Approximate estimation of average actual evapotranspiration and soil water supply of cropped groundwater-affected sites

Klaus Bohne[a] Manfred Renger[b]

August 9, 2015

1 The problem

To evaluate the potential crop yield of a given site it may be helpful to know the average amount of soil water supply during summer that can be used for evapotranspiration. For a given period of time – in this study we consider April 1st to September 30rd –, soil water supply S comprises the plant available soil water of the root zone W_a, water withdrawal from the subsoil W_s, and capillary rise G from the groundwater table,

$$S = G + \Delta W_a + \Delta W_s \tag{1}$$

For this purpose, Rijtema (1968) has coined the technical term "maximum plant available soil water" already half a century ago. Since it is known that crop yield depends on the relation of actual to potential evapotranspiration, E_a/E_p, actual evapotranspiration is of interest as well. For evaluating actual evapotranspiration E_a of a selected area, let us assume that the soil water balance of that area adds up to zero:

$$P - E_a + \Delta W_a + \Delta W_s - R + G = 0 \tag{2}$$

where R is runoff. The area under consideration should be sufficient large to ensure that runoff or runon can be set to zero. Eq. (2) rearranged reads

$$\Delta W_a + \Delta W_s + G = E_a - P \tag{3}$$

Using Eq. (1) in Eq. (3) leads to

$$S = E_a - P \quad \text{or} \quad E_a = S + P \tag{4}$$

This imvestigation is meant to provide an easy-to-use transfer equation to obtain approximate values of soil water supply S and thus for E_a for a range of soil and site conditions. These conditions include standard values of soil hydraulic properties, depth to groundwater and average climatic data.

[a]Corresponding author: klaus.bohne@uni-rostock.de, Faculty of Agricultural and Environmental Sciences, University of Rostock.

[b]TU Berlin, School IV, Department of Ecology

2 Methods applied

2.1 Overview

To create the data basis needed, we used the well documented numerical simulation program "SWAP" (van Dam et al., 1997; Kroes et al., 1999; Kroes/van Dam (eds), 2003). This means that a surrogate reality was used to replace the real world (Razavi/Tolson/Burn, 2012). The SWAP program incorporates many years of research and was extensively tested by several research groups. Details of these investigations are reported by van Dam et al. (2008). Recently, Ma/Feng/Song (2015) used the model to find optimal irrigation scheduling in a selected region. By using this simulation model it was possible to consider a variety of different soil conditions subject to meteorologic data of 30 years. The data gathered from the model do not contain random errors due to spatial variability. As will be discussed later, this may be seen either as an advantage or a disadvantage. Measured multi-annual averages of summer precipitation and simulated ones of actual evapotranspiration for 17 soil classes were used to calculate soil water supply forming the basis to derive a transfer function. The transfer function enables users to evaluate soil water supply from easily available data.

2.2 The SWAP model

Based on a numerical solution of the Richards equation solved by an implicit finite-difference scheme, this model simulates the transient transport of liquid water, heat and solutes in soils due to impacts of daily weather conditions.

Initial and boundary conditions

The inital condition was defined as hydrostatic equilibrium with the groundwater table (Jury/Gardner/Gardner, 1991). In case of deep groundwater table, the equilibrium is approached very slowly. For that reason, soil water pressure head was limited to -63 hPa in accordance with observations (Renger et al., 2009). Since the effect of initial conditions is damped down during a very short time compared to the total simulation period of 30 years, it is not necessary to go into more details. The top of the soil profile was ruled by atmospheric boundary conditions as provided by the SWAP model. The model calculates potential evapotranspiration as grass reference evapotranspiration (Penman-Monteith method, Allen/Wright/Burman (1989)) using daily data of solar radiation, air temperature, humidity and wind speed. Crop parameters such as albedo, crop height, the extinction coefficient for diffuse and direct visible light and minimum canopy resistance were set to the values recommended by van Dam et al. (1997). SWAP uses the Feddes function to obtain actual transpiration from grass reference evapotranspiration in the case actual evapotranspiration is delimitated by soil water content. The reduction coefficient for root water uptake is a function of the soil water pressure head and the potential transpiration rate.

