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Potential Evaporation – A Matter of Definition

A Comment on 'Improvements of Runoff Models – What Way to Go?'*

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The aim of this paper is to discuss the concept of potential evaporation and its use in runoff models. The potential evaporation for forest is defined on basis of estimated minimum canopy resistances for a well-watered spruce forest. The difference between the Penman open water evaporation, commonly used as "potential" evaporation, and a more realistic estimate of the potential evaporation from a dry forest showed a large scatter and a systematic seasonal deviation. Part of the differences were explained by differences in vapour pressure deficit. It was also shown that the evaporation rate of a completely wet forest was typically four times higher than the rate predicted by the Penman equation. The conclusion was that Penman open water evaporation did not give a good representation of forest conditions.

Introduction

When discussing possible improvements of the PULSE/HBV models Andersson (1992) concentrated on two processes: the evaporation and the snow melt. In this paper I will comment on the evaporation process only. The reason for the increasing need to improve the models are that the models have given systematically biased estimates of river flows during some periods. These anomalies have often been attributed to unusual weather conditions but changes in land use or manage-

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ment practices (*e.g.*, clear cutting of forest) have also been suggested as possible explanations. Searching for the cause of these anomalies, the evaporation estimation has come into focus because it is treated in a very simplified way in the original version of the models. Instead of using standard values of monthly "potential" evaporation, Andersson (1992) introduced several other methods for estimation of "potential" evaporation, all more or less based on the Penman (1948) equation. However, introducing these more physical sound evaporation estimates did not improve the results very much. Instead, it was found that an empirical consideration of air temperature was superior to using potential evaporation values calculated for individual months. In my opinion such a conclusion might be misleading because I am not sure that introducing individual estimates of the Penman "potential" evaporation actually introduced more physical soundness into the model. When analyzing the effect of the different approaches for estimating evaporation, the model was run on three different areas in central Sweden. Andersson (1992) did not report the composition of vegetation within these areas or land/lake proportions but judging from their geographical location, it can be assumed that they were mainly forested areas. In the following I will discuss the concept of potential evaporation especially regarding forest.

Potential Evaporation

Potential evaporation is a useful but not a well defined term. It is, however, commonly used in work dealing with evaporation from vegetated as well as non-vegetated surfaces. Since there does not exist a general definition of the term, it need to be defined explicitly in each case. The word "potential" can in this context be interpreted as "something (evaporation) having the capacity or a strong possibility for development into a state of actuality". In this context it is also important to differentiate between the evaporation from a wet and a dry vegetation, respectively.

Beginning with the dry situation and with the above given definition of the word "potential" in mind, it is evident that *e.g.*, two forest stands adjacent to each other but with markedly different water and nutrient availability probably would have different potential transpiration because they would differ in leaf area index and, thus, differ in capacity for transpiration under similar weather conditions. Also, this definition implies that the method used to estimate the potential transpiration must be adapted to the specific properties of the surface concerned. This means that for forest it would not be useful to adopt the commonly used Penman (1948) formula to estimate the potential transpiration because it represents the evaporation from an open water surface and the evaporation process from such a surface is entirely different from that of a forest. However, using the Penman (1953) combination equation, which commonly is referred to as the Penman-Monteith equation,

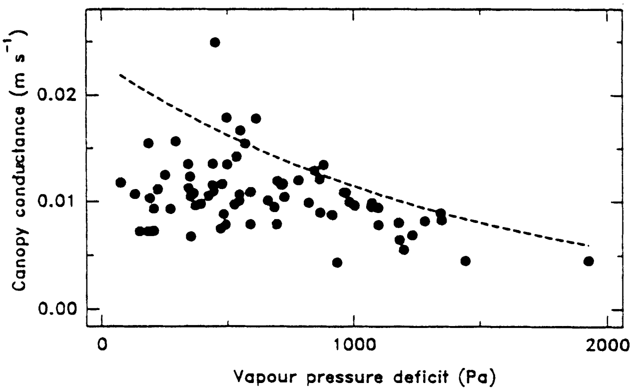

Fig. 1. Mean daytime canopy conductance of an irrigated spruce stand in south of Sweden (Skogaby, Halmstad) as a function of vapour pressure deficit. The dashed line represents maximum conductances (adapted from Cienciala *et al.* 1992).

with appropriate values for aerodynamic and surface resistances would be an acceptable method for calculating the potential transpiration of any surface. It is well known that the surface, or rather the canopy resistance of forests depends on factors such as air humidity, solar radiation and leaf water potential (*e.g.* Jarvis 1976; Stewart and deBruin 1984; Lindroth 1985). Cienciala *et al.* (1992) estimated the canopy conductance (the inverse of which equals canopy resistance) of an irrigated spruce stand as a function of air vapour pressure deficit. There is a considerable scatter in the data (Fig. 1) and part of this is caused by other factors affecting the canopy conductance. It is, thus, likely that the upper range of conductances, the dashed curve in Fig. 1, at the different vapour pressure deficits would represent potential conditions of the spruce stand. The potential transpiration, λE, of the forest can accordingly be calculated using these maximum conductances (or minimum resistances), with the Penman (1953) combination eqation as

$$\lambda E \equiv \frac{\Delta R_n + \rho c_p \ \delta e / r_a}{\Delta + \gamma (1 + r_c / r_a)} \tag{1}$$

where

Δ – the slope of the saturation vapour pressure curve,
R_n – the net radiation,
ϱ – the density of dry air,
c_p – the heat capacity of dry air,
δe – the vapour pressure deficit,
r_a – the aerodynamic resistance to heat and vapour transfer,
γ – the psychrometric 'constant'
r_c – the canopy resistance.

