Nordic Hydrology, 18, 1987, 193-202

Sensitivity of the Groundwater Mound Model for Predicting Mire Topography

Pauline E. Kneale

School of Geography, The University, Leeds, England

The Dupuit-Forcheimer model for groundwater mounds has been proposed to explain the morphology of raised peat mires. This paper discusses the sensitivity of the model as a predictor for mire profiles using data from a raised Irish mire where an attempt was made to reconstruct the equilibrium profile. The most sensitive parameters are shown to be hydraulic counductivity and net recharge. Detailed measurements of saturated hydraulic conductivity show significant spatial variability, which is correlated with mire stratigraphy. Objective determination of an average value for modelling would have an error band of an order of magnitude which is unsatisfactory for prediction. Net recharge is calculated from the water balance but parameters like overlandflow must be estimated, usually from limited data, making the proposed value suspect. This model may be helpful for mire description but its variables cannot be specified accurately enough for predictive purposes.

Introduction

Ingram (1982, 1983) proposes the adoption of groundwater mound theory to describe the shape of raised peat mires. For any given mire width ($2L$) the maximum height of mire growth (Hm) is found by balancing

$$\frac{U}{K}=\frac{Hm^2}{L^2} \qquad (1)$$

where K is the saturated hydraulic conductivity and U is the net annual recharge to the mire (both expressed in m.yr). U is determined by rearranging the water balance equation

$$P-ET-R-\Delta S-G \equiv U \qquad (2)$$

where the input is precipitation (P), the principal loss is by evaporation (E), and overlandflow (R). Change of storage ($\triangle S$) within the mire is assumed to be minimal over the water year as are groundwater losses (G).

Theoretically one can evaluate U for any region where P and E are accurately measured and the groundwater and storage losses assessed. Given a water balance for U then groundwater mound theory will predict the mire topography and estimate its maximum equilibrium height. If L is no longer increasing and mire growth has continued long enough for the balance between vegetative supply and decay to be approaching stability (Clymo 1984) then the model may be used to compare the present topography and potential Hm and to indicate if positive hydrological management measures are required to maintain mire growth.

Ingram (1982) applies this procedure in a post-dictive manner to describe the shape of Dun Moss in Perthshire; he finds close agreement between actual and predicted Hm, although the mire edge topography is less well explained.

The utility of the theory in pre-dictive mode is discussed here in an attempt to reconstruct the equilibrium profile for Mongan Bog, Co. Offaly. Mongan is an ombrotrophic raised mire of unusual ecological and environmental interest and will be conserved as part of an EEC Heritage zone (Tubridy 1984,1986).

Ingram (1982) quotes 7 requirements for the application of the model to a peat mire. 1) A diplotelmic soil structure; 2) Perennial saturation of the catotelm, which is 3) maintained by the groundwater mound, the dimensions of which are governed by 4) the water balance and 5) the hydraulic conductivity of the peat. 6) The water table is confined within a thin acrotelm so that 7) the groundwater surface and acrotelm are essentially the same shape. By Ingram's own definition all raised mires have a diplotelmic structure where the catotelm is defined as the volume of peat which is perennially saturated and therefore not subject to aerobic decomposition. By the same definition the fluctuating water table must be found in the acrotelm.

Hydrologically Mongan is an excellent site to test the groundwater mound theory; the mire has an ideal linear shape, confined in a parallel valley, with eskers north and south which control L, and with a sealed glacial clay basin. Some of the mire margins have been cut-away for fuel or small fields but the edge effects do not affect the central mire which has a dense network of open pools and hummocks. Water table and piezometric measurements over a three year period show the acrotelm to be appropriately thin and the flow lines which are essentially parallel and orthogonal to the mire contours, drain to marginal streams or drains (Fig. 1).

To predict independently the equilibrium shape of the mire the hydraulic conductivity and water balance need to be determined. This paper discusses the problems involved in determining these two variables and the sensitivity of the model to variability in them.