Precipitation along with air temperatures below zero centigrades is considered as snow and the generation and melting of snow covers is taken into account. Although the model generates surface runoff when infiltrability is exceeded while the surface storage is full, this was not used here. Since the effect of hill slopes was not taken into account, the surface storage was set to 2 cm to avoid surface runoff.

The bottom boundary condition used here was a plane with zero pressure head representing the groundwater table. The simulation model SWAP does not consider the drawdown of the groundwater table which may occur when capillary rise gets not compensated by lateral groundwater flow in the aquifer.

Soil hydraulic properties

The model describes soil hydraulic properties by the Mualem-van Genuchten equations (van Genuchten, 1980)

$$
\begin{aligned}
\theta(h) &= \theta_r + \frac{\theta_s - \theta_r}{(1 + (\alpha\, h)^n)^m} \\
K(h) &= K_s \frac{\left(1 - (\alpha\, h)^{n-1}\, (1 + (\alpha\, h)^n)^{-m}\right)^2}{(1 + (\alpha\, h)^n)^{mx}} \quad \text{for} \quad m = 1 - \frac{1}{n}
\end{aligned} \tag{5}
$$

where θ denotes soil water content, h pressure head (taken positive here) and K soil hydraulic conductivity. To account for hysteresis of the water retention function and following a suggestion made by Luckner/van Genuchten/Nielsen (1989), the α parameter for wetting conditions was doubled compared to drying conditions. Since soil temperature was part of the simulation, soil hydraulic properties changed with soil temperature. Effects of macroporisity and preferential flow were not considered.

2.3 Simulations performed

In this study, the soil profile near the surface was subdivided into compartments of 1 cm thickness increasing downward up to 20 cm. The total simulation depth was 600 cm.

For each of the soil classes considered, simulation runs were performed using values of the groundwater table depth beneath soil surface between 100 and 340 cm. As will be shown later, in most soils except silt, capillary rise of groundwater becomes very small for any water table depth larger than 300 cm. For that reason, application of model results is not restricted to soils with less than 300 cm groundwater table depth.

Values of the hydraulic soil parameters were taken from a data base (Renger et al., 2009) that provides characteristic soil hydraulic parameters of soil texture classes (Table 2). From these, 17 soils were selected for simulation (Table 3). To provide an assessment of the texture classes used in Tables 2 and 3, the classification of Twarakavi/Simunek/Schaap (2010) was added to german terms.

In this study, three sites with different meteorological conditions (Table 4) were selected. Simulation periods started on April, 1st 1961 and ended on March, 31st 1991 covering the entire period of 30 years. Please note that the precipitation data used here were corrected for systematic measurement errors (Richter, 1995). This correction yields an increase of measured values by 9 to 20%. The weather station Magdeburg showed the dryest conditions. To extend results even more towards semi-arid conditions, the weather record of this station was modified. The original record contained seven years out of 30 with precipiation excess ($P - E_p > 0$). These data were replaced by data of the seven dryest years from the same station. The entire data set generated comprises 146 simulations runs of 30 years each.

The Feddes function to reduce potential transpiration to actual transpiration uses two main parameters *hlim*3 (see Table 3) applying to high or low potential evapotranspiration ($E_p > 5\,\mathrm{mm\,d^{-1}}$ or 2 to $5\,\mathrm{mm\,d^{-1}}$, respectively). In case of $E_p < 2\,\mathrm{mm\,d^{-1}}$ no reduction is used. The *hlim* parameters mark the soil water pressure head, where transpiration reduction starts. Experiments of crop yield under conditions of irrigation have shown, that plant growth gets restricted when the soil water content drops below 60 to 40% of plant available field capacity. For that reason the *hlim* parameters were based on these threshold values.

