EVAPOTRANSPIRATION – THE MOST UNRELIABLE PARAMETER OF THE WATER BUDGET

Prof. Ognjen Bonacci, Ph. D.
Civil Engineering Faculty, 21000 Split, Matice hrvatske str. 15, Croatia,
e-mail:obonacci@gradst.hr

***Abstract*:** Evapotranspiration, as the transfer of water into the atmosphere from a free surface a bare soil or interception on a vegetal cover and evaporation through stomata, is extremely complicated process. It is very hard to control, monitor and define it on the regional and/or catchment scale. For catchment water budget knowledge of exact actual evapotranspiration is crucial. There are few empirical formulas, which give different results. The paper deals with the problem of assessing the possible accuracy of actual and potential evapotranspiration determination on the catchment and regional scale. Some examples are given. Definite conclusion is that the actual and potential evapotranspiration performs the most unreliable parameter of the water budget.
***Keywords*:** evapotranspiration, water budget

DIE EVAPOTRANSPIRATION – DER UNZUVERLÄSSIGSTE FAKTOR DER WASSERBILANZ

***Zusammenfassung*:** Die Evapotranspiration, als der Prozeβ des Wassertransfers von der Oberfläche in die Atmosphäre, ist ein ziemlich vielfacher Prozeβ. Er lässt sich nur schwer kontrolieren, überwachen oder bestimmen in einem regionalen Maβstab oder Zusammenfluβ. Für die Erstattung der Wasserbilanz eines Zusammenfluβes ist die reale Evapotranspiration sehr wichtig. Es gibt einige empirische Formel, die verschiedene Resultate erweisen. Dieser Artikel befaβt sich mit dem Problem der Einschätzung, wie man wahrscheinlich genau, die reale und potentielle Evapotranspiration in einem regionalen Zusammenfluβ bestimmen kann. Daraus erfolgt unbedingt, daβ die reale und potentielle Evapotranspiration der unzuverlässigste Faktor der Wasserbilanz seien. Es sind in diesem Artikel auch konkrete Beispiele dafür angeführt.
***Schlusselworte*:** Evapotranspiration, Wasserbilanz

1. Introduction

The hydrologic water budget for a strictly defined catchment can be represented by the following differential equation:

$$I-O=dS/dt \tag{1}$$

where: I is inflow per unit time, O is outflow per unit time and (dS/dt) is the change in storage within the catchment per unite time. The quantification of the hydrologic cycle in such a way becomes a simple mass balance equation. For engineering applications the hydrologic budget for a catchment and region can be written simply as:

$$P+(R_I-R_O)+(G_I-G_O)-ET=\Delta S \tag{2}$$

where: P is precipitation R_I is inflow surface runoff, R_O is outflow surface runoff, G_I is groundwater inflow, G_O is groundwater outflow, ET is actual evapotranspiration and ΔS is change in water storage.

The difficulty in solving practical problems lies mainly in the inability to properly measure or estimate various hydrologic equation terms, first of all catchment or regional actual evapotranspiration. The primary objective of this paper is to assess the possible accuracy of actual evapotranspiration determination on the catchment and regional scale.

2. Actual and potential evapotranspiration

Evapotranspiration is the combined consumptive-evaporative process by which water is released to the atmosphere through vegetation, soil and from a free water surface. It is the concurrent occurrence of evaporation and transpiration which influence each other, e.g. soil evaporation is reduced by the occurrence of transpiration. The actual evapotranspiration can be defined as the evapotranspiration from a vegetal cover under the natural or given conditions of catchment of region supply of water and is limited by the availability of moisture. Engineers and/or hydrologist are generally interested in the water-mass balance and not in the individual plant consumption. As evapotranspiration is complicated process there are several approaches for their study. According to the sphere of interest and the related discipline it can be analysed through: 1) Plant physiology (transpiration ratios and pot tests); 2) Hydrology (water budget applied to catchments or regions); 3) Climatology (use of atmometers and pans); 4) Physics (energy budget); 5) Dynamic meteorology (mass transfer methods); 6) Statistics (empirical correlation with meteorological factors). Actual evapotranspiration can be estimated from: 1) Soil moisture depletion studies on small plots; 2) Tanks and lysimeter experiments; 3) Groundwater fluctuations and other mass balance techniques; 4) Relations to pan evaporation; 5) Soil moisture budgets; 6) Energy budgets.