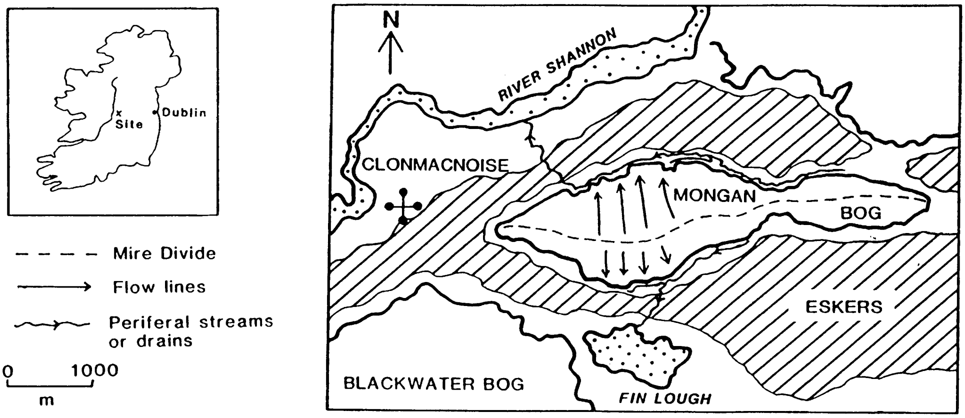

Fig. 1. Site location map.

Hydraulic Conductivity

The model requires a single, average, *K* value to describe flow in the mire. Individual measurements of *K* may be expected to vary considerably (Chason and Siegel 1986, Ingram 1983). *K* was determined in the central areas of the mire, on sites unaffected by cutting, and where the seasonal fluctuation in the water table is less than 20 cm. The catotelm is about 8 m deep and the top of it is found within 20 cm of the surface. Measurements were made using the lined seepage tube method described by Kirkham (1946) following the field methodology of Ryecroft *et al.* (1975a,b), Ingram (1982) and Ingram and Bragg (1984) to ensure comparability.

Seepage tests were conducted at 5 randomly selected sites at each of five depths. To ensure that drawdown at each site did not interfere with adjacent tests the auger holes were randomly located around a pool, at least 1.5 m from the pool margin and at least 5 m apart (Fig. 2).

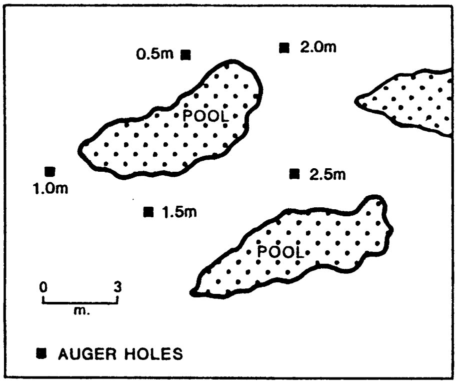

Fig. 2. Location of auger holes with respect to pools.

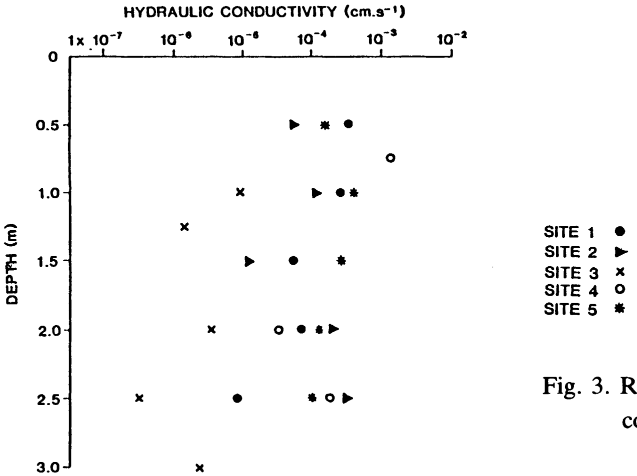

Fig. 3. Relationship between hydraulic conductivity and depth.