The only crop considered here was grass of 12 cm height covering the soil surface completely over the entire year. This study makes no attempt to consider different crops other than grass.

Soil water supply to crops is a site property that can be used to characterize the productivity of crops competing against water shortage. It is not an indicator to analyze the effects of water excess. Previous attempts (Miegel/Bohne/Wessolek, 2013) have shown that anaerobiosis can have a tremendous effect on water uptake by plant roots. Since this study is focussed on soil water supply to crops under conditions of water shortage, anaerobiosis is not considered here. That means that soils whose field capacity is above (θ_s − 0.05) cm^3cm^{-3} are excluded from simulations. The underlying assumption is that values of soil water content around field capacity occur quite frequently and root water uptake is restricted when soil air content goes below 0.05 cm^3cm^{-3}.

3 Hydropedotransfer function

Simulation results include long-term averages of actual evapotranspiration which may be used to evaluate soil water supply (Eq. 4). A generalized use of results requires an estimating function to transfer easily available data into required results without performing simulations of soil water dynamics.

Since soil water supply cannot rise above the atmospheric demand, a saturation function should be used to represent soil water supply. We found the empirical function

$$\hat{S} = \frac{D}{1 + \frac{1}{\left(p_1 W_a + p_2\, q_{max}^{p_3}\right)^{p_4}}} \tag{6}$$

useful for this purpose.

D	in cm	atmospheric demand, $D = E_p - P$
E_p	in cm	potential evapotranspiration during the growing season
P	in cm	precipitation during the growing season (in this study: April to September)
W_a	in cm	plant available water of the root zone
q_{max}	in cm d^{-1}	approximate maximum steady-state flow from the groundwater table to the root zone

W_a was approximated by $W_a = (\theta_c - \theta_{pwp})d_r$, where θ_c and θ_{pwp} (in cm^3cm^{-3}) denote the water content at field capacity and at permanent wilting point, respectively, while d_r (in cm) respresents the depth of the root zone. If local data do not render it possible to estimate W_a, standard values of soil hydraulic parameters may be used to calculate θ_c and θ_{pwp} (see Table 2). The values used in this investigation are shown in Table 3. To represent soil hydraulic properties by a single variable, the approximate maximum value of the steady-state flow rate of capillary rise was used. For steady-state vertical flow, the pressure head profile for any chosen q_i is given by

$$z(q_i,\, h_{min}) = \int_0^{h_{min}} \left(\frac{q_i}{K(h)} + 1\right)^{-1} dh \tag{7}$$

(Jury/Gardner/Gardner, 1991; Bohne, 2005).

z	in cm	vertical coordinate, $z = 0$ at groundwater table
q_i	in cm d^{-1}	flow rate
K	in cm d^{-1}	unsaturated soil hydraulic conductivity
h	in cm	soil water pressure head

Values of $z(q, h_{min})$ were calculated from Eq. (7) for a range of flow rates and the soil hydraulic parameters of texture classes (Renger et al., 2009). For $K(h)$, the van-Genuchten-Mualem model of hydraulic conductivity was used (van Genuchten, 1980). A pressure value threshold of $h_{min} = -3200$ hPa was chosen to obtain an approximate maximum capillary steady-state flow rate depending solely on soil hydraulic properties and flow distance z. The advantage of this threshold is that data on unsaturated soil hydraulic conductivity are still available to some extent in this range. As shown by Miegel/Bohne/Wessolek (2013), the selection of h_{min} has only a moderate effect on q. To bypass processing of Eq. (3), an easy-to-use approximation was prepared, which is given by

$$q_{max}(z) = c_1 z^{c_2} \tag{8}$$

The parameters c_1 and c_2 depend on texture and are shown in Table 5. Please note that q_{max} represents steady-state maximum flow rates depending solely on soil hydraulic conductivity of the layer below the root zone and the flow distance z between the groundwater table and the lower boundary of the root zone without any regard to site, climate, and plant-specific conditions.

