An automatical irrigation within the model calculation may be predefined.

*****************************************************************

Input files

AMBAV.STA

parameters:
1. line: LSTEU (I2)
2. line: INPUT DIRECTORY (max. A40)
3. line: OUTPUT DIRECTORY (max. A40)
4. line: YEAR (I4)
5. line: STATION; JTBEG; JTEND; STATIONB; IZWI; KULTUR;
   CBODART; DUWU; ISTEU; NWA; IOUT; NAUS; ISTWU; NFKMAX;
   GRENZNFK; JTBDR; RRBER; IUHRBER; BERDAUER
6. line: etc.

format: free format, (STATION, STATIONB, KULTUR and CBODART as character)

meaning of parameters:
   LSTEU = 0 (fixed)
   STATION = station number
   JTBEG, JTEND = julian day of begin and of end of calculations
   STATIONB = number of meteorological basic station
   IZWI = rules the reading of start data:
          0 = reading from start data file ...BOD
          1 = reading from interim-file ...ZWI
   KULTUR = crop chosen (2 digits):
          01 = winter wheat
          02 = spring wheat
          03 = winter barley
          04 = maize
          05 = spring barley
          06 = sugar beet
          07 = food potatoes
          08 = rye
          09 = coniferous forest
          10 = deciduous forest
          11 = fruit trees
12 = oilseed rape
13 = grassland
41 = starch potatoes
CBODART = soil type
e.g.: 'SL2', 'LS2' etc. (see table page 7)
DUWU = rooting depth
ISTEU = rules output parameters for file AMB_year.station
1 = sum of potential evapotranspiration for a period wanted (mm)
2 = sum of real evapotranspiration for a period wanted (mm)
3 = sum of water flow in the IOUT layer chosen (mm)
4 = sum of water flow within the rooting zone (%)
5 = layer of rooting depth
8 = water content till 10 cm (mm)
9 = water content till 100 cm (mm)
11 = number of wetness hours for > 20 % leaf area
12 = number of wetness hours for > 0.01 % leaf area
13 = daily amount of interception water (mm)
31 = leaf area index (m**2/m**2)
32 = roughness length (m)
35 = crop resistance at 12 a.m. (s/m)
36 = plant resistance (s/m)
41 = potential evapotranspiration at 12 a.m. (mm/h)
42 = radiation balance at 12 a.m. (W/m**2)
NWA = number of soil layers of 10 cm thickness (NWA < 20)
IOUT = layer for leakage calculations (< NWA)
NAUS = output interval (days)
ISTWU = rules output of root distribution
0 for BEKLIMA module
1 for STICK module (winter cereals only)
NFKMAX = maximum percentage of available water after irrigation
GRENZNFK = percentage of available water to start with irrigation
JTABER = Julian day of irrigation (if 999 set, automatical irrigation within the model)
RRBER = amount of irrigation (mm)
IUHRBER = hour of begin of irrigation
BERDAUER = duration of irrigation (h)
------------------------------------------------------------------------------------------------
further input files:

AMBAV.DAT (in main directory)
(contains plant parameters for the cultures 1 to 13 in columns).

parameters
1. line: maximum crop height (m) (13F5.2)
2. line: minimum crop height (m) (13F5.2)
3. line: maximum leaf area index (13F5.2)
4. line: albedo (13F5.2)
5. line: minimum leaf area index (13F5.2)
6. line: maximum rooting depth (cm) (13F4)
...

PHAAM_year.station
(contains the phenological data for the crops 1 to 13 and has to be held in the main directory of AMBAV)
parameters: 

1st line: julian day of seedling emergence (JT_s)

2nd line: julian day of beginning water uptake (JT_z)

3rd line: julian day of maximum water use (JT_max)

4th line: julian day of begin of reducing water use (JT_r)

5th line: julian day of harvesting (JT_e)

The julian days are coupled to phenology according to the following table. (The correcting figures in brackets are accounted for internally). If the phenological stages are not yet reached within the actual year, realistic values should be put in (e.g. of the year before). Because of the change to winter cereals, the file has to be renewed in autumn.