Results (Fig. 3) show a general decrease in *K* with depth but the data for individual sites are highly variable depending on the peat stratigraphy. Site 2 was Spagnaceous throughout and bulk density decreased to that of a liquid below 3 m. Site 5 on a hummock had a uniform core of predominately *Eriophorum* leaf bases and *Erica sp* material. The low *K* values at 125 cm at site 4 is qualitatively related to the denser layer of material found between 120 and 150 cm.

Statistically there is no simple correlation between *K* and depth but multiple regression relating *K* to depth and incorporating stratigraphy as a second, binomial, variable is significant at the p = 0.01 level.

$$\text{Log } K \equiv -2.98 - 0.00464\,\text{Depth} - 0.94\,\text{Material} \qquad (F_{2,21} = 12.2)$$

where depth (cm), Log *K* (cm/s^{-1}) and Material was classified as 0 where *Sphagnum Sp* predominate, and 1 for *Eriophorum* and *Erica sp.* Plotted as a frequency distribution (Fig. 4a) the data are skewed with a median of 8.1×10^{-5} cm/s.

An additional set of tests was run at 2 m depth and at measured distances from the pools. Results (Fig. 5) show no significant decrease in *K* away from the pool

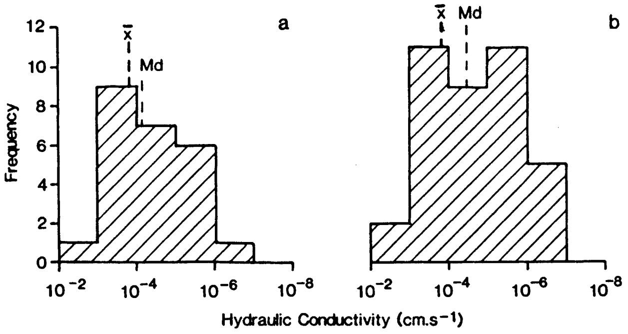

Fig. 4. Distribution of *K* at

a) sites for Fig. 3,

b) all sites.

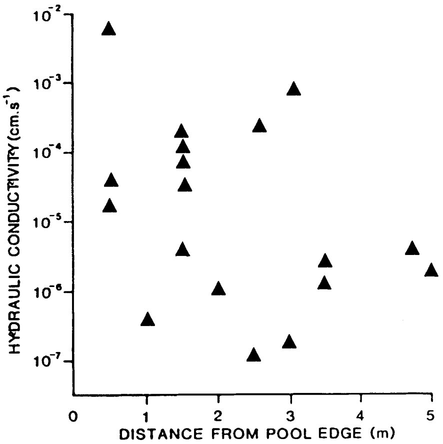

Fig. 5. Hydraulic conductivity at 2 m depth.

edge ($r = 0.32$ $N = 18$) but for a smaller sample for which material type was recorded, Log K is correlated at the $p = 0.05$ level with material type ($r = -0.66$ $N = 11$). When distance is incorporated

$$\text{Log } K \text{ (2m)} = -3.36 - 1.6 \text{ Material} - 0.22 \text{Distance(m)} \qquad (F_{2,8} = 7.16)$$

Adding these data to the frequency diagram reduces the skew and both the median and mean (Fig. 4b).

Mire Recharge

The annual volume of recharge to the mire (U) is calculated from the water balance. Monthly precipitation data was obtained from Blackwater, 5 miles south of Mongan and evaporation data from a class A pan from Boora 10 miles to the southeast, for the twenty year period 1963-1984. Double mass analysis showed the Blackwater and Boora precipitation records to be comparable. The mire is underlain by glacial clay to more than 6 m so groundwater leakage is assumed to be zero. Watertable measurements for 1983-1985 suggest the mire is rewetted by November so the water year is used for calculations to minimise ΔS. Effectively Eq. (2) reduces to

$$P - E - R = U \qquad (3)$$

Ingram suggests that the value of U employed in analysis should be that for the driest year available; Ingram (1982) expects “the water balance to be that through which the mire survives without irreversible dessication”. The driest year on record for Mongan is 1975-1976 (Table 1). However this drought year was an unusually rare event. Estimates of the return period vary but however defined the drought was unpecedented in 250 years of rainfall measurement and probably exceeded a conservative 1:100 year estimate (Grindley 1980).