4 Results

Fitting the parameters p_1 to p_4 of Eq. (6) to SWAP-simulated data of actual evapotranspiration yielded reasonable results. The goodness of fit was checked by the root mean square error, given by

$$RMSE = \sqrt{\frac{\left(S - \hat{S}\right)^2}{N - 1}} \tag{9}$$

Eq. (9) yields a value of $RMSE = 1.325$ cm. Since the average "observed" soil water supply was 8.50 cm, the relative $RMSE$ was 0.156. The correlation coefficient between observed and predicted values of soil water supply was $R = 0.98$. The residuals follow the normal distribution.

Further the coefficient of model efficiency (Willmott/Robeson/Matsura, 2012)

$$COE = 1 - \frac{\sum_{j=1}^{N}\left(y_j - \hat{y}_j\right)^2}{\sum_{j=1}^{N}\left(\left|y_j - \bar{y}\right| + \left|\hat{y}_j - \bar{y}\right|\right)^2} \tag{10}$$

was calculated where y denotes the dependent variable under consideration. The bar denotes the average and the hat the calculated values. The application of Eq. (10) yielded $COE = 0.989$. These parameters indicate a reasonable fit of Eq. (6) to data of surrogate reality (Fig. 1). Please keep in mind that e.g. the annual distribution of precipitation has an effect on soil water supply but cannot be considered in an equation that operates on long-term averages of meteorologic data. The values of fitted parameters of Eq. (6) and some details to characterize the goodness of fit are shown in Table 1.

Table 1: Performance and parameters of the hydropedotransfer function (Eq. 6)

p_1	0.04867	Number of data sets	147
p_2	2.98841	Average supply "observed", cm	8.508
p_3	1.96608	Average E_a, cm	45.231
p_4	0.85434	bias (average of residuals)	0.0063
$RMSE$, cm	1.3238	Normal distribution of residuals:	
Correlation coeff.	0.979	χ^2	17.2*
Willmott index	0.9895	Kolmogorow-Smirnow	0.0936**

* χ^2 crit. = 18.3, $\alpha = 0.05$ ** crit. value 0.134

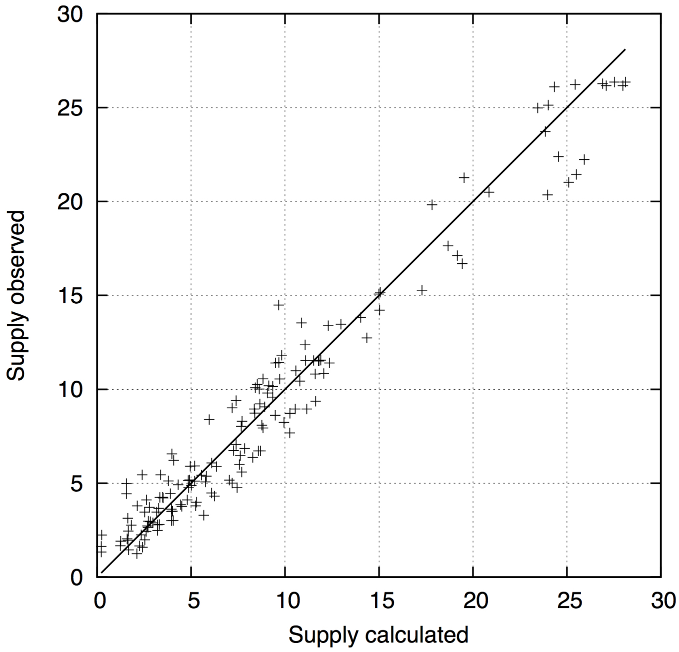

Fig. 1: Comparison between soil water supply (cm) based on the simulation model SWAP and on the transfer function (Eq. 6)

5 Conclusion

Data on soil water supply to the root zone including the contribution of groundwater is a valuable information to assess site and crop conditions or to examine environmental issues. Moreover, actual evapotranspiration of cropped soils can be evaluated easily from soil water supply. Based on data on precipitation, potential evapotranspiration, depth to groundwater and soil class, soil water supply may be available by using hydropedotransfer functions. Since transfer functions contain hidden relations which are common to the data set they were derived from, it is advisable to use these functions under environmental conditions similar to those of their origin. Another restriction pertains to the size of the application area. Because of the spatial variability of soil hydraulic properties any spot-based measurement in the field yields the realization of a random variable. Since the hydraulic soil parameters used here hold for average properties of texture classes, they cannot represent local parameter values. For that reason applications should not focus on narrow localized but rather on regional surveys.