A number of specific evapotranspiration equations are available. Some of them are developed for the potential evapotranspiration determination and they can not be used directly for catchment or region water budget definition. The formulae of Contagne, Turc, Langbein and Wundt refer to the mean annual actual evapotranspiration form the catchment and/or region. They are based on actual data on rainfall and runoff in hundreds of river basins all over the world. Turc has also given empirical formulae for the actual evapotranspiration during specific short periods. Their use in engineering practice is limited by the fact that besides the rainfall and air temperature, data on the soil moisture have to be known.

Good estimates of actual catchment evapotranspiration can be obtained using the water budget equation. Under optimal conditions the order of accuracy of the approach is about 10 %.

Using principles of water exchange on the boundary layer between soil and air Palmer (1965) developed next water budget equation:

$$P+D1=ET+D2+Q \qquad (3)$$

where: P is precipitation, D1 is contribution of water from the deep layers, ET, is actual evapotranspiration, D2 is water percolation in the deep layers and Q is discharge. In the Palmer’s procedure actual evapotranspiration ET calculates using potential evapotranspiration PET taking into account next two conditions:

$$ET=PET \quad \text{if} \quad P>PET \qquad (4)$$

$$ET=P+D1 \quad \text{if} \quad P<PET \qquad (5)$$

Figure 1 shows mean monthly potential evapotranspiration for the Osijek region (1958-1980) defined by four methods (Eagleman, Shermer, Blaney-Criddle and Thorntwaite). It can be seen that differences between various methods are significant, more than 30 %. Table 1 presents monthly and annual potential (PET) and actual (ET) evapotranspiration defined by Eagleman’s method and Palmer’s procedure for the Osijek region (1958-1980). From the two last columns it can be seen the differences between mean monthly and annual values of potential and actual evapotranspiration. It should be stressed that those differences are mach more variable during the individual years.

3. Water badget of the Danube basin between Bratislava and Komarno

Figure 2 gives a schematic representation of the catchment area of Danube River section between Bratislava and Komarno controlled by six discharge ganging stations (Petrovič, 1997). Total area of this lowland landscape is A=16082 km^2. For the ten years or 120 months period (Nov. 1963-Oct. 1972) Petrovič (1997) evaluated runoff contribution from this territory. The intercatchment runoff contribution Q was calculated by the following equation:

$$Q=(Q_{BR.}+Q_{HE.}+Q_{AR.}+Q_{ŠA.}+Q_{N.Z.})-Q_{KO.} \qquad (6)$$

where: Q_i are mean monthly discharges expressed in m^3/s measured on the six ganging stations given on Figure 2.

