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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February 1998

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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. Overwiew 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 Mean Range Weather Forecast) model calculated at Reading/UK. Table 1 gives a rough overview about the European NWP models.

TABLE 1 Some characteristics of European NWP models

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

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 characte-ristics is given in table 2.

TABLE 2: Intercomparison of the German NWP model chain

model	GLOBAL	EUROPA	DEUTSCHLAND
characteristic	global spectral model derived from ECMWF	hydrostatic mesoscale grid point model for	
		Europe and North Atlantic	Germany and its surroundings
diagnostic variables	geopotential, vertical velocity	temperature, water vapour, cloud water content, geopotential, vertical velocity	
predicted variables	surface pressure, temperature, spec. humidity, rel. velocity, horiz. divergence	surface pressure, total heat, total water content, horiz. wind components	
numerics	spectral horizontal **Gaussian grid:**	rotated spherical grid, mesh size:	
	1.125° / ~125 km	0.5° / ~ 55 km	0.125° / ~ 14 km
	19 vert. layers	**20 vert. layers**	**30 vert. layers**
	semi-implicit time integration		
	15 min time step	**5 min time step**	**4 min time step**
	fourth-order linear diffusion,		
	slope correction for diffusion of temperature	slope correction for diffusion of total heat	
parameterization	(see MAJEWSKI, 1995)		
topographic data	mean orography, land/sea mask and roughness length from 10´* 10´ **NCAR/NAVY data set**		
	prevailing soil type from FAO/UNESCO maps		
	FAO vegetation cover,	FAO vegetation cover and root depth,	
	potential vegetation cover (2.5° * 2.5° resolution)		
operation	since 1991	since 1991	since 1993
	initial hours: 00, 12 and 18 UTC		
	integration 168 h	78 h	48 h
	assimilation cycle 00, 06, 12 and 18 UTC with integration up to 6 hours		

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 <u>above</u> 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

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

equation reads:

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 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)

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

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 DOORENBOS & 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. DOORENBOS & PRUITT (1977) made an adjustment to the equation for other climatic regions. From this follows under middle European conditions for the *daily* evapotranspiration

$$ETP = a + b * p * (8.128 + 0.457 * T_m)$$

(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, b = 0.96.

b Extended version after DOORENBOS & PRUITT (1977)

DOORENBOS & 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

$$a = 0.0043 * RF_{14} + q - 1.41$$

$$b = 1.21 + 0.0545 * UB + 0.6*q - 0.01 * RF_{14}$$

(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

$$UB = (u_{10} / 0.87)^{1/1.44}$$

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

$$ETP = f * [E(T_{14}) - e_{14}] ,$$

evapotranspiration *ETP*,

with *ETP* in mm/d, *E* saturation vapour pressure in hPa, T_{14} air temperature (2m) in EC and e_{14} vapour pressure (2m) 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

$$f = f_1 * a_{Pf} + f_2 * a_B$$

(1987) modified the factor *f* in the original Haude approach as follows:

with $f_1 = 1 - f_2$ and $f_2 = 0{,}7_{LAI}$ (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 uninterupted days without precipitation and *b* a soil dependent empirical constant):

$a_B = a_{Bf} (1 – b * N)$.

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

$$f = 1.8 * n / r_{s,min} ,$$

with n number of real daily hours of sunshine and $r_{s,min}$ 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 Td_m (°C) and windspeed u_m (m/s) in 2m height (u_m may be estimated

$$ETP = (0.015 + 4 * 10^{-4} * T_m + 10^{-6}*z) *$$
$$[(380 * (T + 0.006*z) / (84 - |B|)) - 40 + 4*u_m * (T - Td_m)]$$

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

$$ETP = a + b * s / (s + \gamma) * Rs ,$$

evapotranspiration *ETP* (mm/d) resulted in:

with *Rs* in mm/d (1 mm/d . 0.004 J/m^2), *s* slope of vapour pressure curve (in hPa/K) at air temperature in 2 m height (daily mean), γ 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 coefficcients (*a* und *b*) in the Makkink formula, too. It results (SCHRÖDTER, 1985)
$a = -0.3$, when

$$b = 1.165 + 0.043 * UB - 0.00575 * RF_m ,$$

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):

$$ETP = 0.375 * [E(T_m) - e_m] * (1 + 0.224 * u_m)$$

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

$$ETP = 0.018 * n_{max} * [E(T_{14}) - e_{14}] ,$$

inserted:

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 & PRUTT (1977) of the original equation of PENMAN (1948), which follows

$$ETP = c * [(s * Rn + \gamma * f(u) * (E - e)) / (s + \gamma))]$$

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), γ 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: $c = 0{,}79 - 0{,}034 \cdot UB + 0{,}028 \cdot Rs$, 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 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,

$$ETP = 16 * T_m / RF_m \quad .$$

shortened from a month to a day:

with *ETP* in mm/d, T_m daily mean of air temperature in 2 m (in °C) and RF_m 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

$$ETP = 0.16 * T_m \quad .$$

MINTZ & WALKER, 1993):

with *ETP* in 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

$$ETP = 0.533 * (n_{max}/12) * (10 * T_m / WI)^A$$

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

with *ETP* in mm/d, n_{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_{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

$$ETP = 0.17 * (n_{max}/ 12) * T_m$$

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

$$ETP = 0.0133 *(T_m/ (T_m + 15)) * (0.239 * Rs + 50) * (1 + (50 - RF) / 70)$$

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 $RF = 100 \cdot e_m/E(T_m)$, 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

$$ETP = (Rs + 93 * K) * [(T_m + 22) / (150 * (T_m + 123))]$$

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

with $ETP >= 0.1$ 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 kc is defined as ET_c / ET_o (DOORENBOS & PRUITT, 1977).
FAO recommends to replace the term potential evaoptranspiration 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 kc-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 kc-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 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.

L.S.Pereira et al.(eds.): Crop-Water-Simulation Models in Practice. Selected Papers of the 2nd Workshop on Crop-Water-Models held at the occasion of the15th Congress of the ICID at The Hague, Netherlands, 1993, Wageningen Press 1995.
C.R.Camp et al.(eds.): Evapotranspiration and Irrigation Scheduling. Proceedings of the Internat. Conference, San Antonio/Tx., 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

Albrecht, F.: Die Methoden zur Bestimmung der Verdunstung der natürlichen Erdoberfläche. Arch. Meteor. Geophys. Bioklim., Ser. B, 2., 1950, p. 1-38

Allen, R.G., Jensen, M.E. & Burman, R.D.: Operational estimates of reference evapotranspiration. Agronomy Journ., 81., 1989, p. 650-662

Allen, R.G., Pruitt, W.O., Businger, J.A., Fritschen, L.J., Jensen, M.E. & Quinn, F.H.: Evaporation and Transpiration. In: Wootton et al. (eds.): Hydrology Handbook, ASCE, New York, 2nd ed.1996, p. ?

Allen, R.G., Smith, M., Perrier, A. & Pereira, L.S.: An update for the definition of reference evapotranspiration. ICID Bulletin, 43., 1994, p. 1-34

Allen, R.G., Smith, M., Perrier, A. & Pereira, L.S.: An update for the calculation of reference evapotranspiration. ICID Bulletin, 43., 1994, p. 35-92

Allen, R.G., Smith, M., Pruitt, W.O. & Pereira, L.S.: Modifications to the FAO Crop Coefficient Approach. In: C.R. Camp, E.J. Sadler & R.E. Yoder (eds.): Evapotrans-spiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 124-132

Ayars, J.E. & Mc Whorter, D.B.: Incorporating Crop Water Use in Drainage Design in Arid Areas. In: Proceed. of the Specialty Conf. 'Development and Management Aspects of Irrigation and Drainage Systems', IR Div. ASAE, San Antonio/Tx., 1985, p. ...

Babajimopoulos, C., Budina, A. & Kalfountzos, D.: SWBACROS: A model for the estimation of the water balance of a cropped soil. Environmental Software, 10., 1995, p. 211-220

Blaney, H.F., and Criddle, W.D.: Determining water requirements in irrigated areas from climatological and irrigation data. USDA SCS Techn. Pap. No 96, 1950

Brisson, N.: On the Importance of Soil Evaporation and Rainfall Interception in Irrigation Scheduling. In: C.R. Camp, E.J. Sadler & R.E. Yoder (eds.): Evapotranspiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 281-288

Bussay, A.: personal communication, 1996

Choisnel, E., de Villele, O. & Lacroze, F.: Une approche uniformisée du calcul de l'évapotranspiration potentielle pour l'ensemble des pays de la Communauté Européenne. Com. Commun. Européennes, EUR 14223 FR, Luxembourg 1992, 176 pp.

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. ...

Clyma, H.E. & Martin, D.L.: Irrigation Management Using Fuzzy Logic. In: C.R. Camp, E.J. Sadler & R.E. Yoder (eds.): Evapotranspiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 1134 - 1139

Danuso, F., Gani, M. and Giovanardi, R.: Field water balance: BIdriCo 2. In: L.S.Pereira et al.(eds.): Crop-Water-Simulation Models in Practice. Selected Papers of the 2nd Workshop on Crop-Water-Models, 1993, Wageningen Press 1995, p. 49-73

Dobesch, H., Hermann, G. & Sabo, P.: Local Weather Forecast in Austria and its Application for Hydrometeorological Modelling by Means of Model Output Statistics. Symposium of 1st European Conf. on Application of Meteorology, Oxford, Sept. 1993, 4 pp.