References

Allen, R.G./Wright, M.E./Burman, R.D. (1989): Operational estimates of evapotranspiration. Agron. Journal, 81, 650–662

Bohne, K. (2005): An Introduction into Applied Soil Hydrology. Reiskirchen: Catena Verlag

Jury, W.A./Gardner, W.R./Gardner, W.H. (1991): Soil Physics. New York: John Wiley & Sons, 328

Kroes, J.G. et al. (1999): Simulation of water flow, solute transport and plant growth in the Soil-Water-Atmosphere-Plant environment: User's Guide od SWAP version 2.- Technical Document Nr. 53. Wageningen: DLO Winand Staring Centre

Kroes, J.G./van Dam (eds), J.C. (2003): Reference Manual SWAP version 3.0.3. Alterra-report 773. Wageningen, 211

Luckner, L./van Genuchten, M.Th./Nielsen, D.R. (1989): A consistent set of parametric models for the two-phase flow of immiscible fluids in the subsurface. Water Resources Research, 25, Nr. 10, 2187–2193

Ma, Ying/Feng, Shaoyuan/Song, Xianfang (2015): Evaluation of optimal irrigation scheduling and groundwater recharge at representative sites in the North China Plain with SWAP model and field experiments. Computers and Electronics in Agriculture 116, Nr. 08

Miegel, Konrad/Bohne, Klaus/Wessolek, Gerd (2013): Prediction of long-term groundwater recharge by using hydropedotransfer functions. Int. Agrophys. 27, 31–37

Razavi, Saman/Tolson, Bryan A./Burn, Donald H. (2012): Review of surrogate modeling in water resources. Water Resources Research 48, Nr. 7

Renger, M. et al. (2009): Vorschläge zur Schätzung bodenphysikalischer Kennwerte. In **Wessolek, G./ Kaupenjohann, M./Renger, M., editors:** Bodenphysikalische Kennwerte und Berechnungsverfahren für die Praxis. Berlin: TU Berlin, Bodenökologie und Bodengenese 40, 5–51

Rijtema, P. E. (1968): On the relation between transpiration, soil physical properties and crop production as a basis for water supply plans. Inst. for Land and Water Management Research, Wageningen

Twarakavi, N.K.C./Simunek, J./Schaap, G. (2010): Can texture-based classification optimally classify soils with respect to soil hydraulics? Water Resources Research, 46, W01501

van Dam, J. G. et al. (1997): Simulation of water flow, solute transport and plant growth in the soil-water-air-plant environment: Report 71. Wageningen, the Netherlands: Department of Water Resources, Wageningen Technical University and Technical Documentation 45, DLO Winand Staring Centre

van Dam, J.C. et al. (2008): Advances of modeling water flow in variably saturated soils with SWAP. Vadose Zone Journal, 7, Nr. 2, 640–653

van Genuchten, M.Th. (1980): A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44, 892–898

Willmott, C. J./Robeson, S. M./Matsura, K. (2012): A refined index of model performance. Int. Journal of Climatology, 32, Nr. 13, 2088–2094

Table 2: Hydraulic soil parameters (Renger et al., 2009), model Mualem/vanGenuchten (van Genuchten, 1980). Please note: K_0 does not denote saturated hydraulic conductivity, but is a parameter to fit the Mualem function to unsaturated hydraulic conductivity data. Symbol x represents tortuosity.