KOORD.DAT (in input directory)

The file contains the station-IDs and its location with geographical latitude, longitude. New locations have to be added in this list before simulation.

parameters: KEN, LKEN, Stationb, GEOL, GEOBR, H, DAT, STATIONB, NAM

format: I3, I1X, I2, I3, I1X, I4, I1X, I4, 10X, I8, 6X, I3, 2X, A20

meaning of parameters:

KEN = internal ID (dummy, may be blank)

LKEN = country ID (dummy, may be blank)

Stationb = Station ID

GEOL = longitude (1/10 degree)

GEOBR = latitude (1/10 degree)

H = altitude (m)

DAT = date (dummy, may be blank)

Stationb = station ID

NAM = name of the station
<table>
<thead>
<tr>
<th>Season</th>
<th>Plant</th>
<th>winter wheat</th>
<th>spring wheat</th>
<th>winter barley</th>
<th>maize</th>
<th>spring barley</th>
<th>sugar beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>JT_0</td>
<td>1 or emergence</td>
<td>emergence (+5)</td>
<td>stem elongation (-5)</td>
<td>1 or emergence</td>
<td>emergence</td>
<td>emergence (+5)</td>
<td>emergence (+5)</td>
</tr>
<tr>
<td>JT_1</td>
<td>stem elongation (-5)</td>
<td>stem elongation (-10)</td>
<td>stem elongation (-10)</td>
<td>flag leaf emergence (-35)</td>
<td>stem elongation (-5)</td>
<td>canopy closed (-20)</td>
<td></td>
</tr>
<tr>
<td>JT_max</td>
<td>flowering (-5)*</td>
<td>inflorescence emergence (+5)</td>
<td>flowering *</td>
<td>flowering *</td>
<td>inflorescence emergence (-5)</td>
<td>hard dough harvest</td>
<td></td>
</tr>
<tr>
<td>JT_2</td>
<td>hard dough</td>
<td>hard dough</td>
<td>hard dough</td>
<td>dough stage (-14)</td>
<td>hard dough</td>
<td>harvest</td>
<td></td>
</tr>
<tr>
<td>JT_v</td>
<td>harvest</td>
<td>harvest</td>
<td>harvest</td>
<td>harvest</td>
<td>harvest</td>
<td>harvest</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Season</th>
<th>Plant</th>
<th>potatoes</th>
<th>rye</th>
<th>conif. forest</th>
<th>decid. forest</th>
<th>fruit trees</th>
<th>oilseed rape</th>
<th>grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>JT_0</td>
<td>emergence (+5)</td>
<td>emergence</td>
<td>emergence</td>
<td>May shoot</td>
<td>60 leaf emergence</td>
<td>60 flowering</td>
<td>emergence</td>
<td>phenological stages are internally set</td>
</tr>
<tr>
<td>JT_1</td>
<td>emergence (+15)</td>
<td>emergence</td>
<td>stem elongation</td>
<td>May shoot (+14)</td>
<td>leaf emergence</td>
<td>flowering (+14)</td>
<td>stem elongation</td>
<td>begin of flowering</td>
</tr>
<tr>
<td>JT_max</td>
<td>canopy closed (+5)</td>
<td>inflorescence</td>
<td>emergence (+5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JT_v</td>
<td>wilting (+16)</td>
<td>hard dough</td>
<td>hard dough</td>
<td>330 leaf colour change</td>
<td>leaf colour change</td>
<td>leaf colour change</td>
<td>end flowering (+12)</td>
<td></td>
</tr>
<tr>
<td>JT_v</td>
<td>harvest</td>
<td>harvest</td>
<td>harvest</td>
<td>365 leaf fall</td>
<td>leaf fall</td>
<td>leaf fall</td>
<td>harvest</td>
<td></td>
</tr>
</tbody>
</table>

* julian day of flowering compares to inflorescence emergence +5 days
METD_year.stationb

parameters:  JT, TM, TMAX, TMIN, TG, E, E’, SSS, SO, Rg, RR, Br, WW, PD, QH, Fm, Fx, Ft, Fn, Zx, Zy, Zi3, Zi6, Zi10, QB, RF

format:

| JT  | TM  | TMAX | TMIN | TG  | E   | E’   | SSS | SO  | Rg  | RR  | Br  | WW  | PD  | QH  | Fm  | Fx  | Ft  | Fn  | Bn  | Zx  | Zy  | Zi3 | Zi6 | Zi10 | QB  | RF  |
|-----|-----|------|------|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| I3  | 4F6.1, I4, F5.1, I5, F6.1, I3 | 2F5.1, I3, 2F4.1, I3, 2F4.1, I3, 3F1 |

meaning of parameters:

JT = julian day (–99 = no data, 888 = forecast data, 999 = qualitative forecast, 777 = replaced)
TM = air temperature, daily average, °C
TMAX = daily maximum air temp., °C
TMIN = daily minimum temp., °C
TG = soil surface minimum temp., °C
E = soil surface without snow
E’ = soil surface with snow
SSS = height of snow cover
SO = daily sum sunshine duration, h
Rg = daily sum global radiation, Joule/cm²
RR = daily precipitation, mm
Br = sum of hours with precipitation
WW = key number for actual weather (shower, etc.)
PD = saturation deficit, hPa
QH = HAUDE evapotranspiration, mm
Fm = average wind speed, m/s
Fx = maximum wind speed, m/s
Ft = day factor for wind speed
Fn = night factor for wind speed
Bn = hours with RF >= 90%
Zx = number of temperature sums
Zy = number of replacing stations
Zi3 = temperature sum >3°C
Zi6 = temperature sum >6°C
Zi10 = temperature sum >10°C
QB = quality byte (keep blank)
RF = relative humidity, daily average, %

The file METD-year.stationb is read with a constant record length of 113 by direct access, which must not be changed. If some parameters are not available, these columns are to be left blank or –99 (or –99.9, appropriate format) is to be put in.

Only RR is used by AMBAV, or create alternatively:

REGEN_year.station

parameters:  JT, RRTAG

format:  I3, F5.1

meaning of parameters:

JT = julian day
RRTAG = daily sum of precipitation

The file REGEN_year.station is read with a record length of 8 by direct access. A menu for manual data input into the file REGEN_year.station is provided for by the routine REGEN. If the file METD_year.station is available, this is used with priority to the file REGEN...

Further input files:
Files with hourly data:

\[ TL_{year.stationb} \] (screen air temp. in °C)
\[ RF_{year.stationb} \] (screen rel. humidity %)
\[ VV_{year.stationb} \] (wind speed 10m in m/s)
\[ RR_{year.stationb} \] (precipitation in mm)
\[ RG_{year.stationb} \] (global radiation in W/m²)
\[ NG_{year.stationb} \] (cloudiness in octas)

**file structure:**

*parameters:
\[ JT \], 24 hourly values  (beginning with 0 UTC (=GMT) = 1 CET)*

*format:*
\[ I4, 24F5.1 \]

*explanations:
\[ JT \] = julian day
\[ -99 \] = no data
\[ 888 \] = progn. data (numerical model)
\[ 999 \] = progn. data (qualitative)
\[ 777 \] = replaced data (e.g. by neighbouring station)

**BODsoiltypecrop.station**
(contains the crop-specific start and boundary conditions for the water model)

**parameters**

1\textsuperscript{st} line: JTENDV (dummy variable)
2\textsuperscript{nd} line: SCHICHT, WASGEH, DURCHWU, BODEVP, OWAS
3\textsuperscript{rd} line: SCHICHT, WASGEH, DURCHWU
etc. until
line NWA+1

**meaning of parameters:**

- **SCHICHT** = number of the layer (1 to 21)
- **WASGEH** = water content (volumetric portions) of the layer
  negative sign = expressed as % of field capacity (0 to 1)
- **DURCHWU** = rooting portion of the layer
- **BODEVP** = portion of soil evaporation of total evapotranspiration
- **OWAS** = standing water at the soil surface in mm

**remarks concerning the file BODsoiltypecrop.station:**

The start conditions are read from the file BOD.. for IZWI=0. The portion of rooting may be put in freely, as it is internally standardized to 1.
ZWlsoiltypecrop.station

(The file contains 366 (367) lines (days) with fixed record length (350 digits and blanks))

parameters:
JT, OWAS, BODEVP, SCHICHTNR.#, WASGEH, DURCHWU. (SCHICHT 1-NWA)

meaning of parameters:
JT = julian day
OWAS = standing water at soil surface in mm
BODEVP = percentage of soil evaporation of total evapotranspiration
SCHICHTNR.# = number of layer with: #
WASGEH = water content (volumetric portions) of the layer, negative sign = expressed as % available water.
DURCHWU = rooting portion of layer.

This file is created new by direct access when AMBAV is run with IZWI = 0 and when ZWlsoiltype-crop.station does not yet exist. The days calculated are filled with actual data, so that later in the year (or already in the 2nd run) with IZWI = 1 the already calculated interim results are used. Each line contains the data all layers (1 to 20 and the lower boundary conditions). When the calculation includes 31st Dec. (day 365 or 366) the data of the last day are doubled in line 367, from which data are read by AMBAV starting on day 1 next year.

soiltype.PAR

This file contains the soil-hydraulic reference values for the water model. The file soiltype.PAR for the different soil types (according to the following table) can be changed after copying it from the available soiltype.PAR. In this new AMBAV version the data of the first line in the soiltype.PAR file is additionally used for managing the soil parameters. With the identifier 6- KA4 (the minus is deciding) the hydraulic characteristics are not calculated, but directly read from the file.