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

Ernstberger, H.: Einfluß der Landnutzung auf Verdunstung und Wasserbilanz. Thesis, Univ. Gießen 1987

Ernstberger, H. & Sokollek, V.: Effects of Agriculture Land-Use and Forestry on the Seepage out of the Root Zone. (in German) Zeitschrift Deut. Geolog. Gesellschaft, 134., 1983, p. 723-734

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

Feddes, R.A.: Crop factors in relation to Makkink reference-crop evapotranspiration. In: Evapotranspiration and Weather. TNO Committee on Hydrological Research, Proceedings and Information, no. 39, 1987, p. 33-45

Geleyn, J.F., Bazile, E., Bougeault, P., Déque, M., Ivanovici, V., Joly, A., Labbé, L., Piédelievre, J.P., Piriou, J.M. & Royer, J.F.: Atmospheric parametrization schemes in Météo-France's Arpege NWP model. Proceedings of ECMWF Seminar on parametrization of subgrid scale physical processes, Reading/UK, 1994

Hargreaves, G.H. & Samani, Z.A.: Reference crop evapotranspiration from temperature. Applied Engr. in Agric., 1., 1985, p. 96-99

Haude, W.: Zur Möglichkeit nachträglicher Bestimmung der Wasserbeanspruchung durch die Luft und ihrer Nachprüfung an Hand von Topfversuchen und Abflußmessungen. Berichte Deutsch. Wetterdienst US-Zone 32., 1952, p. 27-34

Heger, K.: Bestimmung der potentiellen Evapotranspiration über unterschiedlichen landwirtschaftlichen Kulturen. Mitt. Dtsch. Bodenkundl. Gesell., 26., 1978, p. 21-40

Itier, B.: Measurement and estimation of evapotranspiration. In: L.S. Pereira et al. (ed.): Sustainability of Irrigated Agriculture, NATO ASI Series, vol. 312, 1996, p. 171-191

Jensen, M.E., Burman, R.D. & Allen R.G. (ed.): Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice no. 70, 1990, 332 pp.

Linacre, E.: Climate Data and Resources. Routledge, New York, 1992, 366 pp.

Löpemier, F.-J.: The calculation of soil moisture and evapotranspiration with agrometeorological models. (in German) Zeitschrift f. Bewässerungswirtschaft, 29, 1994, p. 157-167

Majewski, D.: Quarterly Report of the Operational NWP-Models of the DWD. April 1995

Majewski, D. & Wergen, W.: Numerical weather prediction at the Deutscher Wetterdienst (DWD) - current system. Annalen d. Meteorologie, 35., 1997, p. 197-199

Makkink, G.F.: Testing the Penman formula by means of lysimeters. Journ. Int. Water Engin., 11., 1957, p. 277-288

Mintz, Y., and Walker, G.K.: Global fields of soil moisture and land surface evapotranspiration derived from observed precipitation and surface air temperatures. Journ. Appl. Meteor., 32., 1993, p. 1305-1334

Monteith, J.L.: Principles of environmental physics. Edward Arnold, London 1973, 241 pp.

Müller, J., Jörn, P. & Wendling, U.: Untersuchungen zur Eignung des ANTAL-Verfahrens für die Bestimmung der potentiellen Evapotranspiration von Gras auf Flachlandstandorten. Zeitschrift f. Meteorologie, 40., 1990, p. 189-191

Müller, J. & Müller, G.: Berechnung der Verdunstung landwirtschaftlicher Produktionsgebiete. 1. Mitteilung: Beschreibung des zur Bestimmung der aktuellen Evapotranspiration von Kulturpflanzenbeständen erarbeiteten Modells. Zeitschrift f. Meteorologie, 38., 1988, p. 332-337

Müller, J., Müller, G., Krüger, R. & Thomä, T.: Zum Evapotranspirationsverhalten landwirtschaftlicher Nutzpflanzenbestände in Abhängigkeit von den Witterungsbedingungen. Zeitschrift f. Meteorologie, 41., 1991, p. 130-141

Naumann, H.: Die potentielle Tag-Verdunstung als ökologische Qualität des Naturraumes und ihre regionale Differenzierung im Gebiet der DDR. Thesis, Martin-Luther-Univ. Halle, 1987, 95 pp.

Paschold, P.-J.: Irrigation Scheduling in Vegetable Growing in Order to Increase Irrigation Efficiency under Consideration of Ecological Aspects. (in German) Zeitschrift f. Bewässerungswirtschaft, 28., 1993, p. 161-174

Penman, H.L.: Natural evaporation from open water, bare soil and grass. Proc. Roy. Meteorol. Soc., A, 193.,1948, p. 120-145

Pereira, L.S., van den Broek, B.J., Kabat, P. & Allen, R.G. (eds.): Crop-Water-Simulation Models in Practice. Selected Papers of the 2nd Workshop on Crop-Water-Models held at the occasion of the 15th Congress of the ICID at The Hague, Netherlands, 1993, Wageningen Press 1995.

Pereira, L.S., Perrier, A., Allen, R.G. & Alves, I.: Evapotranspiration: Review of Concepts and Future Trends. In: C.R. Camp, E.J. Sadler & R.E. Yoder (eds.): Evapotranspiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 109-115

Plauborg, F., Andersen, M.N., Heidmann, T. & Olesen, J.E.: MARKVAND: A Decision Support System for Irrigation Scheduling. In: C.R. Camp, E.J. Sadler & R.E. Yoder (eds.): Evapotranspiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 527-535

Prenosil, T.: Aktuelle Methoden der numerischen Wettervorhersage. In: Numerik und Synoptik. Fortschritte bei der Wettervorhersage. Deutsche Meteorologische Gesellschaft. Supplem. 1/1994, p.10-28

Priestley, C.H.B. & Taylor, R.J.: On the assesssment of surface heat flux and evaporation using large scale parameters. Mon. Weather Review, 100., 1972, p. 81-92.

Radnoti, G. et al.: The spectral limited area model ARPEGE/ALADIN. 1995, 7pp.

Rötzer, T.: Neuartige Karten der Phänologie und des Wasserhaushalts von Bayern unter Berücksichtigung möglicher künftiger Klimaverhältnisse. Thesis, Techn. Univ. München, 1996

Schulze, R.E.: Hydrology and Agrohydrology: A text to accompany the ACRU 3.00 agrohydrological modelling system. Water Research Commission Report TT69, Pretoria 1995

Schrödter, H.: Verdunstung: anwendungsorientierte Meßverfahren und Bestimmungsmethoden. Springer, Berlin 1985, 186 pp.

Siegert, E. & Schrödter, H.: Erfahrungen mit dem Wasserbilanzschreiber nach Klausing. Deut. Gewässerkundl. Mitteilungen, 19., 1975, p. 167-171

Slack, D.C., Martin, E.C., Sheta, A.E., Fox, F., Clark, L.J. & Ashley, R.O.: Crop Coefficients Normalized For Climatic Variability With Growing-Degree-Days. In: C.R. Camp, E. J. Sadler & R.E. Yoder (eds.): Evapotranspiration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 892-898

Smith, M.: CROPWAT - A computer program for irrigation planning and management. Irrigation and Drainage Paper No. 46, FAO, Rome 1992, 126 pp.

Smith, M., Allen, R., Monteith, J.L., Perrier, A., Pereira, L.S. & Segeren, A.: Report on the expert consultation on revision of FAO methodologies for crop water requirements. Land and Water Development Division, FAO, Rome 1992, 28pp + several annexes

Smith, M., Allen, R. & Pereira, L.: Revised FAO Methodology for Crop Water Requirements. In: C.R. Camp, E.J. Sadler & R.E. Yoder (ed.): Evapotranspi-ration and Irrigation Scheduling, Proceedings of the Internat. Conference, San Antonio/TX 1996, p. 116-123

Specty, R. & Perarnaud, V.: Bilan hydrique et irrigation. Note Météo-France. 1993.

Stein, T.: IRRISOFT - An Introduction to a World Wide Web Database on Irrigation and Hydrology Software. Zeitschrift f. Agrarinformatik, 2/1996, p. 34-37

Thompson, N., Barrie, I.A. & Ayles, M.: The Meteorological Office Rainfall and Evaporation Calculation System: MORECS. Hydrological Memorandum no. 45, 1981

Thornthwaite, C.W.: An approach towards rational classification of climate. Geograph. Review, 38., 1948, p. 55-94

Turc, L.: Évaluation des besoins en eau d'irrigation, évapotranspiration potentielle. Formule climatique simplifiée et mise à jour. Ann. agron. 12.,1961, p. 13-49

Uhlig, S.: Berechnung der Verdunstung aus klimatologischen Daten. Mitteil. Deutsch. Wetterdienst, Nr. 6, 1954.

Wenkel, K.-O. & Mirschel, W.: BERSIM und BEREST-90 - Modelle zur Simulation der Bodenfeuchte und Evapotranspiration sowie operativen Beregnungseinsatzsteuerung im integrierten Landbau. Agrarinformatik, 21., 1991, p. 349-360

Wendling, U.: Beitrag zur Kartierung der Verdunstung unter agrarklimatologischen Gesichtspunkten. Annalen d. Meteorologie, no.31, 1995,p. 143-144

Wendling, U. & Schellin, H.-G.: Neue Ergebnisse zur Berechnung der potentiellen Evapotranspiration. Zeitschrift f. Meteorologie, 36., 1986, p. 214-217

Wendling, U., Schellin, H.-G. & Thomä, M.: Bereitstellung von täglichen Informationen zum Wasserhaushalt des Bodens für die Zwecke der agrarmeteorologischen Beratung. Zeitschrift f. Meteorologie, 41., 1991, p. 468-475

Wenkel, V.O. & Mirschel, W.: BERSIM und BEREST - Modelle zur Simulation der Bodenfeuchte und Evapotranspiration sowie zur operativen Beregnungseinsatzsteuerung im integrierten Pflanzenbau. Agrarinformatik, 21., 1991, p. 349-360

Wergen, W.: Aktuelle Probleme in der Numerischen Wettervorhersage. Annalen d. Meteorologie, no. 29, 1994, p.41-49

Wright, J.L.: New evapotranspiration crop coefficients. Journ. Irrigation and Drainage, 108., 1982, p. 57-74

Zazueta, F.S.: IFAS Software Catalog. Doc. SW-001, Florida Cooperative Extension Service, Inst. of Food and Agricult. Sciences, Univ. of Florida, Gainesville 1995, 21 pp.

