Actual evapotranspiration and micrometeorology of a raised peat bog in Clara, Co. Offaly, Ireland

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Summary

This study focuses on the estimation of two parameters of the Penman-Monteith equation, namely, the aerodynamic and the surface resistances, for a raised bog in the Irish Midlands. Data were provided by an automatic weather station which was installed in the middle of the bog and several other types of data were also collected. The typical zero-plane displacement $d = 0$ and the roughness length $z_0 = 0.021$ m were estimated from average hourly wind speed profiles. The surface resistance was found to vary between 30 and 125 $s m^{-1}$. A predictive model of surface resistance versus time was only partially successful.

Key index words: peatland, conservation, climate, water balance

Introduction

A raised peat bog can only survive when its drainage is slow enough for the acrotelm to remain wet for most of the time. It is rarely possible to measure the surface runoff from a raised bog as a whole, unless it has been artificially drained. Hence, the runoff, and not the evapotranspiration, is often the water balance component that is most difficult to measure. It may be more feasible to measure the actual evapotranspiration and then to obtain the runoff as a balance-closing component rather than the other way round. The actual evapotranspiration of a raised bog can be measured either with lysimeters or by using micrometeorological methods of which the Penman-type combination methods, in particular the Penman-Monteith equation, seem to be the most feasible way. However, the Penman-Monteith equation contains two resistances that are difficult to determine, namely, the aerodynamic resistance r_a (sm^{-1}) and the surface resistance r_s ($s.m^{-1}$). The present paper is focused on the estimation of these resistances from the available micrometeorological data and other information.

Materials and Methods

One of the relatively intact raised bogs in Ireland is Clara Bog in Co. Offaly, south of Clara town. The bedrock below the wetland is Lower Carboniferous limestone overlain by glacial deposits. The bottom of the glacial depression is covered with shelly marl and glaciolacustrine clay sediments. The depression is filled with dead organic matter. The top of the bog, poor in nutrients, is covered with low vegetation of which the most representative examples are *Sphagnum* spp. (mostly *S. magellanicum and S. papillosum*), heather (*Calluna vulgaris*), *Molinia caerula* and *Eriophorum vaginatum*. Samples of this vegetation were used in lysimeters for the estimation of actual evapotranspiration of the bog surface (van der Schaaf, 1999). Typical vegetation around the automatic weather station, referred to below, was composed of a more or less continuous sphagnum cover, with absolute roughness of about 5 centimetres; stalks of grass covering about 70 % of the ground surface, about 10-20 cm high; and sparse bunches of heather, covering about 10 % of the ground surface, about 15 to 25 cm high (observed 18/3/2000). The bog surface area is about 520 ha. The peat thickness is up to 10.5 m. The climate is typical for Irish midlands, with mean annual precipitation between 800 and 1000 mm and mean annual temperature 9.3 °C (Birr station, 1951-1980).

An automatic weather station was installed in the middle of the Clara Peat Bog West in 1991. The period covered by the present study starts on 29/12/1991 and ends on 9/4/2002. Hourly averages of instantaneous data were used for all work reported below. The list of weather elements measured by the weather station comprised global solar radiation, net radiation, air temperature and humidity, wind speed at three heights above the ground (2.00 m, 1.45 m and either 0.65 m or 0.55 m), precipitation and shallow groundwater table depth. Several other types of data were also collected, most importantly the actual evapotranspiration in lysimeters and groundwater levels measured by a Dutch team between 24/7/1992 and 28/7/1993. Occasional manual checks of the automatic weather station were made and data from nearby Met Éireann weather stations (Birr, Kilkenny) were used to correct them when necessary.

The evapotranspiration analysis was mainly based on the Penman-Monteith equation (Monteith and Unsworth, 1990). The aerodynamic resistance r_a (sm^{-1}) was estimated from the wind speed u (ms^{-1}) measured at a particular standard height z (m) above the ground, using the Thom-Oliver equation (Thom and Oliver, 1977). This equation contains two parameters, namely, the zero-plane displacement d (m) and the roughness length z_0 (m). The values of d and z_0 were estimated from direct measurements of wind speed profiles when the layering of the atmosphere near to the ground was approximately neutral. The presence of neutral layering was estimated indirectly from the global radiation and wind speed measurements. The conditions were considered to be neutral when the solar radiation was positive but low and the wind speed was high. In a neutrally stratified atmosphere, the wind speed u is known to depend on the height z in a logarithmic manner (Monteith and Unsworth, 1990, p. 113). In order to estimate the two parameters, d and z_0, the wind speed had to be measured at least at three different depths. The surface resistance r_s was estimated from the actual evapotranspiration as measured in lysimeters, using the Penman-Monteith equation in which all other quantities were known.

