Estimation of actual evapotranspiration and groundwater recharge with hydropedotransfer functions (Program GWR)

Preface

Actual evapotranspiration and groundwater recharge may be estimated by employing hydropedotransfer functions as described by Miegel et al. (2013). To perform calculations conveniently, the computer code GWR is provided.

Principles

Long-term groundwater recharge R is given by

$$R = P - E_a \qquad (1)$$

P average annual precipitation

E_a average annual average evapotranspiration

Under conditions of hydrologic equilbrium, i.e. P-E_a-R=0, actual evapotranspiration is calculated implicitly by the Bagrov equation (Glugla et al., 2003) given by

$$\frac{dE_a}{dP} = 1 - \left(\frac{E_a}{E_p}\right)^b \qquad (2)$$

Bagrov recognized that the mean actual evapotranspiration E_a strongly depends on mean annual precipitation P. In case of arid conditions, when potential evapotranspiration E_p is large and actual evapotranspiration E_a is low, dE_a/dE_P is very small and approaches zero. It follows that dEa /dP will approach 1 and the entire precipitation evaporates. Under conditions like these, actual evapotranspiration depends to a large extend on precipitation. From the opposite condition of excess precipitation follows that dEa/dP is very small or almost zero. Therefore E_a/E_P will approach unity, E_a will be close to E_p and the dependence of E_a on P vanishes. In the first case, water availability dominates evapotranspiration. In the second case, energy availability is crucial. Thus, evapotranspiration is strongly limited either by water or by energy availability. Regarding these basic conditions, Eq. (2) is a plausible simplification of the inherently complex processes of real evapotranspiration.

The parameter b expresses the amount of soil water (including capillary rise from groundwater) available for evapotranspiration and the simultaneity of energy supply and rainfall. Site conditions are specified by climate, soil texture class and depth to groundwater. The computer code GWR calculates actual evapotranspiration and groundwater recharge from equations (1) and (3).

$$P = \int_0^{E_a} \frac{1}{1 - \left(\frac{E_a}{E_p}\right)^b} dE \qquad (3)$$

The unknown parameter b is estimated by a transfer function from data which are in general easily available. The best agreement between SWAP-simulated and Bagrov-estimated actual evapotranspiration (see Miegel et al., 2013) was obtained by a transfer function of the form

$$b=c_1 W_a^{c_2}+c_3 \exp(c_4 q_{max})+c_5 \frac{C_s}{P_s - E_{pot,s}} \tag{4}$$

where W_a represents the plant available soil water storage, given by

$$W_a = d_r(\theta(63)-\theta(15800)) \tag{5}$$

d_r rooting detph, cm

θ soil water content as a function of positively taken soil water pressure head

To consider the effect of capillary rise of water from the groundwater table to the root zone, an arbitrary steady-state flow rate q_{max} is chosen, which approximates the maximum flow rate to be expected under most conditions.
Cs considers the simultaneity of water and energy supply.

For details, users are referred to Miegel et al. (2013).

Limitations of the Bagrov method

There are two different conditions where the Bagrov method fails.
(A) Because of the underlying assumption that infiltrated soil water be available to evapotranspiration, the method requires the residence time of infiltrated water in soil to be sufficient to make water available to evapotranspiration. This condition is not met when rainfall of high intensity hits soils from coarse sand or gravel.
(B) The second limitation holds for plains under dry climatic conditions where the aquifer is recharged by groundwater inflow from regions with precipitation excess. Since the Bagrov equation restricts actual evapotranspiration to precipitation, it may not be used for wetlands where E_a is enhanced by capillary rise from the groundwater table so much that it might exceed the local precipitation leading to groundwater depletion. To cope with conditions (B), the computer program given here uses a statistic-based prediction equation instead of the Bagrov method.

Getting started

The code is provided as a source file (GWR.f) written in FORTRAN 95 and as an executable file to run under Linux (*.go). For the entire input the keyboard is used and results are displayed on the screen. Please note that the unit used throughout the program is centimeter ! The decimal sign is the point. Several data belonging to one prompt must be separated either by a comma or by one or more space characters or by newline. Users are requested to respond to some questions with yes or no. Instead of characters, “0” (zero) is used for “no” and “1” for “yes”.

Input

1. Long-term average annual precipitation and potential evapotranspiration, cm. It is assumed that precipitation data are corrected for measurement errors caused by wind and evaporation from inside the rain gauge. Potential evapotranspiration should be calculated using the Penman-Monteith method.

2. Long-term average annual summer precipitation and potential summer evapotranspiration, cm. In central Europe, the months April to September are considered as summer months.

3. Root zone depth and depth to groundwater table, cm. In this context, the root zone is seen as that part of the soil profile, which is intensely penetrated by plant roots. The soil surface is expected to be plant-covered. The depth to groundwater is considered being constant in time. For that reason, values should apply to those months of the year showing the bigger part of evapotranspiration.

4. Soil class number. A list of texture classes following the german classification is displayed on the monitor. Table 1 provides more information about their average soil properties. Instead of using standard values as offered by the program, different soil hydraulic parameters may be employed (vanGenuchten model). This would include parameters of capillary rise which must be calculated beforehand. For details see Miegel et. al., 2013. After this input, preliminary results on soil hydraulic properties are displayed. These are intended for assessing whether or not soil properties are close to expectations.