Annex:

Contents:

IRRIGATION SCHEMES of COST member countries

(after questionnaire of Mr. Delecolle, 1994)

		data input			model characteristics						
Country, system	**ET_o (PET) formula**	**para-meter**	**time reso-lu-tion**	**far-mer too?**	**water model type**	**crop model**	**mod. time step**	**met. fore-cast**	**no of crops**	**results/ informa-tion**	**area of recom-mend.**
DENMARK Markvand	Makkink, mod.Penman	RR, T, RH others, soil, crop	d d d - -	yes	crop co. 3 reser- voirs	yes	d	yes +5d- option	~20	soil wat., irrigation amount	farm
EC (Ispra) CGMS of produc-	Penman	RR, T, RH, others, soil	d d d -	-	ET_o, crop co., 1 reser- voir	yes	h	no	9	soil water, estimate final tion	EC-wide
FRANCE Irritel	Penman- Monteith	RR, T, RH, others, agron.	d d d -	-	crop co. multiple reservoirs	no	d	no	~70	soil water, irrigation	farm, country amount
GERMANY AMBAV	Penman- Monteith	RR, T, RH, G, VV, soil, crop	h h h - d	pos- sible	crop co., mult. re- servoirs, flux mod.	yes	h	yes 5d	13	ET_c, soil water, irri- gation	country to farm amount
HUNGARY	empirical	T, RH, A-pan	d d	-	crop co.	yes	d 10d	yes	10	irrigation amount	farm, 10 km²
ITALY	modif. Blaney- Criddle	RR, T	d	-	ET_o, crop co., multiple reserv.	no	d	yes	3	irrigation amount	30 km²

SLOVENIA IRRFIB	Penman	RR T, RH, others	d d d	-	ET_o, crop co.	yes	d	yes	>20	soil water, irrigation amount	10 km²

IRRIGATION SCHEMES continued

Country, system	ET_o (PET) formula	para-meter	time reso-lu-tion	far-mer too?	water model type	crop model	mod. time step	met. fore-cast	no of crops	results/ informa-tion	area of recom-mend.
		data input			**model characteristics**						
SPAIN **Telefone Verde**	Penman, P.-Monteith, Blan.-Criddle & others	RR, T, RH, others	h,d d d	-	crop co.	-	d	?	?	irrigation	farm to 100 km²
Eto	Penman, P.-Monteith, Priestley-Taylor, Hargreaves, Bowen ratio	RR, T, RH,	20min	-	?	yes	20 min	yes	7	irrigation amount	farm, 100 km²
UNITED water, **KINGDOM** **Irriguide**	Penman- farm Monteith	RR, T, RH, others, soil	d d d -	-	?	yes	h	yes	no limit	soil irrigation amount	

ABBREVIATIONS:

A-pan	=	class A-pan for evaporation
ET_c	=	crop evapotranspiration (~ETA)
ET_o	=	reference crop evapotranspiration (~PET)
crop co.	=	crop coefficient
d	=	day , daily
G	=	global radiation
h	=	hour, hourly
min	=	minutes
PET	=	potential evapotranspiartion (see ET_c)
RR	=	rain amount
RH	=	relative humidity
T	=	air temperature
VV	=	wind speed

annex 2

IRRIGATION SCHEMES of COST member countries
(evaluation of autumn 1995 questionnaire to COST member countries)

part 1:

-1- country	-2- name and place of replier	-3- organization which operates the irrigation model	-4- who are the users?	-5- costs? / acceptance of recommendation scheme
AUSTRIA	H.Dobesch, Inst.for Met.& Geodynamics, Vienna	planned for 1996 to start with German Weather Service	-	-
BELGIUM	R.Oger, University of Gembloux	X.Dimitri of Hydraulique Agric., Univ. of Gembloux	farmers, vegetable growers, factories of deep-frozen vegetables	yes: 1000 BEF/ha year / good
DENMARK	F.Plauborg, Danish Inst. Plant & Soil Science, Tjele	Danish Agric. Advisory Centre, Aarhus: "MARKVAND"	farmers, local advisors about 200	yes: ~2000 DKR / well
FRANCE	V.Perarnaud/S.Paniagua Meteo France, Toulouse	Meteo France & agric. institute: "IRRITEL", further models exist	farmers, farmer advisors, agric. teachers	yes: ~400 FF/ y no longer in use
GERMANY	F.J.Löpmeier/Friesland Centr.Agromet.Research Station Braunschweig, Deutscher Wetterdienst	5 agromet. advisory stations of German Weather Service: "AMBAV"; region.models	farmers, vegetable growers, scientists about 800	yes: 150 DM / season for fax abonnement with addition. agromet.output / rather good
HUNGARY	A.Bussay, Hungarian Meteorol. Service, Budapest	Agric. Univ./Inst. at: Debrecen, Gödöllö & Szarvas; Hung.Met.;	(not in the moment) (4 models given up)	-
ITALY (1)	G.Zipoli, Institute of Agromet.& Env.Analys. for Agric., Florence	regional agromet. services in Emilia-Romagna	farmers (500 in E.-Romagna) & technicians of extension service	no, but videotel term. rent 100000 LIT/year / in general good
ITALY (2)	C.Palchetti, Hydrol.& Meteor. Exper. Centre, Teolo, Veneto region	Agrometeorol. Service of Veneto region	farmers in Veneto (regional service, not at farm level)	no / good

SLOVAKIA information	P.Nejedlik, Slovak Hydromet.Institute, Kosice	V.Cislak / A.Heldi Research Inst.Irrig. Managem., Bratislava	~120 operators of irrigation systems	no / no
SLOVENIA reasonable expected	I.Matajc, Hydromet. Inst.of Slov., Dept. of Agromet.,Ljubljana	Agricult. High School Racikan, Murska Sobota	26 farmers and advisory services, Agric. Institute	no /

part 2:

country	executable file available?	which data for validation of irrigation models?	weather data available for irrigation relevant sites?	models possible to validate in your country?
	6	7	8	9
AUSTRIA	no, because only research version	1 station soil moist. 1 station lysimetric data (hourly)	many files (all sites?)	yes
BELGIUM	yes	no	some files (not all sites)	no
DENMARK	no (only demo version)	2 stat.lysim.data [soil moist.?]	many files, daily all sites	yes
FRANCE	yes, pc vers. (not longer used)	no	some files	maybe with data from INRA
GERMANY	yes	20 stat. soil moist. 1 station lysimetric data and energy bal. measurements	many files 1 hour - 15 min, all sites	yes
HUNGARY	no	1 station soil moist.	1 station (driest) 3-4 years	?
ITALY (1) (Zipoli)	yes	26 stat. soil moist. (1 probe per 2 months)	no	yes
ITALY (2) (Palchetti)	no	soil moisture data [number of sites?]	180 stations with hourly data	no
SLOVAKIA	yes	10 stat. soil moist. (weekly)	many files all sites	yes
SLOVENIA	yes	2 stations soil moist. (daily, as comp. files)	many files all sites	yes

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NETHERLANDS, NORWAY and SWEDEN: no or no official irrigation service

annex 3

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

	MEY	=	Meyer
	ANT	=	Antal
	SCH	=	CZERATZKI-disk data (evaporative ceramic disk)
	NAU	=	Nauman
	SHE	=	Schendel
	SMI	=	Smith

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

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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:

Method	**from METD**	**TL**	**RF**	**VV**	**RG**	**NG**	**RR**	**CZ**
HAU	SAE_{14}							
HAS		X	X					
HAM	SAE_{14}							
HAH	SAE_{14}							
PE1		X	X	X	X	X		
PE2		X	X	X	X	X		
PE3	SO, TMI		mean	mean				
BLA	TMI, SO							
BL1	TMI, SO		mean	mean				
TUR	TMI, RGSUM							
THO	TMI							
LIN	TMI		mean TD	mean				
MA1	TMI, RGSUM							
MAK	TMI, RGSUM							
MA2	TMI, RGSUM							
ALB	TMI		mean E	mean				
WEN	TMI, RGSUM							
MEY	TMI		mean	mean				
ANT	TMI		mean E					
SCH								X
TH2	TMI, SO							
NAU		TL_{14}	RF_{14}					
SHE	TMI		mean					
SMI	TMI							

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 und 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.LS1*****

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     Schroedter, H., 1985.
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     ------------------------------------------------------------
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     Mueller, J., Jörn, P., und Wendling, U., 1990.
C     Wendling, U., Schellin, H.-G., und Thom,,, M., 1991.
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     Verdunstung nach einer von Doorenbos & Pruitt (1977 ) modifi-
C     zierten Formel der monatlichen pot. Verdunstung von Blaney &
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           Schroedter (1985, S. 102ff).
C     ACHTUNG: Die Formel wurde hier sinnvollerweise ergaenzt durch den
C     Ausschluss negativer ETPT-Werte.
C     Literatur:
C     Schroedter, H., 1985. Verdunstung.
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 moeglichen 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 moegliche Sonnenschein-
C              dauer in Prozent der Jahres-Sonnenscheindauer
C     UTB        Tagesmittel der Windgeschwindigkeit in 2m [Beaufort=BFT];
C              Berechnung aus m/s in 10m Hoehe mittels Invertierung einer
C              gaengigen Formel {m/s = 0.87*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!).
       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
```

```
C    Verdunstung nach einer von Doorenbos & Pruitt (1977 ) modifi-
C    zierten Formel der monatlichen pot. Verdunstung von Blaney &
C    Criddle (1952) in Abhaengigkeit von Lufttemperatur und
C    Sonnenscheindauer. Die Zitate finden sich bei Schroedter (1985).
C    Literatur:
C    Schroedter, H., 1985.
C    Variablenbedeutung und Einheiten:
C    ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C    J          Jahrestag oder Julianisches Datum
C    PFAK       taegliche astronomisch maximal moegliche Sonnenschein-
C               dauer in Prozent der Jahres-Sonnenscheindauer
C    SJ         Jahressumme der astronomisch maximal moeglichen Sonnen-
C               scheindauer [h]
C    ST         taegliche astronomisch maximal moeglichen Sonnen-
C               scheindauer [h]
C    TLT        Tagesmittel der Lufttemperatur in 2m [Grad C]
C    -------------------------------------------------------------
      dimension ST(366)
      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    HAUMOD.FOR
      SUBROUTINE HAUDE (SAE,monat,etp)
      include 'bestan.inc'
      ETP = HAUFAK(MONAT)*SAE
      RETURN
      END