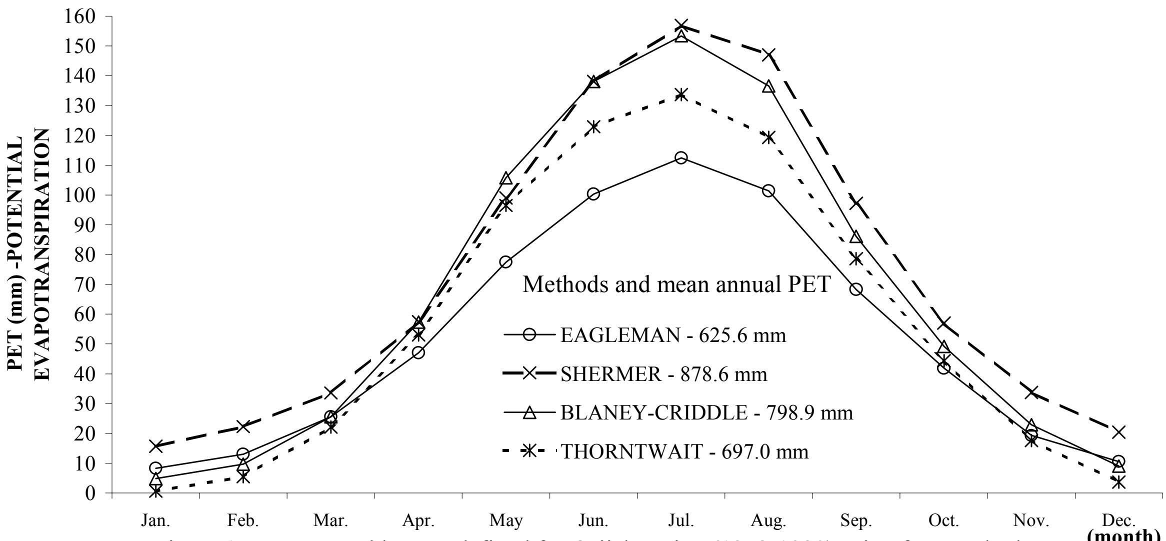

Figure 1: Meam monthly PET defined for Osijek region (1958-1980) using four methods

Table 1. Monthly and annual potential (PET) and actual (ET) evapotranspiration defined by Eagleman's method and Palmer's procedure for the Osijek region (1958-1980)

PERIOD	PET (mm)	ET (mm)	D=PET-ET (mm)	(D/PET)/100 (%)
Jan.	8.3	8.3	0	0
Feb.	13.0	13.0	0	0
Mar.	25.6	25.6	0	0
Apr.	47.1	46.5	0.6	1.3
May	77.5	72.1	5.4	7.0
Jun	100.3	91.2	9.1	9.1
Jul.	112.4	90.3	22.1	19.7
Aug.	101.4	67.5	33.9	33.4
Sep.	68.3	45.9	22.4	32.8
Oct.	41.9	30.0	11.9	28.4
Nov.	19.3	19.2	0.1	0.5
Dec.	10.6	10.6	0	0
Year	625.7	520.2	105.5	16.8

Results of this evaluation are extremely surprising from the hydrological point of wiev. The values of Q vary from - 935 m^3/s to 389 m^3/s. During the 72 months, or 60 % of the period, the runoff contribution of the uncontrolled part of the interchatchment was negative, which is hydrologicaly unacceptable or at least hardly explainable. Only partly it could be explained by the inaccuracy of discharge measurement and setting. It should be stressed that the similar results were obtained in some other sections and their intercatchments of the Danube River and its tributaries.