5. Coefficient of simultaneity. If this coefficient is not known (- type 0 to indicate this -) monthly values of the average rainfall and potential evapotranspiration must be entered. The coefficient of simultaneity may vary from <0.2 for evenly distributed rainfall and evapotranspiration to 1 for extreme nonuniformity. After this input, it is indicated on the screen whether the Bagrov equation or an alternative hydropedotransfer function is used.

6. The user is now requested to choose whether or not anaerobiosis is to consider. Anaerobiosis must be expected in wetlands, where almost saturated soils do not provide that degree of soil aeration that is necessary for water uptake by plant roots. Since knowledge on anaerobiosis is rather poor and the approximation used here is a mere makeshift users are advised to be very careful in using this option. If on the other hand severe anaerobiosis actually happens then its disregarding would lead to large errors.

Results

Results comprise annual average actual evapotranspiration and groundwater recharge. Investigations (Miegel et al., 2013) have shown that the Bagrov equation was able to predict the groundwater recharge of the calibration data set with a standard error of RMSE=1.5 cm. If groundwater depletion prevails, this is indicated by a negative recharge value.

We tried to debug the code as far as possible and performed test runs successfully. Nevertheless we disclaim all liability for direct, incidental or consequential damage resulting from the use of the program. Users are advised to compare results with known data of the region considered or with experiences valid for similar site conditions. Please note that the program does not contain any provisions against incorrect input data.

References

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Table 1: Soil hydraulic parameters of the Mualem/vanGenuchten model valid for German soil texture classes (Renger et al.,2009). Please note that K_0 is a parameter chosen to fit data of unsaturated soil hydraulic conductivity. It is not identical to saturated hydraulic conductivity. Parameter τ denotes the tortuosity parameter.

The van Genuchten model (van Genuchten, 1980) is given by $\theta = \theta_r + \frac{\theta_s - \theta_r}{\left(1+(\alpha h)^n\right)^{(1-1/n)}}$

Texture class	Clay %	Silt %	θ_r cm^3cm^{-3}	θ_s cm^3cm^{-3}	α hPa^{-1}	n 1	τ	K_0 $cm\ d^{-1}$
Ss	0-5	0-10	0	0.3879	0.2644	1.3515	-0.59	512
Sl2	5-7	5-20	0	0.3949	0.1165	1.2542	0	192
Sl3	7-12	5-40	0.0519	0.3952	0.07097	1.351	0	90
Sl4	13-17	13-40	0	0.4101	0.1049	1.1843	-3.24	141
Slu	7-15	40-50	0	0.4138	0.08165	1.177	-3.92	109
St2	5-15	0-10	0	0.4049	0.4846	1.1883	-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	1.2347	-3.34	285
Su3	0-7	25-40	0	0.3764	0.08862	1.2140	-3.61	120
Su4	0-7	40-50	0	0.3839	0.3839	1.2223	-3.74	83
Ls2	15-25	40-50	0.1406	0.4148	0.04052	1.3242	-2.07	38
Ls3	15-25	27-40	0.0336	0.4092	0.06835	1.2050	-3.23	98
Ls4	17-20	15-25	0.0463	0.4129	0.09955	1.1821	-3.6	170
Lt2	25-35	35-50	0.149	0.4380	0.07013	1.2457	-3.18	62
Lt3	35-45	30-50	0.1629	0.4530	0.04947	1.1700	-4.10	44
Lts	25-45	17-35	0.1154	0.4325	0.03401	1.1944	0	52
Lu	17-28	50-70	0.0534	0.4284	0.04321	1.1652	-3.23	83
Uu	0-7	80-100	0	0.4030	0.01420	1.2134	-0.56	34
Uls	7-13	50-65	0	0.3985	0.02260	1.1977	-2.04	40
Us	0-7	50-80	0	0.3946	0.02747	1.2239	-2.73	35
Ut2	7-13	>50	0.0101	0.4001	0.01868	1.2207	-1.38	29
Ut3	13-17	>50	0.0053	0.4030	0.01679	1.2067	-1.20	28
Ut4	17-24	>50	0.0276	0.4162	0.01697	1.2048	-0.77	25
Tt	67-100	0-30	0	0.5238	0.06612	1.0522	0	155
Tl	47-67	17-30	0	0.4931	0.07339	1.0625	0	172
Tu2	47-67	>30	0	0.4971	0.07242	1.0606	0	179
Tu3	37-47	>40	0	0.4589	0.0550	1.0817	0	124
Tu4	25-35	>45	0.0170	0.4372	0.04538	1.1204	0	89
Ts2	51-67	0-17	0	0.4836	0.08402	1.0767	0	250
Ts3	35-51	0-17	0.0784	0.4374	0.06194	1.1456	0	118
Ts4	25-35	0-17	0	0.4355	0.2092	1.1142	-7.61	322
fS	0-5	0-10	0	0.4095	0.1504	1.3358	-0.33	285
mS	0-5	0-10	0	0.3886	0.2619	1.3533	-0.58	507
gS	0-5	0-10	0	0.3768	0.2206	1.4657	1.38	872