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

C    PROGRAMM ZUR BERECHNUNG DER stuendlichen 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    HAUMOD.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 IBODEN/4/, IDAU/18/
C    IDAU = Dauer des erhöhten Wasserverbrauchs
C    HIER WIRD ENDE DES BESTANDES DEFINIERT (VORLAUEFIG)
C    IDAU  DAUER des HOHEN WASSERVBRAUCHS
C     Bodenfaktoren von Lehm bis Sand
C   HAUDE= HAUDEVERDUNSTUNG
C   HAU = SAETTIGUNGSEDFIZIT 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. Haudefaktor nach Haenel
C     (1995, unveroeffentlicht) in Abhaengigkeit von minimalem Bulkstomata-
C     widerstand und tatsaechlicher taeglicher 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        minmaler Bulkstomatawiderstand [s/m]
C     S           tatsaechliche 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     SDADR       Funktion: berechnet Saettigungsdampfdruck [hPa]
C     ---------------------------------------------------------------
      HF = 1.8 * S / RSMIN
      ETPT = HF * SDADR( TL14 ) * ( 1. - RH14 / 100. )
      RETURN
      END
************************************************************

      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, Hoehe ueber NN,
```

```
c     Lufttemperatur, Taupunkt und Windgeschwindigkeit.
C     Die Anwendbarkeit beschraenkt sich wegen der verwendeten
C     Strahlungsparameterisierung (s. Linacre, 1992, S. 181/182)
C     auf geogr. Breiten von -60 bis +60 Grad.
C     Literatur:
C     Linacre, E., 1992.
C     Variablenbedeutung und Einheiten:
C     ETPT      Tageswert der potentiellen Verdunstung [mm/d]
C     GEOB      geographische Breite [Grad]
C     TLT       Tagesmittel der Lufttemperatur in 2m [Grad C]
C     TDT       Tagesmittel des Taupunkts [Grad C]
C     UT        Tagesmittel der Windgeschwindigkeit in 2 Meter [m/s]
C     ZNN       Hoehe ueber Meeresniveau NN [m]
C     ----------------------------------------------------------
      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 )
C   Diese Subroutine berechnet den Tageswert der potentiellen
C     Verdunstung nach der Formel von Makkink (1957) in Abhaengigkeit
C     von Lufttemperatur und Globalstrahlung.
C     Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C     Literatur:
C     Makkink, G.F., 1957:
C     Variablenbedeutung und Einheiten:
C     **** Input ****
C     J         Jahrestag oder Julianisches Datum
C     RGTSU     Tagessumme der Globalstrahlung [J/cm^2]
C     TLT       Tagesmittel der Lufttemperatur in 2m [Grad C]
C     **** Output ****
C     ETPT      Tageswert der potentiellen Verdunstung [mm/d]
C     **** Intern ****
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     ----------------------------------------------------------------
      DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
      PSYKO  = 0.67
      RGTMM  = RGTSU / 250.
      ETPT = - 0.12 + 0.61 * RGTMM * DSDADR / ( DSDADR + PSYKO )
      IF ( ETPT .LT. 0. ) ETPT = 0.
      RETURN
      END
*******************************************************************