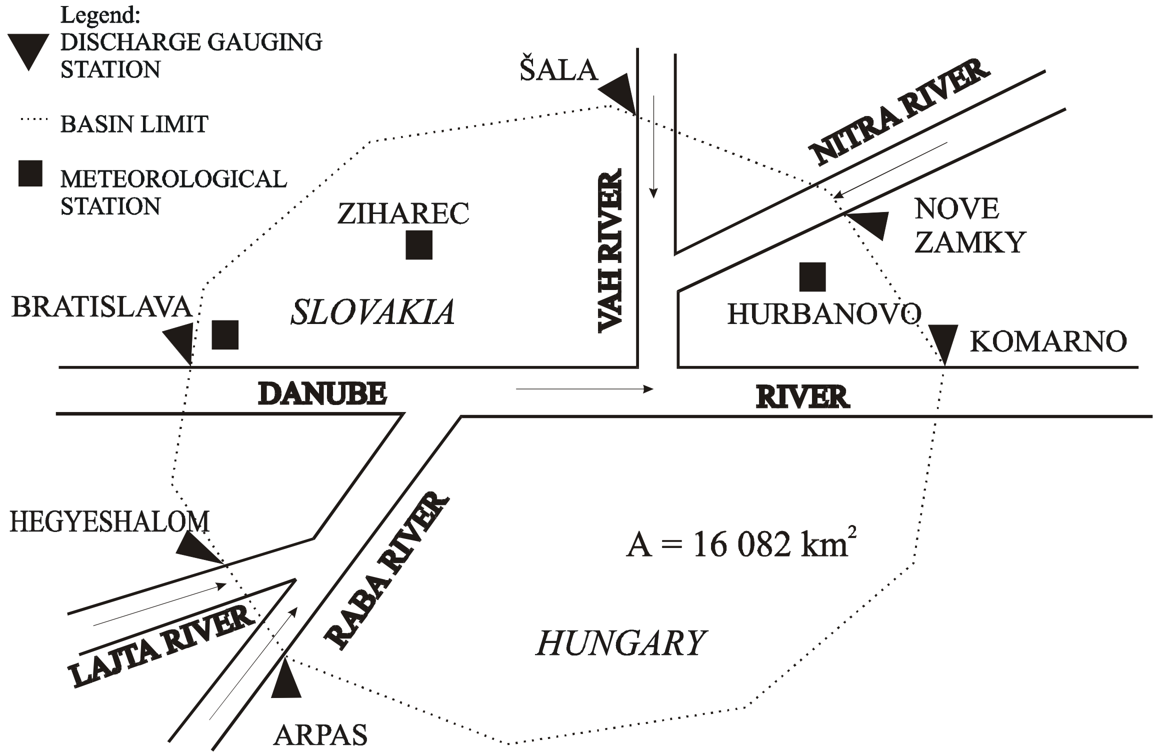

Figure 2: Scheme of the analysed part of the Danube River basin between Bratislava and Komarno

Using the climatological data (precipitation, air temperature, and relative air humidity) measured at three methodological stations, given on Figure 2, it was possible to calculate monthly values of potential evapotranspiration by Eagleman's method during the analysed period (Nov. 1963-Oct. 1972). Table 2 gives characteristic (minimum, mean and maximum) monthly and annual potential evapotranspiration PET and actual evapotranspiration ET calculated using following water budget equation:

$$ET=Q+P \tag{7}$$

where P is areal precipitation and Q is defined by equation 6.

In the last column of Table 2 the difference between mean monthly and annual potential and actual evapotranspiration were calculated. It can be seen that during the winter period from November to February mean monthly potential evapotranspiration is less than actual evapotranspiration what is physically impossible. Only part this could be explained by inevitable inaccuracy of determination and measurement of precipitation, air temperature and air moisture of the analysed area as well as rivers' discharges. In the lowland area between Bratislava and Komarno a vertical component of water balance is dominant in comparison with a horizontal component of the water transport on the ground surface. Due to this reason the conventional hydrology approaches, predominantly based on the horizontal component of runoff, cannot be used for solving the lowland hydrological processes (Bonacci, 1996). During the period from November to March the groundwater level in this large flatland area is very high, in average less than one meter bellow the ground surface. As the strong and frequent winds blow the evapotranspiration (especially soil evaporation) in this area is high during the cold winter period. The Eagleman's equation does not use wind data, which is probably main reason for great and unacceptable difference between actual and potential evapotranspirations given in Table 2.

Table 2. Characteristic monthly and annual potential evapotranspiration PET (Eagleman's method) and actual evapotranspiration (equation 7) on the analysed part of the Danube River between Bratislava and Komarno (Nov. 1963-Oct. 1972)

PERIOD	**PET (m^3/s)**			**ET (m^3/s)**			**Mean PET-ET (m^3/s)**
	Min.	**Mean**	**Max.**	**Min.**	**Mean**	**Max.**	
Nov.	202	257	319	205	343	631	-86
Dec.	76.5	140	184	-36.3	261	479	-121
Jan.	99.9	130	167	16.3	230	368	-100
Feb.	116	206	283	48.0	258	811	-52
Mar.	193	289	376	5.6	223	618	66
Apr.	411	492	607	149.1	304	485	188
May	530	671	819	21.4	407	1198	264
Jun.	719	824	940	124.9	583	1562	241
Jul.	718	888	1070	187.6	444	1279	444
Aug.	647	777	992	18.5	431	756	342
Sep.	469	600	680	-35.6	236	485	364
Oct.	338	384	489	-37.5	203	868	181
Year	419	472	519	214	327	441	145

4. Conclusions

The determination of the exact values of the potential and actual evapotranspiration is essential for the water budget calculation. Numerous existing methods, approaches and equations for potential and actual evapotranspiration determination give very different and for engineering practice unreliable results. The problem is especially complex for the lowland areas. In this region the application of the mass transfer methods for the areal evapotranspiration determination should be used. The implication of these methods requires the continious measurement of actual vapour pressure and wind velocity at various heights above the ground surface. From these data the vapour pressure and wind velocity gradient can be derived. The instantaneous evaporation is proportional to the product of a function of the two gradients.

The aim of this paper is to demonstrate the existence and indicate the problems of areal evapotranspiration (potential and actual) determination. Definite conclusion is that evapotranspiration represents the most unreliable parameter of the catchment and/or region water budget determination.

5. References

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