Table 1 – Calculations for U 1963-1984

Water years	*P* (mm)	*E* (mm)	*P-E* (mm)
1963-64	770	561	209
1964-65	931	486	445
1965-66	967	526	441
1966-67	829	473	354
1967-68	840	532	308
1968-69	751	479	272
1969-70	741	452*	289
1970-71	692	445	213
1971-72	707	440*	267
1972-73	809	467	342
1973-74	776	426	350
1974-75	691	487	205
1975-76	608	513	95
1976-77	900	458	442
1977-78	729	457	272
1978-79	887	494*	393
1979-80	911	482*	428
1980-81	860	467	393
1981-82	785	547	238
1982-83	1086	593	494
1983-84	876	522	354

* Includes an estimated value for evaporation in one winter month. (error ± 10 mm)

It seems unlikely that the mire would be hydrologically adjusted to the 95 mm recharge in 1975-76. A more useful value might be $U = 210$ mm, an average of the next three lowest years on record 1963-64, 1970-71, and 1974-75.

To test the groundwater model both the 95 and 210 mm values are used as they certainly bracket the appropriate value. In this calculation no account of the overland flow loss has been made. Trough and regular bucket catch measurements of overland flow in 1983-84 gave an estimated total volume loss of less than 20 mm in a much wetter year, and as will be seen this has a negligible affect on the model despite it being an over-estimate of the *R* value in a dryer year.

Model Sensitivity

The equilibrium surface is estimated for two mire cross-sections, 740 and 1,040 m in length, using the two values of *U* and a range of *K* values. The results (Fig. 6) show that the model is relatively insensitive to the recharge value, and adjusting for overlandflow by reducing *U* by 20 mm has a negligible effect. The overall width of

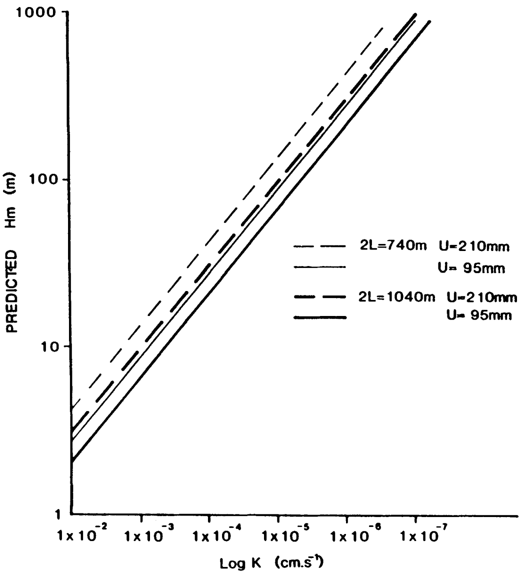

Fig. 6. Predicted mire height with varying *K, L* and *U*.

the mire also has a relatively minor effect on mire height. The model is however highly sensitive to hydraulic conductivity. The equilibrium profile predicted from the mean or median catotelm *K* values predicts *Hm* of 15 to 35 m. Clearly the equilibrium profiles (Fig. 7a,b) are considerably over predicted. Back calculation to find *K* from the present *Hm* gives *K* in the range 9×10^{-3} cm/s to 5×10^{-3} cm/s depending on the value of *U*. This is an order of magnitude greater than the empirical measurements of *K*.

Discussion

In the context of mire development the application of the Dupuit-Forcheimer model to predict the natural equilibrium mire height is confused by two unknowns. Recharge calculated from the water balance has a relatively small effect on the final profile but evidence of drought history needs careful consideration (Verry 1984). A mire is unlikely to be in equilibrium with a recharge event that occurs less than every 100 years, but presumably adjusts continually to changes in the local climate.

Hydraulic conductivity affects significantly values of predicted *Hm*. Mire height approximately doubles for every half order of magnitude decrease in *K*. In the case of Mongan the use of the mean or median *K* values determined in the field predicts an equilibrium mire height greater than that of the eskers that surround the basin (Fig. 7c).