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

```
C    Luftfeuchte, Windgeschwindigkeit und Globalstrahlung. Hierbei
C    wurden die Modifikationen nach Schroedter (1985) zitiert.
C    Hinweis: gegenueber Doorenbos & Pruitt (1977) muss die Wind-
C            geschwindigkeit im folgenden mit der Einheit m/s anstelle
C            von Beaufort vorgegeben werden. Die Umrechnung in Beau-
C            fort erfolgt programmintern.
C    Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C    Literatur:
C    Doorenbos, J., and Pruitt, W.O., 1977
C    Makkink, G.F., 1957
C    Schroedter, H., 1985.
C    Variablenbedeutung und Einheiten:
C    **** Input ****
C    J          Jahrestag oder Julianisches Datum
C    RGTSU      Tagessumme der Globalstrahlung [J/cm^2]
C    RGTMM      Tagessumme der Globalstrahlung [mm Wasser„q.]
C    RHT        Tagesmittel der Luftfeuchte [%]
c             (Was immer das auch sein mag...)
C    TLT        Tagesmittel der Lufttemperatur in 2m [Grad C]
C    UT         Tagesmittel der Windgeschwindigkeit in 10m [m/s]
C    **** Output ****
C    ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C    **** Intern ****
C    B          Koeffizient nach Doorenbos & Pruitt (1977)
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    UTB        Tagesmittel der Windgeschwindigkeit in 2m [Beaufort=BFT];
C               Berechnung aus m/s in 10m Hoehe mittels Invertierung einer
C               gaengigen Formel {m/s = 0.87*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    ------------------------------------------------------------------
      DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
      PSYKO  = 0.67
      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 )
      IF ( ETPT .LT. 0. ) ETPT = 0.
      RETURN
      END

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

      SUBROUTINE MAKKINK2( TLT, RGTSU, ETPT )
C    Diese Subroutine berechnet den Tageswert der potentiellen
C    Verdunstung nach der von Feddes (1987) modifizierten (=vereinfach-
C    ten) Formel von Makkink (1957) in Abhaengigkeit von Lufttemperatur
C    und Globalstrahlung. Diese Formel gilt fuer Gras (fuer landwirtschaft-
C    liche Kulturen finden sich bei Feddes, 1987, vom Entwicklungsstadium
```

```
C    abhaengige Bestandsfaktoren).
C    Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C    Literatur:
C    Feddes, R.A., 1987.
C    Makkink, G.F., 1957
C    Variablenbedeutung und Einheiten:
C    **** Input ****
C    RGTSU      Tagessumme der Globalstrahlung [J/cm^2]
C    TLT        Tagesmittel der Lufttemperatur in 2m [Grad C]
C    **** Output ****
C    ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C    **** Intern ****
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    ---------------------------------------------------------------
      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 )
C    Diese Subroutine berechnet eine die potentielle Verdunstung nach
C         einem Ansatz von Meyer (1926, 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.
C    Literatur:
C    Schroedter, H., 1985. Verdunstung.
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    ---------------------------------------------------------------
c    Umrechnung 10 Meterwind auf 2 Meter
      UT=UT/1.3
      ETPT = 0.5 * ( SDADR( TLT ) - DT )/1.33322 * ( 1. + 0.224 * UT )
c   1.3333 Umrechnung hPa in Torr
      RETURN
      END


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

      SUBROUTINE NAUMAN( J, TL14, RH14, ST, ETPT )
C    Diese Subroutine berechnet die pflanzenspezifisch potentielle Tagesver-
C    dunstung nach einer auf Monatsbasis entwickelten Formel von Naumann
C         (1987) aus Dampfdruckdefizit und relativer Feuchte zur Mittagszeit.
C         Der originale Vorfaktor lautet bei Naumann (1987) 0.54 und wurde zur
C         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 ueberein" mit dem Haude-Ansatz,
C          wie Wendling et al. (1991) feststellen. Nach ihrer Tabelle 1
C          entspricht die hier programmierte "Naumann-Verdunstung" der
C          Haude-Verdunstung ueber Gras.
C          Die unten programmierte Naumann-Formel erhaelt 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          scheindauer S mit ca 70% von ST eingesetzt wird.
C     Literatur:
C     Haude, W., 1952.
C          Naumann, H., 1987.
C     Wendling, U., Schellin, H.-G.
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     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 Saettigungsdampfdruck [hPa]
C     --------------------------------------------------------------
      Dimension     ST(366)
      HF = 0.018 * ST(J)
      ETPT = HF * SDADR( TL14 ) * ( 1. - RH14 / 100. )
      RETURN
      END

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

      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     Schroedter, H., 1985.
C     Variablenbedeutung und Einheiten:
C     **** Input ****
C     J         Jahrestag 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 moeglichen 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 Hoehe mittels Invertierung einer
C             gaengigen Formel {m/s = 0.87*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   ----------------------------------------------------------------
      dimension ST(366)
    DSDADR = ( SDADR( TLT + 0.1 ) - SDADR( TLT - 0.1 ) ) / 0.2
    PSYKO  = 0.67
      H         = DSDADR / ( DSDADR + PSYKO )
    RGTMM  = RGTSU / 250.
      F1        = 1.98E-9 * ( 273. + TLT )**4
      F2        = 0.34 - 0.044 * SQRT( DT )
      F3        = 0.1 + 0.9 * S / ST(J)
      RNTMM  = 0.75 * RGTMM - F1 * F2 * F3
    UTB    = ( UT10 / 0.87 )**( 1. / 1.44 )
      WIWEG  = 86.4 * ( UT10 / 1.3 )
      FW        = 0.27 * ( 1. + WIWEG / 100. )
    C      = 0.79 - 0.034 * UTB + 0.028 * RGTMM
    ETPT   = C * ( H * RNTMM + (1. - H) * (SDADR( TLT ) - DT) * FW )
    IF ( ETPT .LT. 0. ) ETPT = 0.
    RETURN
    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: VEROEFFENTLICHUNGEN 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                        (K)
C      FF    = WINDGESCHWINDIGKEIT IN 10 M            (M/S)
C     N     = BEDECKUNGSGRAD                         (ACHTEL)
C     GLN   = GLOBALSTRAHLUNG BEI N=1...8            (W/M**2)
C                                BZW.     (J/H*CM**2)
C     XM     = MESSHOEHE FUER WIND                   (M)
C     WIND  = WINDGESCHWINDIGKEIT UMGERECHN.AUF 2 M  (M/S)
C     SRA   = RELATIVE SONNENSCHEINDAUER             (DIM.LOS)
C     SVP   = SAETTIGUNGSDAMPFDRUCK                  (MBAR)
C     VAP   = DAMPFDRUCK                             (MBAR)
C     EAED  = SAETTIGUNGSDEFIZIT                     (MBAR)
C     FU    = WINDFUNKTION
C     DELTA = NEIGUNG D.SAETTIGUNGSDAMPFDRUCKKURVE   (MBAR/K)
C     W     = TEMPERATURABHAENG. WICHTUNGSFAKTOR     (DIM.LOS)
C     WI    = AERODYNAM. TERM D. PENMAN-FORMEL       (MM/H)
C     LE    = SPEZIF. VERDUNSTUNGSENTHALPIE Z.UMRECHN. STRAHLG.-MM/D
C     FED   = DAMPFDRUCKFUNKTION (    -"-     )
C     RNL   = LANGWELL. ANTEIL D.STRAHLUNGSBILANZ    (MM/H)
C     AL    = ALBEDO                                 (DIM.LOS)
C     LE    = SPEZIF. VERDUNSTUNGSENTHALPIE (ZUR UMRECHNUNG
C             D. STRAHLUNGSWERTE IN MM/H)
C     XNET  = NETTOSTRAHLUNG (STRAHLUNGSBILANZ)      (MM/H)
C     EVAP  = STUENDLICHE VERDUNSTUNG (POTENTIELLE
C                   EVAPOTRANSPIRATION)      (MM/H)
      WIND  = FFF *(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   = rf*svp/100.
      EAED  = SVP-VAP
      FU    = 0.27 *(1.+(WIND*3600.*24./1000.) /100.)
      DELTA = 6.1078 *(EXP(17.08085*(T+1.) / (234.175+(T+1.))))-SVP
      W     = DELTA/(DELTA+0.67)
      WI    = EAED * FU * (1.-W)/24.
      LE    = (2501.- 2.36*T) * 0.1
      FT    = ((4.898E-7) / LE / 24.) * (273.15+T)**4
      FED   = 0.56-0.092 * 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*SIGMA*(T+273.1)**4
C     EVETUELL BESSERE PARAMETRSIERUNG DER BODENAUSSTRAHLUNG NACH
C     BRUIN UND HOLTSLAG
CC    RE=EPS*SIGMA*(TL+273.1)**4 + 0.07*(1.-AL)*GLN
      RNL=-(RH-RE)
C    UMRECHNUNG AUF JOULE PRO CM**2 UND STUNDE UND AUF MM /STUNDE
      RNL=RNL*0.36 / LE
C      XNET  = (1.-AL) * (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 Aehnlichkeit
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: ergaenzend wird ETPT nach unten durch Null begrenzt.
C    Literatur:
C         Schendel, ?, 1968.
C         Mintz, Y., and Walker, G.K., 1993.
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         Formel von Smith & Stopp (1978, zitiert nach Mintz & Walker, 1993).
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 -
```

```
C          sowie zur Formel von Schendel (1968) - s. Subr. ETP_SCHE.FOR.
C    Achtung: ergaenzend wird ETPT nach unten durch Null begrenzt.
C    Literatur:
C          Mintz, Y., and Walker, G.K., 1993.
C          Schendel, ?, 1968.
C          Thornthwaite, C.W., 1948.
C    Variablenbedeutung und Einheiten:
C    **** Input ****
C    TLT        Tagesmittel der Lufttemperatur in 2m [Grad C]
C    **** Output ****
C    ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C    ---------------------------------------------------------------
     ETPT = 0.16 * TLT
     IF ( ETPT .LT. 0. ) ETPT = 0.
     RETURN
     END

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

     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    Die Zitate finden sich bei Schroedter (1985).
C    In geringfuegiger Abwandlung gegenueber Siegert & Schroedter (1975)
C    wird anstelle des dortigen Faktors 'f' im folgenden das Verhaeltnis
C    von taeglicher astronomisch moeglicher 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    WI ist der sogenannten Waermeindex
C    fuer die Thornthwaite-Verdunstungsformel aus den langjährigen
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    ---------------------------------------------------------------
C    Literatur:
C    Schroedter, H., 1985.
C    Variablenbedeutung und Einheiten:
C    ETPT       Tageswert der potentiellen Verdunstung [mm/d]
C    J          Jahrestag oder Julianisches Datum
C    ST         taegliche astronomisch maximal moeglichen Sonnen-
C               scheindauer [h]
C    TLT        Tagesmittel der Lufttemperatur in 2m [Grad C]