German texture class	Clay < 0.002 mm %	Silt 0.002 ⋯ 0.06 mm %	θ_r $cm^3 cm^{-3}$	θ_s $cm^3 cm^{-3}$	α hPa^{-1}	n 1	x 1	K_0 $cm\,d^{-1}$
Ss	0 ⋯ 5	0 ⋯ 10	0	0.3879	0.2644	1.35154	-0.59	512
Sl2	5 ⋯ 7	5 ⋯ 20	0	0.3949	0.1165	1.25425	0	193
Sl3	7 ⋯ 12	5 ⋯ 40	0.0519	0.3952	0.0710	1.35096	0	90
Sl4	13 ⋯ 17	13 ⋯ 40	0	0.4101	0.1049	1.18427	-3.24	141
Slu	7 ⋯ 15	40 ⋯ 50	0	0.4138	0.0817	1.17695	-3.92	110
St2	5 ⋯ 15	0 ⋯ 10	0	0.4049	0.4846	1.18828	-6.19	420
St3	15 ⋯ 25	0 ⋯ 13	0	0.4214	0.1802	1.1323	-3.42	306
Su2	0 ⋯ 5	10 ⋯ 25	0	0.3786	0.2039	1.23473	-3.34	285
Su3	0 ⋯ 7	25 ⋯ 40	0	0.3765	0.0886	1.21398	-3.61	120
Su4	0 ⋯ 7	40 ⋯ 50	0	0.3839	0.0601	1.22228	-3.74	83
Ls2	15 ⋯ 25	40 ⋯ 50	0.1406	0.4148	0.0405	1.32416	-2.07	38
Ls3	15 ⋯ 25	27 ⋯ 40	0.07284	0.4091	0.0684	1.20501	-3.23	98
Ls4	17 ⋯ 20	15 ⋯ 25	0.04630	0.4129	0.0996	1.18213	-3.6	170
Lt2	25 ⋯ 35	35 ⋯ 50	0.1492	0.4380	0.0701	1.24572	-3.18	63
Lt3	35 ⋯ 45	30 ⋯ 50	0.1629	0.4530	0.0495	1.17003	-4.10	44
Lts	25 ⋯ 45	17 ⋯ 35	0.1154	0.4325	0.0340	1.19442	0	52
Lu	17 ⋯ 28	50 ⋯ 70	0.0534	0.4284	0.0432	1.16518	-3.23	83
Uu	0 ⋯ 7	80 ⋯ 100	0	0.4030	0.0142	1.21344	-0.56	34
Uls	7 ⋯ 13	50 ⋯ 65	0	0.3985	0.0226	1.19770	-2.04	40
Us	0 ⋯ 7	50 ⋯ 80	0	0.3946	0.0275	1.22393	-2.73	36
Ut2	7 ⋯ 13	> 50	0.0101	0.4001	0.0187	1.22068	-1.38	29
Ut3	13 ⋯ 17	> 50	0.0053	0.4030	0.0168	1.20668	-1.20	28
Ut4	17 ⋯ 24	> 50	0.0276	0.4162	0.0170	1.20483	-0.77	25
Tt	67 ⋯ 100	0 ⋯ 30	0	0.5238	0.0661	1.05215	0	155
Tl	47 ⋯ 67	17 ⋯ 30	0	0.4931	0.0734	1.06254	0	173
Tu2	47 ⋯ 67	> 30	0	0.4971	0.0724	1.06062	0	179
Tu3	37 ⋯ 47	> 40	0	0.4589	0.0550	1.08166	0	124
Tu4	25 ⋯ 35	> 45	0.0170	0.4372	0.0454	1.12039	0	89
Ts2	51 ⋯ 67	0 ⋯ 17	0	0.4836	0.0840	1.07669	0	250
Ts3	35 ⋯ 51	0 ⋯ 17	0.07841	0.4374	0.0619	1.14565	0	118
Ts4	25 ⋯ 35	0 ⋯ 17	0	0.4355	0.2092	1.11419	-7.61	322
fine sand	0 ⋯ 5	0 ⋯ 10	0	0.4095	0.1504	1.33576	-0.33	285
medium sand	0 ⋯ 5	0 ⋯ 10	0	0.3886	0.2619	1.35330	-0.58	508
coarse sand	0 ⋯ 5	0 ⋯ 10	0	0.3768	0.2207	1.46574	1.38	873