Description of the columns in soiltype.PAR:
lower depth of layer [cm], soil type, clay content [weight %], silt content [weight %], bulk density of layer [g/cm³], \( C_{org} \) content [weight %], saturation water content [vol. fraction], residual water content (perm. wilt. point) [vol. fraction], shape parameter, air entry pressure [cm], shape parameter, shape parameter, water conductivity at saturation [cm/d]
### Table: Soil types with abbreviations, clay ($m_T$) and silt ($m_U$) content, as well as field capacity ($w_{FK}$, $pF = 2$) and wilting-point ($w_{WP}$) in percentage of volume

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Abbreviation</th>
<th>$m_T$</th>
<th>$m_U$</th>
<th>$w_{FK}$</th>
<th>$w_{WP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt</td>
<td>U</td>
<td>4.00</td>
<td>88.00</td>
<td>35.1</td>
<td>14.9</td>
</tr>
<tr>
<td>Sandy silt</td>
<td>Us</td>
<td>4.00</td>
<td>65.00</td>
<td>30.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Sandy-loamy silt</td>
<td>Ul</td>
<td>12.50</td>
<td>57.50</td>
<td>33.7</td>
<td>14.4</td>
</tr>
<tr>
<td>Light loamy silt</td>
<td>Ul2</td>
<td>10.00</td>
<td>77.50</td>
<td>35.9</td>
<td>16.3</td>
</tr>
<tr>
<td>Medium loamy silt</td>
<td>Ul3</td>
<td>14.50</td>
<td>75.25</td>
<td>37.2</td>
<td>18.4</td>
</tr>
<tr>
<td>Very loamy silt</td>
<td>Ul4</td>
<td>21.33</td>
<td>74.33</td>
<td>39.3</td>
<td>21.8</td>
</tr>
<tr>
<td>Light sandy loam</td>
<td>Us2 (*)</td>
<td>20.00</td>
<td>45.00</td>
<td>35.2</td>
<td>16.8</td>
</tr>
<tr>
<td>Medium sandy loam</td>
<td>Us4</td>
<td>19.00</td>
<td>34.33</td>
<td>33.3</td>
<td>15.0</td>
</tr>
<tr>
<td>Very sandy loam</td>
<td>Us4</td>
<td>21.00</td>
<td>21.50</td>
<td>32.5</td>
<td>14.6</td>
</tr>
<tr>
<td>Silt loam</td>
<td>Lu</td>
<td>23.50</td>
<td>60.00</td>
<td>38.2</td>
<td>20.5</td>
</tr>
<tr>
<td>Light clay loam</td>
<td>Lt2</td>
<td>30.00</td>
<td>42.50</td>
<td>38.2</td>
<td>21.3</td>
</tr>
<tr>
<td>Medium clay loam</td>
<td>Lt3</td>
<td>40.00</td>
<td>40.00</td>
<td>40.4</td>
<td>25.1</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>Lt4</td>
<td>37.50</td>
<td>56.25</td>
<td>41.3</td>
<td>26.3</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>Lt</td>
<td>35.00</td>
<td>27.67</td>
<td>38.2</td>
<td>22.1</td>
</tr>
<tr>
<td>Light sandy clay</td>
<td>Ts2</td>
<td>58.00</td>
<td>9.00</td>
<td>41.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Medium sandy clay</td>
<td>Ts3</td>
<td>43.00</td>
<td>9.00</td>
<td>38.8</td>
<td>24.1</td>
</tr>
<tr>
<td>Very sandy clay</td>
<td>Ts4</td>
<td>30.00</td>
<td>9.00</td>
<td>35.0</td>
<td>18.4</td>
</tr>
<tr>
<td>Loamy clay</td>
<td>Tl</td>
<td>55.00</td>
<td>31.50</td>
<td>42.3</td>
<td>29.5</td>
</tr>
<tr>
<td>Clay</td>
<td>T</td>
<td>76.67</td>
<td>11.67</td>
<td>43.7</td>
<td>33.7</td>
</tr>
<tr>
<td>Sand</td>
<td>S</td>
<td>2.50</td>
<td>5.00</td>
<td>10.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Light silty sand</td>
<td>Su2</td>
<td>2.50</td>
<td>17.50</td>
<td>15.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Medium silty sand</td>
<td>Su3</td>
<td>4.00</td>
<td>32.50</td>
<td>22.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Very silty sand</td>
<td>Su4</td>
<td>4.00</td>
<td>45.00</td>
<td>25.9</td>
<td>7.2</td>
</tr>
<tr>
<td>Silty loamy sand</td>
<td>Slu</td>
<td>11.50</td>
<td>45.00</td>
<td>31.1</td>
<td>11.9</td>
</tr>
<tr>
<td>Light loamy sand</td>
<td>Sl2(*)</td>
<td>6.50</td>
<td>15.00</td>
<td>19.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Medium loamy sand</td>
<td>Sl3</td>
<td>10.00</td>
<td>23.50</td>
<td>25.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Very loamy sand</td>
<td>Sl4</td>
<td>14.67</td>
<td>29.33</td>
<td>30.2</td>
<td>11.6</td>
</tr>
<tr>
<td>Light clay sand</td>
<td>Sl2</td>
<td>10.00</td>
<td>6.25</td>
<td>20.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Medium clay sand</td>
<td>Sl3</td>
<td>19.00</td>
<td>9.33</td>
<td>29.4</td>
<td>11.6</td>
</tr>
</tbody>
</table>