C    WI         Waermeindex  (Subroutine waerme_i.for)
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)
```

```
      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         Mintz, Y., and Walker, G.K., 1993.
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 stuendlich
C     aufgeloesten 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     Schroedter, H., 1985.
C     Turc, L., 1961.
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    Monteith-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    Turc, L., 1961.
C    Wendling; U., 1995.
C    Wendling, U., Schellin, H.-G., und Thom„, M., 1991.
C    Wendling, U., und Mueller-Westermeier, G., 1995.
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 Programm-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/cm^2]
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)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Large mature trees												
providing ~=70%												
tree ground cover,												
clean cultivated	0.75	0.75	0.70	0.70	0.70	0.65	0.65	0.65	0.65	0.70	0.70	0.70
No weed control	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Trees providing ~=50%												
tree ground cover,												
clean cultivated	0.65	0.65	0.60	0.60	0.60	0.55	0.55	0.55	0.55	0.55	0.60	0.60
No weed control	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Trees providing ~=20%												
tree ground cover												
Clean cultivated	0.55	0.55	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.45	0.50	0.50
No weed control	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

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

annex 5

kc values for full grown decidous fruit and nut trees

	with ground cover crop*										without ground cover crop (clean cultivated, weed free)								
	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov		Mar	Apr	May	June	July	Aug	Sep	Oct	Nov
COLD WINTER WITH KILLING FROST : GROUND COVER STARTING IN APRIL																			
Apples, cherries:																			
humid, light to mod. wind	-	0.50	0.75	1.00	1.10	1.10	1.10	0.85	-		-	0.45	0.55	0.75	0.85	0.85	0.80	0.60	-
humid, strong wind	-	0.50	0.75	1.10	1.20	1.20	1.15	0.90	-		-	0.45	0.55	0.80	0.90	0.90	0.85	0.65	-
dry, light to mod.wind	-	0.45	0.85	1.15	1.25	1.25	1.20	0.95	-		-	0.40	0.60	0.85	1.00	1.00	0.95	0.70	-
dry, strong wind	-	0.45	0.85	1.20	1.35	1.35	1.25	1.00	-		-	0.40	0.65	0.90	1.05	1.05	1.00	0.75	-
Peaches, apricots pears, plums:																			
humid, light to mod. wind	-	0.50	0.70	0.90	1.00	1.00	0.95	0.75	-		-	0.45	0.50	0.65	0.75	0.75	0.70	0.55	-
humid, strong wind	-	0.50	0.70	1.00	1.05	1.10	1.00	0.80	-		-	0.45	0.55	0.70	0.80	0.80	0.75	0.60	-
dry, light to mod.wind	-	0.45	0.80	1.05	1.15	1.15	1.10	0.85	-		-	0.40	0.55	0.75	0.90	0.90	0.70	0.65	-
dry, strong wind	-	0.45	0.80	1.10	1.20	1.20	1.15	0.90	-		-	0.40	0.60	0.80	0.95	0.95	0.90	0.65	-
COLD WINTER WITH LIGHT FROST : NO DORMANCY IN GRASS COVER CROPS																			
Apples, cherries, walnuts,																			
humid, light to mod. wind	0.80	0.90	1.00	1.10	1.10	1.10	1.05	0.85	0.80		0.60	0.70	0.80	0.85	0.85	0.80	0.80	0.75	0.65
humid, strong wind	0.80	0.95	1.10	1.15	1.20	1.20	1.15	0.90	0.80		0.60	0.75	0.85	0.90	0.90	0.85	0.80	0.80	0.70
dry, light to mod.wind	0.85	1.00	1.15	1.25	1.25	1.25	1.20	0.95	0.85		0.50	0.75	0.95	1.00	1.00	0.95	0.90	0.85	0.70
dry, strong wind	0.85	1.05	1.20	1.35	1.35	1.35	1.25	1.00	0.85		0.50	0.80	1.00	1.05	1.05	1.00	0.95	0.90	0.75
Peaches, apricots,pears, plums, almonds, pecans:																			
humid, light to mod. wind	0.80	0.85	0.90	1.00	1.00	1.00	0.95	0.80	0.80		0.55	0.70	0.75	0.80	0.80	0.70	0.70	0.65	0.55
humid, strong wind	0.80	0.90	0.95	1.00	1.10	1.10	1.00	0.85	0.80		0.55	0.70	0.75	0.80	0.80	0.80	0.75	0.70	0.60
dry, light to mod.wind	0.85	0.95	1.05	1.15	1.15	1.15	1.10	0.90	0.85		0.50	0.70	0.85	0.90	0.90	0.90	0.80	0.75	0.65
dry, strong wind	0.85	1.00	1.10	1.20	1.20	1.20	1.15	0.95	0.85		0.50	0.75	0.90	0.95	0.95	0.95	0.85	0.80	0.70

*** 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)

	April			May			June			July			August			September		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Grass	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90
Cereals	0.70	0.80	0.90	1.00	1.00	1.00	1.20	1.20	1.20	1.00	0.90	0.80	0.60	-	-	-	-	-
Maize	-	-	-	0.50	0.70	0.80	0.90	1.00	1.20	1.30	1.30	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Potatoes	-	-	-	-	0.70	0.90	1.00	1.20	1.20	1.20	1.10	1.10	1.10	1.10	1.10	0.70	-	-
Sugar beets	-	-	-	0.50	0.50	0.50	0.80	1.00	1.00	1.20	1.10	1.10	1.10	1.20	1.20	1.20	1.10	1.10
Leguminous plants	-	0.50	0.70	0.80	0.90	1.00	1.20	1.20	1.20	1.00	0.80	-	-	-	-	-	-	-
Plant-onions	0.5	0.70	0.70	0.80	0.80	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-	-	-	-	-
Sow-onions	-	0.40	0.50	0.50	0.70	0.70	0.80	0.80	0.90	1.00	1.00	1.00	1.00	0.90	0.90	0.70	-	-
Chicory	-	-	-	-	-	-	0.50	0.50	0.50	0.80	1.00	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Winter carrots	-	-	-	-	-	-	0.50	0.50	0.50	0.80	1.00	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Celery	-	-	-	-	-	0.50	0.70	0.70	0.70	0.80	0.90	1.00	1.10	1.10	1.10	1.10	1.10	-
Leek	-	-	-	-	0.50	0.50	0.50	0.50	0.70	0.70	0.80	0.80	0.80	1.00	0.90	0.90	0.90	0.90
Bulb/tube crops	-	-	-	-	0.50	0.70	0.70	0.90	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Pome/stone-fruit	1.00	1.00	1.00	1.40	1.40	1.40	1.60	1.60	1.60	1.70	1.70	1.70	1.30	1.30	1.20	1.20	1.20	1.20

R. A. Feddes: Crop factors in relation to Makkink reference-crop-evapotranspiration. In: Evaporatranpiration and Weather. TNO Comm. on Hydrol. Res., Proceed. and Inform., no. 39, 1987

Plant factors (f) acc. to HAUDE

HAUDE formula: PET = f * SD14h **(SD14h = saturation deficit at 14 h)**

crop	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
oilseed rape	0.18	0.18	0.20	0.32	0.37	0.35	0.26	0.20	0.18	0.18	0.18	0.18
rye, barley	0.18	0.18	0.20	0.30	0.38	0.36	0.28	0.20	0.18	0.18	0.18	0.18
winter wheat	0.18	0.18	0.19	0.26	0.34	0.38	0.34	0.22	0.21	0.20	0.18	0.18
early potatoes	0.15	0.15	0.18	0.26	0.36	0.35	0.30	0.20	0.18	0.18	0.18	0.18
spring barley, oats	0.15	0.15	0.18	0.25	0.30	0.36	0.26	0.18	0.18	0.18	0.18	0.18
peas	0.15	0.15	0.18	0.25	0.35	0.36	0.34	0.30	0.20	0.18	0.18	0.18
beans	0.15	0.15	0.18	0.25	0.32	0.36	0.36	0.36	0.30	0.18	0.18	0.18
mod. early potatoes	0.15	0.15	0.18	0.20	0.25	0.35	0.36	0.35	0.25	0.18	0.18	0.18
late potatoes	0.15	0.15	0.18	0.20	0.22	0.30	0.35	0.36	0.30	0.18	0.18	0.18
sugar beet	0.15	0.15	0.18	0.15	0.23	0.30	0.36	0.32	0.26	0.19	0.14	0.14
maize	0.15	0.15	0.18	0.14	0.18	0.26	0.26	0.26	0.24	0.21	0.14	0.14
sunflower	0.15	0.15	0.18	0.20	0.25	0.32	0.36	0.34	0.25	0.18	0.18	0.18
grass	0.20	0.20	0.21	0.29	0.29	0.28	0.26	0.25	0.23	0.22	0.20	0.20

F. J. Löpmeier: The calculation of soil moisture and evapotranspiration with agrometeorological models (in German). Zeitschrift für Bewässerungswirtschaft, 29, 1994, 157 - 167

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

crop	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
barley	0.15	0.16	0.2	0.28	0.5	0.75	0.9	0.96	1.00	1.00
peas	0.2	0.17	0.16	0.2	0.29	0.38	0.47	0.065	0.8	0.9
sugar beet	0.2	0.17	0.15	0.15	0.16	0.2	0.27	0.4	0.7	1.00
potatoes	0.15	0.15	0.15	0.2	0.35	0.48	0.6	0.72	0.78	0.8
maize	0.15	0.15	0.16	0.17	0.18	0.25	0.38	0.55	0.74	0.93
beans	0.15	0.16	0.18	0.22	0.35	0.45	0.6	0.75	0.88	0.92
winter wheat	0.15	0.15	0.3	0.55	0.8	0.95	1.00	1.00	1.00	1.00

b kc according to days after effective plant cover

crop	10	20	30	40	50	60	70	80	90	100
barley	1.00	1.00	0.8	0.4	0.2	0.1	0.05	.	.	.
peas	0.86	0.72	0.5	0.32	0.15	0.1	0.05	.	.	.
sugar beet	1.00	1.00	1.00	0.98	0.91	0.85	0.8	0.75	0.7	0.65
potatoes	0.8	0.8	0.75	0.74	0.72	0.68	0.6	0.3	0.2	0.15
field maize	0.93	0.93	0.9	0.87	0.83	0.77	0.7	0.3	0.2	0.15
sweet maize	0.91	0.91	0.88	0.8	0.7	0.5	0.25	0.15	.	.
beans	0.92	0.86	0.65	0.3	0.1	0.05	.	.	.	.
winter wheat	1.00	1.00	1.00	0.95	0.5	0.2	0.1	0.05	.	.

J. L. Wright : New evapotranspiration crop coefficients. Journ. Irrigation and Drainage, 108, 1982, p. 57 ff

Seasonal consumptive use coefficients, kc, for irrigaed crops in Western United States (values for Blaney-Criddle formula)

Crop	Consumptive use coefficient (kc)		
	more humid		**more arid**
Beans	0.60	to	0.70
Maize	0.75	to	0.85
Cereals	0.75	to	0.85
Oil seeds	0.65	to	0.75
Orchard, decid.	0.60	to	0.70
Grass	0.75	to	0.85
Potatoes	0.65	to	0.75
Rice	1.00	to	1.10
Sugar beet	0.65	to	0.75
Tomatoes	0.65	to	0.70
Vineyard	0.50	to	0.60

M. E. Jensen, R. D. Burman and R. G. Allen (eds): Evapotranspiration and Irrigation Water Requirements, 1990

Crop coefficients (examples for Italy) for PET

winter wheat															
Crop coefficients for the period following winter dormancy:															
decade=	1/2	2/2	3/2	1/3	2/3	3/3	1/4	2/4	3/4	1/5	2/5	3/5	1/6	2/6	3/6
Kc =	0.30	0.30	0.40	0.50	0.60	0.80	0.90	1.0	1.0	1.0	1.0	1.0	0.90	0.70	0.50
spring wheat															
Crop coefficients for a 150 day wheat variety from the emergence stage:															
decade=	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Kc =	0.30	0.30	0.40	0.70	1.0	1.0	1.0	1.0	1.0	1.0	0.90	0.80	0.70	0.50	0.40
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	1.0	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	

FAO: Early agrometeorological crop yield assessment. FAO Plant Production and Protection Paper no. 73, Rome 1986, p. 47 ff

annex 5

Preliminary crop coefficients for vegetables (Forschungsstelle Geisenheim)
kc dependent on development stage, (AET = PET(Penman) * kc)

vegetable	stage 1	stage 2	stage 3	stage 4
cauliflower	from planting	diam. 30 cm	diam. 70 cm	height > 60 cm
	0.5	0.8	1.2	1.4
broccoli	from planting	> 4th leaf	> 8th leaf	> 12th leaf
	0.5	0.8	1.2	1.4
bush beans	from emergence	> 6th leaf	from pod developm.	
	0.5	0.8	1.0	
chinese cabbage	from planting	> 5th leaf	canopy closed	
	0.5	0.8	1.2	
cucumbers	from emergence	begin of flowering	begin of harvest	
	0.5	0.8	1.2	
endives	from planting	> 6th leaf	> 8th leaf	
	0.5	0.8	1.2	
tomatoes	from planting	height > 0,75 m	height > 1,0 m	
	0.5	0.8	1.2	
potatoes (early)	from planting	first shoots	main leaf developm.	canopy closed
	0.5	0.8	1.0	1.2
green cabbage	from planting	> 6th leaf	> 10th leaf	
	0.5	0.8	1.2	