The situation becomes more complicated when the canopy is intercepted, totally or partially, by rain. In principle, when the canopy is totally wet, the evaporation can also be estimated by Eq. (1) but with zero canopy resistance. Also in this situation, the structure of the vegetation, primarily height and density (leaf area index), of the vegetation is important. These factors will affect the interception capacity and the aerodynamic properties of the vegetation. When discussing potential evaporation from a wet canopy it might be appropriate to define it as the evaporation of a totally wet canopy.

Comparison Between Different Estimates of "Potential" Evaporation

Using data from Jädraås (lat. 60°49'N, long. 16°30'E), central Sweden, collected during the period 1976 to 1982 and the above defined minimum canopy resistances the potential transpiration for a hypothetical dense spruce forest was estimated. The stand was assumed 20 m high with a roughness length of 1 m and a displacement height of 13 m. Using the same climatic data the Penman (1948) evaporation was also calculated. The mean monthly difference between these two estimates showed a considerable scatter but also a systematic seasonal difference (Fig. 2a). The comparison was made only during the growing season because our knowledge about transpiration during the other part of the year is limited. Part, but far from all, of the variations seen in Fig. 2a were explained by differences in vapour pressure deficit (Fig. 2b). Furthermore, a comparison between evaporation from a wet canopy estimated by Eq. (1) using zero canopy resistance, and the corresponding Penman (1948) evaporation shows that the rate is about four times higher according the former equation.

Discussion and Conclusion

Realizing that evaporation is one of the largest components in the water balance it is obvious that the differences between the two approaches of calculating "potential" evaporation (Fig. 2) will have a large effect on the calculated runoff. In my opinion, introducing monthly values of Penman (1948) evaporation instead of standard values into the PULSE/HBV models does not really introduce much more of physical soundness into the models. This is mainly because Penman (1948) evaporation is not a good estimate of the potential evaporation of a forest. In order to make a model explain things also under "unusual" weather conditions or when vegetation changes in some way, there is no short-cut – the models must be based on physically sound relationships. It is another question to what degree and detail this have to be made. It depends largely on what the model is supposed to be used for. Normally, introducing more of physically based relationships into a model also

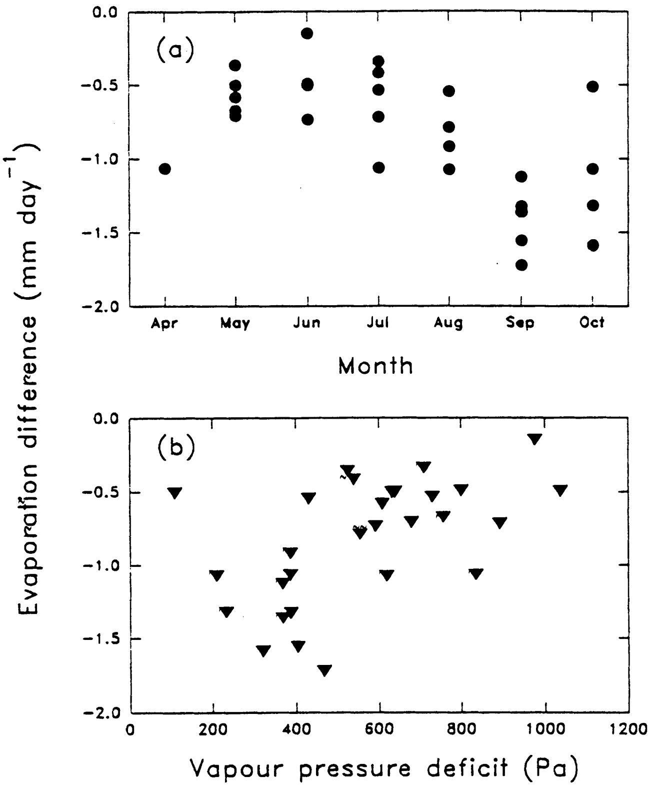

Fig. 2. Mean monthly differences between Penman (1948) evaporation and potential evaporation of a spruce stand as a function of: a) time of season and b) vapour pressure deficit.

means that more parameters are introduced. However, if the parameters can be clearly identified and possible to estimate this might not be such a hopeless problem as it might look like. So, my recommendation to PULSE/HBV modelers is to use the available knowledge about the evaporation processes and try to really make the models more physically sound!

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