The range of hydraulic conductivities found in the top 3 m of this mire is not

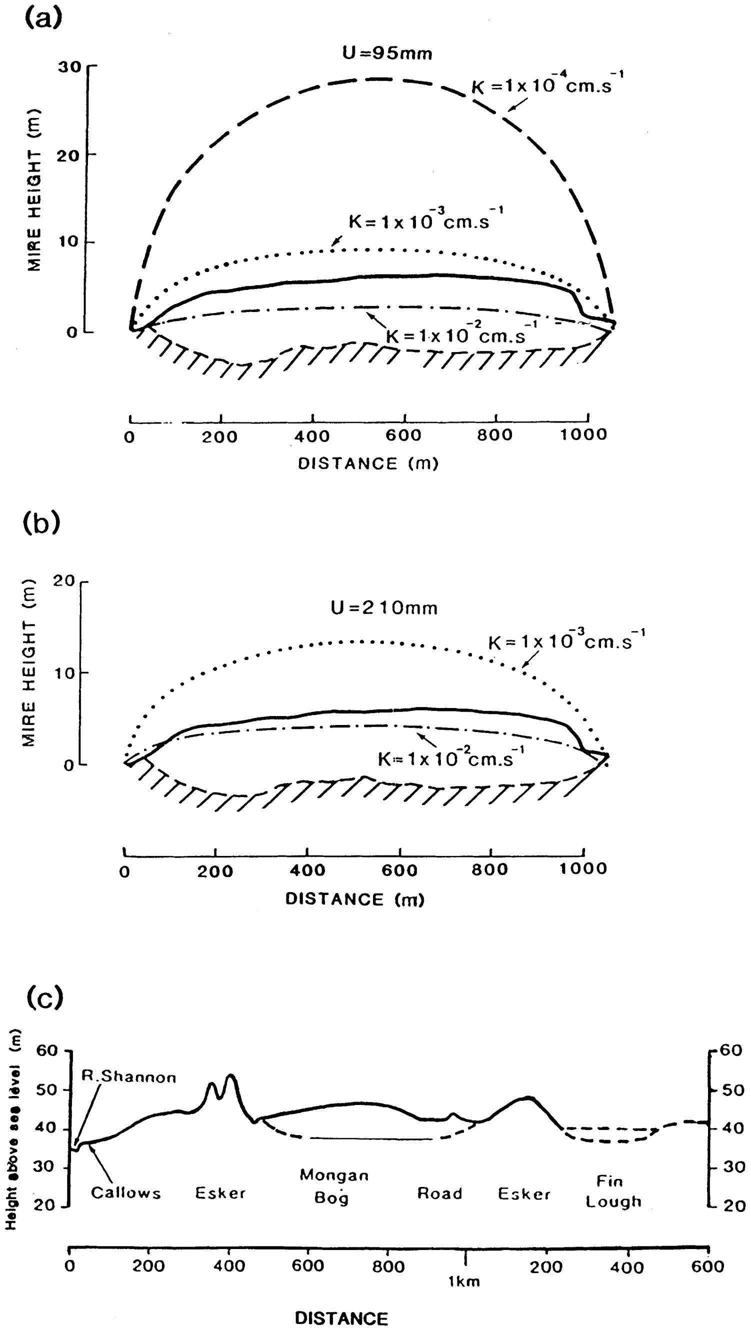

Fig. 7. Actual and predicted mire profiles where a) U = 95 mm and b) U = 210 mm, c) cross section through the eskers.

unusual. Chason and Siegel (1986) review 17 studies of field *K* measurements in mires and show that variability across three orders of magnitude is common. The logarithmic nature of hydraulic conductivity adds to the problem of characterising an average value. Clearly the range of field values suggests that a relatively large sample of *K* measurements should be made at every site and that the results should be interpreted carefully. There is a relationship between *K* and depth when stratigraphy is considered. This measure of stratigraphy is a coarse surrogate for bulk density and degree of humification which should in theory correlate with *K*. Here, as in Chason and Siegel's study, the absence of significant simple correlations with depth is due to the high degree of variability in both humification and bulk density in the catotelm; this would require an impractically large sampling program to evaluate.