Results and Discussion

Estimation of aerodynamic resistance

As the roughness of the peat bog surface and its vegetation did not vary significantly over its area or over time, it was assumed that both the zero-plane displacement d and the roughness length z_0 were constant. The average hourly Clara wind speed data measured over the period between 25/11/1994 and 9/4/2002 at three different heights were used and a nonlinear optimisation procedure based on the logarithmic wind profile was applied. Out of the total of 49878 hourly wind records, 4582 corresponded to neutral stratification. The optimisation results suggested the roughness length z_0 = 0.021 m and no displacement of the zero-plane, i.e., d = 0.

Estimation of surface resistance

The surface resistance was estimated for the period 24/7/1992 to 28/7/1993, i.e. the period for which the lysimeters of the Dutch team were located in the Clara Bog near to the automatic weather station. The actual evapotranspiration was estimated from the water balance of the lysimeters at approximately weekly intervals. The data had been comprehensively processed by van der Schaaf (1999, p. 289) who gives a table of monthly actual evapotranspiration sums for individual representative vegetation types and also for the Clara peat bog as a whole, the latter figures being obtained as weighted means of the former. The relative areas of different vegetation types occurring on the bog surface were used as weights. For this study, only the weighted mean figures were used. Another evaluation of the same data was made by Shuaib (1993).

Parallel estimates of the peat bog actual evapotranspiration were obtained from the automatic weather station data using the Penman-Monteith equation. The aerodynamic resistance was estimated from the Thom-Oliver equation, taking d = 0 and z_0 = 0.021 s.m^{-1} as obtained from the wind speed profiles. Then, in the first stage, the surface resistance was estimated in the same manner as in Shuaib (1993), following Calder (1990, p. 11). The surface resistance was assumed to be a sinusoidal function of the Julian day, with the parameters r_{smax} and r_{smin} (the maximum and minimum surface resistances, sm^{-1}) and D (the Julian day on which the surface resistance was at its minimum). Following Shuaib (1993), the values r_{smin} = 0, r_{smax} = 22 s.m^{-1} and D = 355 (winter solstice) were adopted. With these parameter values, the actual evapotranspiration of the peat bog was almost permanently overestimated. Hence some parameters had to be optimised. When both r_{smin} and r_{smax} were optimised, their values tended to become equal to each other. When r_{smin} was kept at zero and only r_{smax} was optimised, it gave the result r_{smax} = 58.8 s.m^{-1} for the average hourly weather data. However, the Penman-Monteith equation, with the sinusoidal model and r_{smax} optimised, still overestimated the actual evapotranspiration for autumn 1992 and winter 1992-1993, while it underestimated it for summer 1993. The conclusion drawn from this is that the sinusoidal model is inadequate.

As an alternative, we modelled the surface resistance as a stepwise function of time, optimised separately for each calendar month. However, this procedure was found to have no predictive power. Finally an attempt was made to associate the surface resistance with the depth of groundwater table. For this purpose, data from the Irish-Dutch project groundwater well CWG1, located about 100 m from the automatic weather station and about 120 m from the lysimetric station, were used. The groundwater table depths are plotted in Fig. 1 and compared with the variation of surface resistance according to the sinusoidal model after optimisation of r_{smax} and with the r_s optimised independently for individual months. The sinusoidal model reproduces quite well the high groundwater table values (and low surface resistances) in autumn 1992, but is too crude to reflect the increase of the groundwater table in January 1993 and its rapid fall in June 1993. Hence, the correlation between the groundwater table depth and the surface resistance, though it may exist, is not very strong.