Table 3: Selected soil classes (see Table 2) with assumed root depth. θ_c water content at $h_p = -63$ cm ("field capacity"), pwp water content at $h_p = -15800$ cm ("permanent wilting point"), $hlim4$ was set to -15850 cm. $hlim$ are the parameters of the Feddes function zo reduce transpiration as used in SWAP.

Soil hydraulic class (Twarakavi et al., 2010)	German texture class	Root depth cm	θ_c $cm^3\ cm^{-3}$	pwp $cm^3\ cm^{-3}$	$hlim3$, high evapotransp. cm	$hlim3$, low evapotransp. cm
A1	Ss	60	0.143	0.021	-212	-500
A2	Sl2	60	0.234	0.0584	-271	-705
A3	Sl3	60	0.2484	0.081	-307	-827
A3	Su3	60	0.255	0.080	-308	-828
A4	Sl4	60	0.285	0.105	-331	-916
A4	Ls3	70	0.331	0.174	-253	-616
B1	Uu	80	0.361	0.127	-443	-1156
B2	Uls	80	0.340	0.126	-393	-1059
B3	Slu	70	0.303	0.116	-344	-955
B3	Ls2	70	0.331	0.174	-253	-616
	Lt2	70	0.344	0.201	-287	-751
B4	Lt3	70	0.394	0.256	-371	-1009
B4	Tu4	70	0.376	0.206	-439	-1249
C2	Ts2	70	0.421	0.278	-475	-1391
C2	Ts3	70	0.366	0.210	-389	-1101
C3	Tu2	70	0.442	0.320	-510	-1495
C4	Lts	70	0.374	0.209	-367	-993

Table 4: Mean values (1961-1990) of precipitation P and potential evapotranspiration E_p at three locations

Location	Annual average, cm		Summer average, cm	
	P	E_p	P_s	$E_{p,s}$
Bremen	79.6	69.8	42.2	54.6
Uelzen	68.8	59.7	38.4	48.0
Magdeburg, modified	49.0	69.7	27.2	55.5

Table 5: Parameters of Eq. (7) holding for soil hydraulic parameters shown in Table 2. Pressure head threshold $hmin = -3200$ hPa

texture class	p_1 cm d^{-1}	p_2	texture class	p_1 cm d^{-1}	p_2
Ss	1.5244E+03	-2.4467	Uu	9.6900E+03	-2.0996
Sl2	1.8344E+03	-2.3827	Uls	2.7659E+03	-1.9182
Sl3	5.8747E+03	-2.5284	Us	1.9477E+03	-1.8381
Sl4	5.1832E+02	-1.7925	Ut2	3.8354E+03	-1.9891
Slu	5.6573E+02	-1.7205	Ut3	3.7122E+03	-1.9858
St2	3.9707E+02	-1.4971	Ut4	3.0780E+03	-2.0077
St3	2.2651E+02	-1.8035	Tt	6.2126E+01	-1.8051
Su3	8.5042E+02	-1.7423	Tl	9.9199E+01	-1.8691
Su4	1.2992E+03	-1.7361	Tu2	9.8138E+01	-1.8643
Ls2	1.4856E+03	-1.5862	Ts2	2.2292E+02	-1.9629
Ls3	9.7394E+02	-1.7943	Ts3	8.5734E+02	-2.1027
Ls4	7.2012E+02	-1.7661	Ts4	2.0702E+02	-1.5199
Lt2	7.6150E+02	-1.7619	fS	3.0197E+03	-2.4811
Lt3	3.8861E+02	-1.6707	mS	1.5653E+03	-2.4537