grain-maize	from emergence	height > 0,5 m	height > 1,0 m	height > 1,5 m
	0.4	0.5	0.6	0.8
kohlrabi	from planting	> 5th leaf	bulb daim 2 cm	
	0.5	0.8	1.2	
headed cabbage	from planting	> 7th leaf	> 10th leaf	begin of bulb devel.
	0.5	0.8	1.2	1.4
lettuce	from planting	diam. > 15 cm	> diam. 25 cm	
	0.5	0.8	1.2	
carots	from emergence	> 4th leaf	> 7th leaf	canopy closed
	0.5	0.8	1.2	1.4
leek	from planting	diam. shaft > 1 cm	diam. shaft > 1,6 cm	diam. shaft >2 cm
	0.5	0.8	1.2	1.4
broad beans	from emergence	height > 10 cm	begin of flowering	pods visible
	0.5	0.8	1.2	1.4
brussels sprouts	from planting	> 5th leaf	canopy closed	sprout initials
	0.5	0.8	1.2	1.4
beetroot	from emergence	> 4th leaf	> 8th leaf	canopy closed
	0.5	0.8	1.2	1.4
asparagus	from end of cutting	from complete devel.	from September	
	0.5	of phyllokladia 0,8	0	
celery	from planting	> 6th leaf	begin of tuber devel.	canopy closed
	0.5	0.8	1.1	1.4
spring cereals	from emergence	canopy closed	begin of hard dough	
	0.2	0.8	0	
onions (summer)	from emergence	> 4th leaf	> 6th leaf	from middle of
	0.5	1.0	1.2	august 0
potatoes (late)	from planting	first shoots	main leaf devel.	canopy closed
	0.2	0.6	0.9	1.1
spinach (spring)	from emergence	> 3th true leaf	> 6th leaf	

	0.5	0.8	1.0	
sugar beet	from emergence	> 4th leaf	canopy closed	> 12 cm beet diam.
	0.2	0.4	0.6	0.8

acc. to Paschold & Zengele, 1996

annex 5

Crop coefficient (kc) for field and vegetable crops for different stages of crop growth and prevailing climatic conditions

Crop	Humidity	RHmin	>70%	RHmin	<20%
	wind [m/s]	0 - 5	5 - 8	0 - 5	5 - 8
	Crop stage:				
Barley	3	1,05	1,10	1,15	1,20
Beans (green)	3	0,95	0,95	1,00	1,05
"	4	0,85	0,85	0,90	0,90
Beans (dry) and pulses	3	1,05	1,10	1,15	1,20
Beets (table)	3	1,00	1,00	1,05	1,10
"	4	0,90	0,90	0,95	1,00
Carrots	3	1,00	1,05	1,10	1,15
Celery	3	1,00	1,05	1,10	1,15
Maize (grain)	3	1,05	1,10	1,15	1,20
Crucifers (cabbage)	3	0,95	1,00	1,05	1,10
Cucumber	3	0,90	0,90	0,95	1,00
Lettuce	3	0,95	0,95	1,00	1,05
"	4	0,90	0,90	0,90	1,00
Oats	3	1,05	1,10	1,15	1,20
Onion (dry)	3	0,95	0,95	1,05	1,10
Peas	3	1,05	1,10	1,15	1,20
Potato	3	1,05	1,10	1,15	1,20
Radishes	3	0,80	0,80	0,85	0,90
Spinach	3	0,95	0,95	1,00	1,05
Sugarbeet	3	1,05	1,10	1,15	1,20
"	4	0,90	0,95	1,00	1,00
Sunflower	3	1,05	1,10	1,15	1,20
Tomato	3	1,05	1,10	1,20	1,25
"	4	0,60	0,60	0,65	0,65
Wheat	3	1,05	1,10	1,15	1,20

crop stages: **3 = mid season**
4 = at harvest or maturity

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

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

winter wheat:

time	f	f
	RÖTZER (1996)	ERNSTBERGER (1987)
Jan.	0.30	0.30
Feb.	0.30	0.30
Mar.	0.35	0.35
Apr.	0.50	-
tillering	0.81	0.70
stem elongation - heading	sin (0,81 - > 1,30)	0,92 / 1,20
heading - end of flowering	1.30	1,20 / 1,30
end of flowering - hard dough	sin (1,30 - > 0,95)	1,10 / 0,95
hard dough - harvest	0.95	0.95
harvest - Aug.	0.70	0.70
Sep.	0.60	0.60
Oct.	0.45	0.45
Nov.	0.30	0.30
Dec.	0.30	0.30

spring wheat:

time	f
	RÖTZER (1996)
Jan.	0.30
Feb.	0.30
Mar. - emergence	0.35
emergence - heading	sin (0,35 - > 1,35)
haeding - end of flowering	1.35
end of flowering - hard dough	sin (1,35 - > 0,95)
hard dough - harvest	0.95
harvest - begin of green manure	0.70
begin of green manure - Aug.	1.15
Sep.	0.85
Oct.	0.70
Nov.	0.40
Dec.	0.40

silage maize:

time	f	f
	RÖTZER (1996)	ERNSTBERGER (1987)
Jan.	0.30	0.30
Feb.	0.30	0.30
Mar.	0.30	0.30
Apr. - emergence	0.40	0.40
emergence - flag leaf em.	sin (0,4 - > 1,05)	0,55 / 0,70 / 0,85
flag leaf em. - end of flowering	1.05	1.05
end of flowering - harvest	sin (1,05 - > 0,70)	0,90 / 0,70
harvest - oct.	0.45	0.45
Nov.	0.30	0.30
Dec.	0.30	0.30

Th. Rötzer: Neuartige Karten der Phänologie und des Wasserhaushaltes von Bayern unter Berücksichtigung möglicher künftiger Klimaverhältnisse, 1996
H. Ernstberger: Einfluß der Landnutzung auf Verdunstung und Wasserbilanz, 1987

Table 1: Availability and system requirements of available irrigation models within the COST 711 member countries ANNEX 6

Model /Vers. no. (country)	**AMBAV** / 7.96 (Germany)	**IRRFIB-1**/ 1.0 (Slovenia)	**SISETA** / - (Slovakia)	**BIDRICO 2**/ 2.0 (Italy)	**Beregeningsplanner**/ 2.0 (Netherlands)	**BEREST**/ 90.4 (Germany)
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programming language	FORTRAN 77	DELPHI	Excel + Visual Basic	TURBOBASIC	QBasic (DOS) Visual Basic (Windows)	Turbo-Pascal
dialogue language	German or english	Slovene or english	Slovak	Italian	Dutch	German
documentation or manual language (pages)	German or english (12 p.)	Slovene or english (5p.)	Slovak (10p.)	Italian or english (~150p)	Dutch (45p.)	German (54 p.)
availability source code / exe-file	no / yes	no/yes	no/yes	no/yes	no / yes	no/yes
conditions for usage	testing within COST 711	test version	test version	Research: free of charge anyth. else: 250000 LIT	500,- Dfl.	for research and education
hardware requirements	PC 386 at least	PC 386 at least	PC AT/Pentium	PC 80286 or higher	PC 286 at least	PC 286 at least
operating system	DOS	WINDOWS 3.x	WINDOWS 95 WINDOWS NT	DOS WINDOWS 3.1	DOS/WINDOWS 3.11 WINDOWS 95	DOS
minimum RAM	4 MB	4 MB	16 MB	512 KB	640 KB	480 KB
disc space required	8 MB	2 MB	?	5 MB	2 MB	720 KB
recommended user	local met. advisory service	local met. advisory service / farmers	?	central or local met. advisory service / farmers	local met. advisory service/ farmers	local met. advisory service / farmers

Table 2: Characteristic of fundamental meteorological processes and meteorological input requirements of available irrigation models within the COST 711 member countries

Model /Vers. no. (country)	**AMBAV** / 7.96 (Germany)	**IRRFIB-1**/ 1.0 (Slovenia)	**SISETA** / - (Slovakia)	**BIDRICO 2** / 2.0 (Italy)	**Beregeningsplanner** /2.0 (Netherlands)	**BEREST** / 90.4 (Germany)
fundamentals process method driving variables output	potential evapotranspiration Penman-Monteith temp., wind vel.., humidity, global rad. ETP	pot. evapotranspiration Penman-Monteith temp., wind vel., humidity, sunshine ETP - corr.	pot. evapotranspiration ? ETPcrop	crop specific pot. ET (modified FAO) ET0, phenology, soil moisture, rootdepth actual ETcrop	pot. ET ? ? actual ETcrop	crop spec. ET Turc/Wendling temp., wind vel., global radiation, crop cover, root depth actual ETcrop
meteorological input data data format	ASCII	ASCII	ASCII	ASCII	ASCII	ASCII
variable / unit / time resolution / type	air temperature / °C 1h / average	air temperature dry / °C 1 day / average 7, 14, 21 o´clock	air temperature / °C 1 week / diurnal average	min. air temp. dry / °C 1 day / minimum		
		air temperature wet / °C 1 day / average 7, 14, 21 o´clock		max. air temp. dry / °C 1 day / maximum		
	rel. humidity / % 1h / average	rel. air humidity / % 1 day / average 7, 14, 21 o´clock	saturation deficit / ? 1 week / diurnal average	reference ET0 / mm 1 day / daily sum	evaporation / mm 1 day / daily sum	ET0 / mm 1 day / daily sum
	global radiation / W m^{-2} 1h / sum	sunshine duration / h 1 day / daily sum				
	wind velocity / m s^{-1} 1 h / average	wind velocity / m s^{-1} 1 day / average 7, 14, 21 o´clock				
	precipitation / mm 1h / sum	precipitation / mm 1day / daily sum at 7 o´clock	precipitation / mm 1 week / diurnal average	precipitation / mm 1 day / daily sum	precipitation / mm 1 day / daily sum	precipitation / mm 1 day / daily sum
	cloud cover / octas 1h / moment observation			rain intensity / mm h^{--1} 1 day / average (optional)		
use of weather forecast data	possible up to 5 days (or more)	possible up to 7 days	?	not possible	possible up to 5 days	possible up to 5 days

Table 3: Characteristic of fundamental soil processes and soil data input requirements of available irrigation models within the COST 711 member countries **ANNEX 6**

Model /Vers. no. (country)	**AMBAV** / 7.96 (Germany)	**IRRFIB-1**/ 1.0 (Slovenia)	**SISETA** / - (Slovakia)	**BIDRICO 2** / 2.0 (Italy)	**Beregeningsplanner** /2.0 (Netherlands)	**BEREST** / 90.4 (Germany)
fundamentals						
process	water balance / water fluxes	water balance	water balance	water balance	water balance	water balance
method	Richard´s equation	capacity approach	capacity approach	capacity approach	potential approach (?)	capacity approach
driving variables	ETPcrop, precipitation	ETPcrop, precipitation	ETPcrop, precipitation	ETcrop, precipitation, irrigation	ET, precipitation, irrigation, groundwater level	ET0, precipitation, irrigation, groundwater level
parameters	pF-curves, hydraulic conductivity	field capacity, wilting point, saturation	available water capacity	field capacity, wilting point, water table	pF-curves, hydraulic conductivity ?	field capacity, wilting point, retard. coeff.
final output	ETA, soil water contents, water fluxes, irrigation amounts and schedule	percentage of available water, irrigation amounts	percentage of available water, irrigation amounts	soil moisture, easily avail. water (EAW), water deificit, EAW depletion time,runoff, percolation, capillary rise, irrigation amounts and schedule	soil water contents, water fluxes,run-off, irrigation amounts	ETA, soil water contents, water fluxes, irrigation amounts and schedule
soil input data						
data format	ASCII	ASCII	ASCII	ASCII	ASCII	ASCII
variable / unit depth / depth resol. type	soil type / - 2 m / 21 layers initial input	wilting point / vol% root depth / 1 layer initial input	light-middle-heavy soil/ - ? / 1 layer initial input	wilting point /g g^{-1} max.explor.depth / 2 l. initial input	soil type / - 2 m / ? initial input	wilting point / mm 2 m / ? initial input
	water cont. / vol% or %f.c. 2 m 21 layers / initial/permanent inp.	field capacity/ vol % root depth / 1 layer initial input		field capacity /g g^{-1} max. explor.depth /2 l. initial input		field capacity / mm 2 m / ? initial input
	root distribution / % 2 m / 21 layers			bulk density /g cm^3/ max. explor.depth /2 l. initial input		
	% soil evaporation of ET initial input			gravel content /g g^{-1} max. explor.depth/ 2 l. initial input		
	standing water at soil surface initial value			water table/cm bel. gr. periodic (free inter-vall, lin. interpol.)	water table/cm below gr. periodic, every 14 days	water table/dm bel. gr initial input
Remarks					soil classification acc. to "Starinfg reeks"	soil classification acc. to "regional site type"