The relatively high equilibrium *K* value obtained by back calculation might be explained on the grounds that the central part of the mire has an open pool network covering about 25% of the surface. *K* cannot be determined in or close to the pools where the mire is essentially liquid. Given that the median *K* values apply to say 75% of the mire then one could argue for a higher overall value. This however is post-dictive justification to explain the present surface profile. Moreover the presence of the pool and hummock network generating the variable density profile over time must lead to variation in the flow paths within the mire such that the simple pattern that the Dupuit model assumes may be invalid.

The groundwater mound theory is not therefore an accurate enough methodology to predict the profile of a mire where the margins have been partially exploited for fuel and agriculture and an independent estimate of the natural mire topography could have indicated whether the mire is stable or shrinking. For conservation purposes it was hoped to estimate the required annual recharge to maintain growth and determine the required height of the watertable in the surrounding area to allow optimal conservation over a 30 year period, but the margin of error around the *K* values generates an unacceptable uncertainty in any prediction of mire height.

Conclusion

The groundwater model makes very sweeping assumptions about the homogeneity of flow through the peat matrix. The flow paths are assumed to be parallel and *K* is assumed to be constant over the entire mound. Field measurements of *K* show variability which suggests that the model assumptions are not valid for the complex arrangement of pool and hummock structures found on a raised mire. While post-dictive use of the groundwater model *may* be helpful for mire description, for predictive purposes in conservation, agriculture or harvesting, the use of this model is limited by the field variability of its components.

Acknowledgements

The Meteorological Office, Glasnevin, Dublin for the data in Table 1.

References

Chason, D.B., and Siegel, D.I. (1986) Hydraulic conductivity and related physical properties of peat, Lost River Peatland, Northern Minnesota, *Soil Science, Vol. 142,* pp. 91-99.

Clymo, R.S. (1984) The limits to peat bog growth, *Philosophical Transactions of Royal Society, London, Vol. B 303,* pp. 605-654.

Grindley, J. (1980) Rainfall, in Doornkamp, J.C. and Gregory, K.J. (Eds) *Atlas of Drought in Britain,* pp. 27-28.

Ingram, H.A.P. (1982) Size and shape in raised mire ecosystemes: a geophysical model, *Nature, Vol. 297,* pp. 67-158.

Ingram, H.A.P. and Bragg, O.M. (1984) The diplotelmic mire: some hydrological consequences reviewed, Proceedings Seventh International Peat Congress Dublin 1, pp. 220-234.

Kirkham, D. (1946) Proposed method for field measurement of permeability of soil below the water table, Proceedings Soil Science Society America 10, pp. 56-68.

Ryecroft, D.W., Williams, D.J.A. and Ingram, H.A.P. (1975) The Transmission of water through peat: 1 Review, *Journal of Ecology, Vol. 63,* pp. 535-556.

Ryecroft, D.W., Williams, D.J.A. and Ingram, H.A.P. (1975) The transmission of water through peat: 2 Field Experiments, *Journal of Ecology, Vol. 63,* pp. 557-567.

Tubridy, M. (Ed) (1984) Creation and Mangement of a Heritage Zone at Clonmacnoise, Co Offaly, Ireland, EEC Final Report, Trinity College Environmental Sciences Unit, Dublin, 206 pp.

Tubridy, M. (Ed) (1987) Heritage Zones: the Clonmacnoise example, Occ. Pub. 1/87, Trinity College Environmental Sciences Unit, Dublin 54 pp.

Verry, E.S. (1984) Microtopgraphy and water-table fluctuation in a *Spagnum* mire, Proceedings Seventh International Peat Congress, Dublin 2, pp. 11-31.

First version received: 13 July, 1987
Final version received: 4 September, 1987

Address:
School of Geography,
The University,
Leeds, LS2 9JT,
England.