Conclusion

The roughness parameters of the raised bog surface were estimated from the hourly averages of wind speed profile measurements. Typical values are z_0 = 0.021 m and d = 0. The value of the roughness length z_0 is in accordance with the prevailing height of the canopy (about 20 cm) and is smaller than we and others had assumed earlier (e.g., Shuaib, 1993, relying on Dutch data, assumed z_0 = 0.041 m). Our estimate of z_0 is also in accordance with that established by Mölder and Kellner (2002) for central Sweden. Unlike these authors, we were not able to distinguish between z_0 attributable to heat and vapour and that to momentum transfer. As for the surface resistance, we found that typical values for a raised peat bog, similar to that in Clara, vary between 30 and 125 s m^{-1}, which is much lower than the values estimated by Campbell and Williamson (1997) for New Zealand conditions. We were

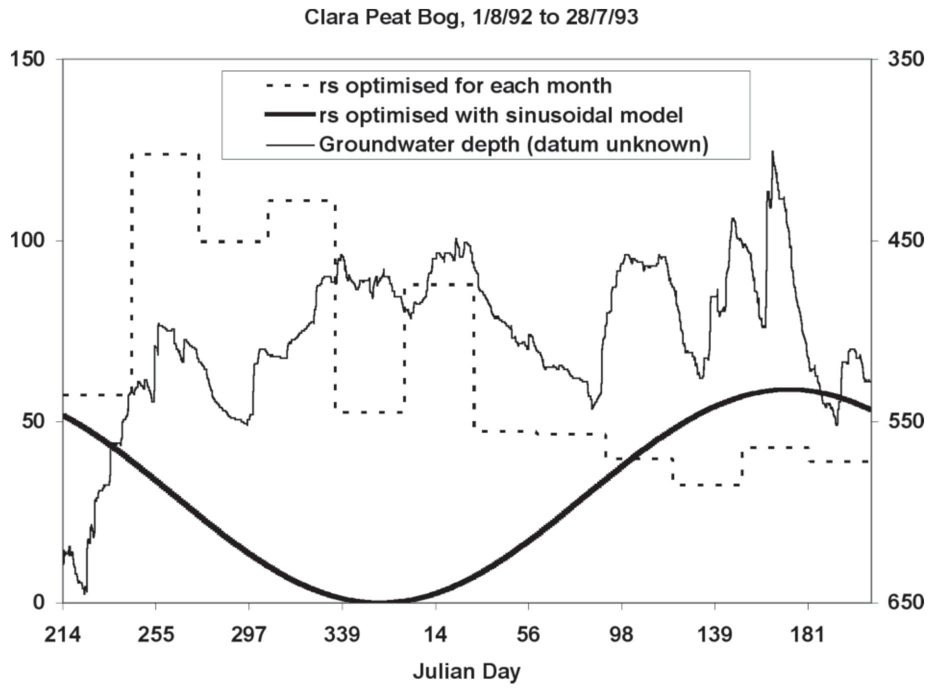

Figure 1. Raised peat bog surface resistance variation approximated with a sinusoidal model (r_{smax} optimised) and with a step-wise function (optimised separately for each month) compared with the groundwater table depth variation.

not fully successful in trying to develop a predictive model explaining the variation of the surface resistance over time. The sinusoidal model is too crude, because it assumes that wet and dry periods occur each year regularly, which is not true for the conditions in the Irish Midlands. The surface resistance may to some degree depend on the groundwater table depth but this dependence appears to be weak and, therefore, other explanatory factors must be identified.

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REFERENCES

Calder, I.R. (1990). *Evaporation in the uplands.* Wiley, Chichester, 148 p.

Campbell, D.I. and Williamson, J.L. (1997). Evaporation from a raised peat bog. *Journal of Hydrology* 193: 142-160.

Mölder, M., Kellner, E. (2002). Excess resistance of bog surfaces in central Sweden. *Agricultural and Forest Meteorology* 112: 23-30.

Monteith, J.L. and Unsworth, M.H. (1990). *Principles of environmental physics* (2nd Ed.). E. Arnold, London, 291 p.

Shuaib, A.A. (1993). *Evaluation of the Penman-type evaporation models for the Clara Bog in Ireland.* M.Sc. Thesis. Dept. Engineering Hydrology, University College Galway, Ireland, December 1993.

van der Schaaf, S. (1999). *Analysis of the hydrology of raised bogs in the Irish Midlands. A case study of Raheenmore Bog and Clara Bog.* Doctoral thesis. Agricultural University, Wageningen, The Netherlands, 375 p. ISBN 90-5808-062-5.

Thom, A.S. and Oliver, H.R. (1977). *On Penman's equation for estimating regional evaporation.* Quart. J. Roy. Meteorol. Soc. 103: 345-357.