Table 4: Characteristic of crop related processes, crop input data requirements and crops covered by available irrigation models within the COST 711 member countries **ANNEX 6**

Model /Vers. no. (country)	**AMBAV** / 7.96 (Germany)	**IRRFIB-1**/ 1.0 (Slovenia)	**SISETA** / - (Slovakia)	**BIDRICO 2** / 2.0 (Italy)	**Beregeningsplanner** / 2.0 (Netherlands)	**BEREST** / 90.4 (Germany)
fundamentals						
process	crop specific ET	crop specific ET	crop specific ET	root depth / crop yield response, crop spec. ET	plant development / root depth/water requirements	root depth / crop spec. ET water requirements
method	plant specific coefficients	plant specific coeff	plant specific coefficients biological curves	spec. deepening rates	standard dev. stages/ max. effective root depth	stand. curves ontogenesis, soil cover,crop spec. coeff
driving variables	lai, crop height		ETPcrop	phenol.,soil moisture, temp., explorable soil	opt. and max. pF	ontogenesis, draught sensitivity, soil cover
final output	ETPcrop	ETPcrop		rooting depth / actual crop yield	rooting depth, irrigation threshold	rooting depth, irrigation demand
crop data						
data format	ASCII	ASCII	ASCII	ASCII	ASCII	ASCII
data unit type	phenological stages julian day initial / periodic (at key stages)	sowing date day - month initial input	?	sowing date / veg. renew. julian day initial input	emergence date day - month	sowing date day - month initial input
	crop height (min/max) / cm initial / permanent input	rooting depth cm initial input		development stages elapsed time initial input	soil coverage %	development stages day months (optional) periodic
	leaf area index initial / permanent input					
	albedo initial input					
	max. rooting depth initial input					
crops covered	sugar beet, maize, wheat, w. barley, rye, oats, potatoes, pasture, fruit trees, coniferous forest, deciduous forest	sugar beet, maize, potatoes, pasture, alfalfa, apples, peaches, pears, apricots, cherries, plums, kiwi, strawberries, cabbage, tomatoes, salads, endives, cucumber, cauliflower, beets, onions	sugar beet, maize, wheat, barley, rye, pasture, alfalfa, soybean, sunflower, rape, hop, peas, beans, lentil, apples, grape, cabbage, tomatoes, pepper	sugar beet, maize, wheat, potatoes, soybean, sunflower, grape	all crops (grass, arable and vegetable) ?	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

ANNEX 6

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)

Model /Vers. no. (country)	**AMBAV** / 7.96 (Germany)	**IRRFIB-1**/ 1.0 (Slovenia)	**SISETA** / - (Slovakia)	**BIDRICO 2** / 2.0 (Italy)	**Beregeningsplanner** / 2.0 (Netherlands)	**BEREST** / 90.4 (Germany)
meteorological parameters						
included in program code (fixed)	-	-		-	-	-
input by dialogue	-	+	?	-	+	+
separate parameter file	+	+		+	+	+
(file format)	ASCII	ASCII		ASCII	ASCII	ASCII
crop parameters						
included in program code (fixed)	-	-		-	-	+
input by dialogue	+	-	?	-	+	-
separate parameter file	+	+		+	+	-
(file format)	ASCII	ASCII		ASCII	ASCII	-
soil parameters						
included in program code (fixed)	-	?	?	-	-	+ (default)
input by dialogue	-			-	+	+
separate parameter file	+			+	+	-
(file format)	ASCII			ASCII	ASCII	-
Reference	Löpmeier (1983)	Matajc (in preparation)	Sláma & Pýcha (?)	Danuso et al. (1995)	?	Wenkel & Mirschel (1991)

annex 6

Table 6: Sources of other evapotranspiration models

Model	Contact person	Adress	Availability/ price	Reference
BIGSIM	J. E. Ayars	Water Management Research Lab., 2021 South Peach Ave., Fresno CA 93727-5951 / USA phone: +1 209 453-3100 FAX : +1 209 453-3122 e-mail: JAyars@asrr.arsusda.gov	free of charge	Ayars & Schoneman (1986)
CROPWAT	M. Smith	Land & Water Develeopment Div. FAO, Via delle Terme di Caracalla 00100 Rome / Italy phone: +39 6 52253818 FAX: +39 6 52256275 e-mail: Martin.Smith@fao.org	exe file 19,- US$	Smith (1992)
CWR - VB	D. Clarke	Inst. of Irrigation Studies, Univ. of Southampton, Southampton SO17 1BJ / UK phone: +44 1703 593728 FAX : +44 1703 677519 e-mail : DC@soton.ac.uk	exe file on request	Clarke & El-Askari (1996)
IMS	T. Hess	Dept. of Water Management Cranfield Univ., Silsoe College Silsoe, Bedford, MK45 4DT / UK phone: +44 1525 863292 FAX : +44 1525 863300 e-mail: T.Hess@cranfield.ac.uk	exe file £ 150.00	
Citrus Irrgation Scheduling	D. Ayers	Univ. of Florida, PO Box 110340 Gainesvile, FL 32611-0340 / USA phone: +1 904 392 7853 FAX: +1 904 392 3856 e-mail: softsub@gnv.ifas.ufl.edu	exe file 35.00 US$	Zazuata (1995)
SWBACROS	C. Babajimopoulos	Dept. of Hydraulics, Soil Sci. & Agric. Engineering, School of Agriculture, Aristole University Thessaloniki 540 06 / Greece FAX: +30 31 998767 e-mail: babajim@olymp.ccf.auth.gr	exe file for qualified users for cost of reproduction, manual, shipping and handling	Babajimopoulos et al. (1995)

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; JTBER; 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 til 10 cm (mm)
9 = water content til 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

JTBER = 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) (13I4)
...

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 (JTs)*
2nd line: julian day of beginning water uptake (JTz)
3rd line: julian day of maximum water use (JTmax)
4th line: julian day of begin of reducing water use (JTr)
5th line: julian day of harvesting (JTe)

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: *I3,1X,I2,I3,1X,I4,1X,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: characteristical phenological stages of plants for the model AMBAV (the correction in brackets are calculated internally)

	winter wheat	***spring wheat***	***winter barley***	***maize***	***spring barley***	***sugar beet***
JT_s	*1 or emergence*	*emergence (+5)*	*1 or emergence*	*emergence*	*emergence*	*emergence (+5)*
JT_z	*stem elongation (-5)*	*stem elongation (-10)*	*stem elongation (-10)*	*flag leaf emergence (-35)*	*stem elongation (-5)*	*canopy closed (-20)*
JT_{max}	*flowering (-5)**	*inflorescence emergence (+5)*	*flowering **	*flowering **	*inflorescence emergence (-5)*	*canopy closed (+10)*
JT_r	*hard dough*	*hard dough*	*hard dough*	*dough stage (-14)*	*hard dough*	*harvest (-14)*
JT_e	*harvest*	*harvest*	*harvest*	*harvest*	*harvest*	*harvest*

	potatoes	***rye***	***conif.forest***	***decid.forest***	***fruit trees***	***oilseed rape***	***grassland***
JT_s	*emergence (+5)*	*emergence*	*1*	*60*	*60*	*emergence*	*phenological stages are internally set*
JT_z	*emergence (+15)*	*stem elongation*	*May shoot*	*leaf emergence*	*flowering*	*stem elongation*	
JT_{max}	*canopy closed (+5)*	*inflorescence emergence (+5)*	*May shoot (+14)*	*leaf emergence (+14)*	*flowering (+14)*	*begin of flowering*	
JT_r	*wilting. (+16)*	*hard dough*	*330*	*leaf colour change*	*leaf colour change*	*end flowering (+12)*	
JT_e	*harvest*	*harvest*	*365*	*leaf fall*	*leaf fall*	*harvest*	

* 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, Bn, Zx, Zy, Zi3, Zi6, Zi10, QB, RF*

format: *I3, 4F6.1, 2I2, I4, F5.1, I5 ,F6.1, 2I3 2F5.1, F4.1, I3, 2F4.1, 3I3, 3I5, I2, I5*

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/cm^2
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 menue 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

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

meaning of parameters:

SCHICHT	= number of the layer (1 to 21)
WASGEH	= water content (volumetrie 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.

ZWIsoiltypecrop.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 ZWIsoiltype-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*

soil type	***abbreviation***	m_T %	m_U %	w_{FK} %	w_{WP} %
silt	*U*	*4.00*	*88.00*	*35.1*	*14.9*
sandy silt	*Us*	*4.00*	*65.00*	*30.5*	*10.6*
sandy-loamy silt	*Uls*	*12.50*	*57.50*	*33.7*	*14.4*
light loamy silt	*Ul2*	*10.00*	*77.50*	*35.9*	*16.3*
medium loamy sil t	*Ul3*	*14.50*	*75.25*	*37.2*	*18.4*
very loamy silt	*Ul4*	*21.33*	*74.33*	*39.3*	*21.8*
light sandy loam	*Ls2(*)*	*20.00*	*45.00*	*35.2*	*16.8*
medium sandy loam	*Ls3*	*19.00*	*34.33*	*33.3*	*15.0*
very sandy loam	*Ls4*	*21.00*	*21.50*	*32.5*	*14.6*
silt loam	*Lu*	*23.50*	*60.00*	*38.2*	*20.5*
light clay loam	*Lt2*	*30.00*	*42.50*	*38.2*	*21.3*
medium clay loam	*Lt3*	*40.00*	*40.00*	*40.4*	*25.1*
silty clay loam	*Ltu*	*37.50*	*56.25*	*41.3*	*26.3*
sandy clay loam	*Lts*	*35.00*	*27.67*	*38.2*	*22.1*
light sandy clay	*Ts2*	*58.00*	*9.00*	*41.4*	*28.6*
medium sandy clay	*Ts3*	*43.00*	*9.00*	*38.8*	*24.1*
very sandy clay	*Ts4*	*30.00*	*9.00*	*35.0*	*18.4*
loamy clay	*Tl*	*55.00*	*31.50*	*42.3*	*29.5*
clay	*T*	*76.67*	*11.67*	*43.7*	*33.7*
sand	*S*	*2.50*	*5.00*	*10.0*	*0.7*
light silty sand	*Su2*	*2.50*	*17.50*	*15.5*	*2.1*
medium silty sand	*Su3*	*4.00*	*32.50*	*22.5*	*5.2*
very silty sand	*Su4*	*4.00*	*45.00*	*25.9*	*7.2*
silty loamy sand	*Slu*	*11.50*	*45.00*	*31.1*	*11.9*
light loamy sand	*Sl2(*)*	*6.50*	*15.00*	*19.5*	*3.8*
medium loamy sand	*Sl3*	*10.00*	*23.50*	*25.6*	*7.6*
very loamy sand	*Sl4*	*14.67*	*29.33*	*30.2*	*11.6*
light clay sand	*St2*	*10.00*	*6.25*	*20.5*	*4.5*
medium clay sand	*St3*	*19.00*	*9.33*	*29.4*	*11.6*

(*) 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.

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☜ 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 Sl2 (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*****

*****ZWIsoiltypecrop.station*****

*****ETP_year.station*****

parameters *JT; ETP(1 to 13)*

format: *I4, 13F5.1*

explanation of parameters: **ETP = potential evapotranspiration (mm/day)**

*****ETA_year.station*****

parameters: *JT; ETA(1 to 13)*

format: *I4, 13F5.1*

explanation of parameters: **ETA = actual evapotranspiration (mm/day)**

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

parameters: *JT;NFK(1 to 13)*

format: *I4,13F5.0*

explanation of parameters: **NFK = 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 beat
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 til 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)

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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 ZWI...-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 ZWI... 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