(*) when these soil types are chosen, the results are written into the file AMBERERG.station and are automatically used for the result tables instead of the soil moistures of the AMBER main program.

### Remarks concerning the files BODsoiltypecrop.station and soiltype.PAR.

The files BODsoiltypecrop.station and soiltype.PAR have to exist in the AMBAV main directory. The parameters for the soil layers 13 to 21 are not needed urgently, but are recommended to provide a realistic coupling of the soil water to the ground water, in order to guarantee the capillary rise as well as to prevent a water storage in the lower soil layers of a nitrogen model.
**output files**

**AMBAV.LS1**
output of control data of each run

**AMBAV.LS2**
detailed record of results as
- calculated leaf area index and derived root distribution
- water content of the single layers
- water flow in the single layers
- amount of leakage
- hourly water loss during irrigation
- etc.

**AMBERERG.station**
Output of the following parameters for the crops considered, if the calculations are made with the soil S12 (sand) or Ls2 (loam) (which is checked in the first soil layer in the file soiltype.PAR):
- percentage of field capacity 0 to 60 cm
- percentage of field capacity in the rooting zone
- real plant-specific evapotranspiration
- potential plant-specific evapotranspiration
- capillary rise or seepage water
- irrigation water amount recommended (results from NFKMAX and GRENZNFK)
- daily precipitation
- actual irrigated water amount (RRBER)
- water content in rooting zone
- surface runoff
- soil depth (cm) of continuous saturation under winter cereals
- soil depth (cm) of continuous dryness under winter cereals

The program for irrigation tables as well as other programs for tables need this data. If this data do not exist, the table programs take the values from AMBER main program.

**ERGLAUF.DAT**
control data ....... and:  
last but one column: number of crop  
last column: 1 = run successful, -99 = program abortion
further output files:

Review of files actualized by AMBAV (description see below, all files are read or written in direct access):

**ETP_year.station**

**ETA_year.station**

**NFK_year.station** (and NFsoiltype_...)

**AMB_year.station**

**WURZ_cult.station** resp.

**WUSTI_cult.station**

**BEREG_year.station**

**ZWlsoiltypecrop.station**

**ETP_year.station**

parameters

$ JT; ETP(1 \text{ to } 13)$

format:

$I4, 13F5.1$

explanation of parameters:

$ETP = \text{potential evapotranspiration (mm/day)}$

**ETA_year.station**

parameters:

$ JT; ETA(1 \text{ to } 13)$

format:

$I4, 13F5.1$

explanation of parameters:

$ETA = \text{actual evapotranspiration (mm/day)}$

**NFK_year.station** (also NFsoiltype_year.station)

parameters:

$ JT; NFK(1 \text{ to } 13)$

format:

$I4, 13F5.0$

explanation of parameters:

$NFK = \text{field capacity in \% for 0 to 60 cm}$

**AMB_year.station**
contains output data according to the choice of parameter ISTEU in file AMBAV.STA
as follows:

parameters:

1. line JT; PARAMETER(1 to 13)
   etc.
line 366 JT; PARAMETER(1 to 13)
line 367 JTENDE, ISTEU(1 to 13)

format:

I4,13F6.1 resp. F6.0

explanation of parameters:

PARAMETER = result chosen by ISTEU of the single crops
JTENDE = last calculated day of latest run
ISTEU = chosen parameter of latest run for the crop in question (1 to 13)

**WURZ_cult.station**
contains daily values of plant parameters. As this file serves as input for other programs (ISTWU = 0 in file AMBAV.STA), the culture parameter "cult" here stands for:

01 = bare soil
02 = winter wheat
03 = spring wheat
04 = winter barley
05 = sugar beet
06 = potatoes

in the file WURZ_cult.station.

parameters:

1. line JT; JTmax, JTe, LAI, ZB, WURZ (1 to 12)
   etc. until
line 366 ..... 

format:

I4, 2I4, 2F5.2, 1x, 9F5.2

explanation of parameters:

JTmax = julian day of beginning increase of stomatal resistance
JTe = julian day of end of increase of stomatal resistance
LAI = leaf area index
ZB = crop height
WURZ = calculated relative root density in the soil layers
         (which reach till a depth of 0.5, 1.5, 3, 7, 15, 25, 47, 82, 140, 240, 410, 700 cm)
**BEREG_year.station**

contains data about irrigations carried out

parameters:

1. line               JT; RRBER(1 to 13)
etc. until
line 366                ....

format:

I4, 1X, 13(F5.1,1X)

explanation of parameters:

JT = actual julian day
RRBER = irrigation amounts for crop 1 to 13

Remark: when testing the program, do not forget to replace manually by 0 or -9.9 those irrigation amounts you do not want no longer

**ZWIsoiltypecrop.station**

See the same file described under input chapter.

This file contains 366 (367) lines (days) with fixed record length (350 digits and spaces).

Interim results of the start and boundary conditions for further runs.

JT, OWAS, BODEVP, SCHICHTNR.#, WASGEH, DURCHWU.. (layer 1-NWA)

Supporting programs for AMBAV

There exist programs creating the files METD..., TL.., etc.

Special tables for recommended irrigation are produced with the help of WORD and cannot be supplied here. The handling of file **BEREG_year.station** can be managed by starting file AMBAV.STA (parameters JTBER, RRBER).

Helps for data processing

The flexible output file AMB_year.station offers the possibility to obtain different results without creating a lot of single files. Dependent on the question interim results or derived values may be recorded in this file. But there also exists the danger to create a mixture of the different results of different periods. Generally the chosen output parameters for the chosen crop are written in line 367 of file AMB_year.station, but only for the latest run of AMBAV. Therefore it is recommended, to erase this file in case of doubt and to recreate it with new start data.

Concerning calculations for winter cereals in autumn and winter it has to be regarded that phenological stages to be reached only in the following year have to be characterized by julian days greater than 366 (concerns PHAAM_year.station).

If in AMBAV.STA the parameter JTBERis set to 999, an automatical irrigation is done by the program within the thresholds of NFKMAX and GRENZNFK.

Maintenance of phenology data in file PHAAM_year.station

- at the beginning of the season this file should first be filled with mean range data of the region in question. It can be recommended to create such a file as a backup and to copy it into an actual file in the beginning of the year.
- When reaching the actual phenological stages, these data are to be put into the file.
- When early or late phenological development occurs, the following stages which are to come next days, should be adjusted (set e.g. ear emergence 10 days later than normal, or flowering some days earlier than normal).
Remarks and status of verification

Parts of the scientific contents of this model base on an older AMBAV version of 1983, which F.-J. Löpmeier published in German (Beiträge zur Agrarmeteorologie 7/83). Since then a lot of improvements were made in the software like altered parameterizations of radiation and incorporation of plant resistances of new crops. Now the slightly modified soil water model of H. Braden is implemented\(^1\). In this AMBAV version the calculation of rooting depth distribution and the rate of soil evaporation of total evapotranspiration is coupled to the phenological development. The surface runoff during and after strong rain is redesigned in dependence of the soil type.

The input of the crop-specific boundary and starting data has been redesigned. The naming of the BOD... - and ZW1...-files now considers the soil type and crop. When reading from files with interim results, the values of the latest calculated day are taken, if for the chosen starting day (JTBEG minus 1) no start data are available in the ZW1... file.

The calculations for forest and orchards are adopted from the MORECS model of the British Met.Service and have not yet been verified for these canopies in Germany.

\(^1\) H. Braden: The model AMBETI. A detailed description of a soil-plant-atmosphere model. 
*Berichte des Deutschen Wetterdienstes*, no. 195, Offenbach/Main 1995