Nordic Hydrology, 10, 1979, 41-48

An Approach to Calculating Evaporation Rates at Remote Sites

D. Ovadia and R. K. Pegg
University of Liverpool, Dept. of Geography

This paper describes work which has been undertaken to assess the feasibility of calculating evaporation rates for remote sites in North Wales from the recordings taken at a central site. In the course of the work it was found that data derived from radiosonde ascents and published in the Daily Aerological Records proved to be beneficial in the analysis.

Introduction

The maintenance of efficient hydrometeorological instrumental networks is expensive and especially so in remote upland areas. The accuracy of the data obtained is frequently of a low order and this is particularly the case with estimates of evapotranspiration. Indeed when a number of different methods are used to estimate evapotranspiration in a low altitude area many different results are obtained, all of which may be incorrect (Pegg and Ward 1972).

During the period 1970 to 1973 the Welsh National Water Authority operated four automatic weather recording stations at different altitudes at lake or reservoir sites to collect the data necessary to estimate evaporative losses by the Penman method (Penman 1948). Although the area is not large it is diverse in topography, vegetation and aspect. Local and microclimatic factors add greatly to the complexity of already intricate evaporation theories and hence an essentially pragmatic approach to the problem was used.

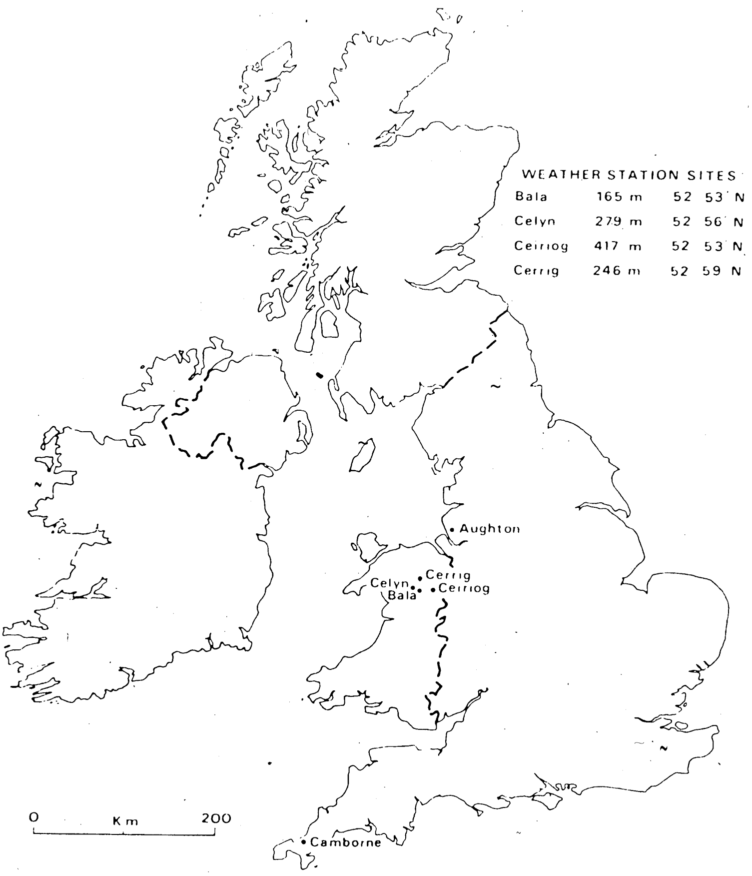

Fig. 1. Location of sites.

The Approach

At each automatic weather station site, twenty measured or derived parameters were monitored. Linear regression was used on some of the important parameters for selected monthly comparisons in order to see if these were different from the year round results, (Table 1). Subsequently, for the entire run of available daily data, polynomial regression analysis of up to the third order was undertaken between all the parameters between the base station at Bala (Fig. 1) and each satellite station in turn. For each comparison a correlation coefficient, significance level, regression equation and standard error of the estimate was calculated. Fig. 2 shows a summary of the correlation between the main parameters for the three inter-site comparisons, the values being derived from the year-round polynomial analysis, all values being significant at 0.1%.

Table 1 – Linear correlations between calculated evaporation. Bala and Ceiriog sites – selected monthly analysis:

	APRIL 1972	MAY 1972	JUNE 1972	JULY 1972
Number of days in sample	29	27	30	31
Correlation coefficient	0.687	0.557	0.330	0.813
Significance level (%)	0.1	0.1	10	0.1

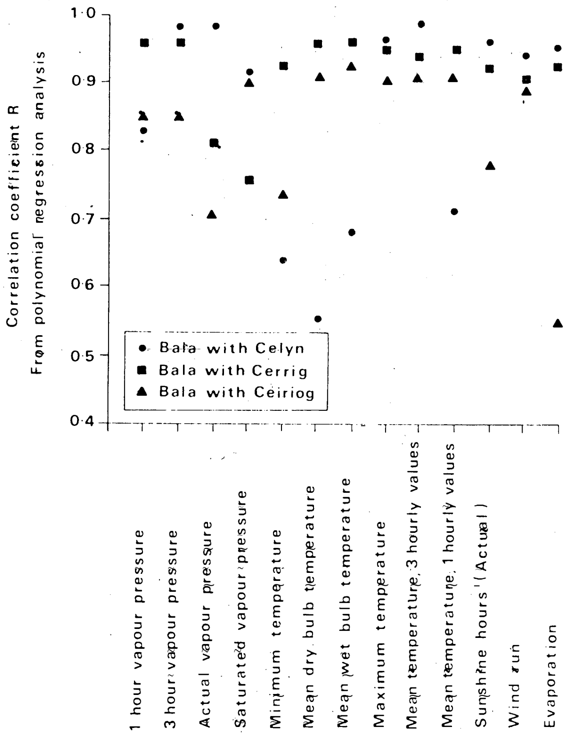

Fig. 2. Summary of correlations between sites. Year round values.

Subsequently a comparison was made between the calculated daily evaporation rates at the satellite stations derived from parameters measured on site, and the daily evaporation rate at the same stations recalculated from parameters given by the polynomial regression equation using the equivalent parameter measured at the base station at the same time. These two values of calculated evaporation were the further compared for a randomly selected sample taken from the Bala-Ceiriog comparisons (Fig. 3), this pair of sites being chosen as the pair with the lowest direct correlations (Fig. 2).

It was realised at an early stage in the work that certain of the comparisons (expecially those between sites at Bala and Ceiriog) did not reach an acceptable level of correlation, having coefficients less than 0.6 and in some cases less than 0.5. This was attributed to four causes.

1. Small errors in the measurement of individual parameters accumulated; the final error increasing beyond acceptable limits, as the difference between each parameter at two dissimilar sites increases;
2. Microclimatic anomalies assuming overriding importance;
3. Spatial variations in the macroclimatic conditions over the area;
4. The existence of weaknesses in the basic (Penman 1948) derivation theory.

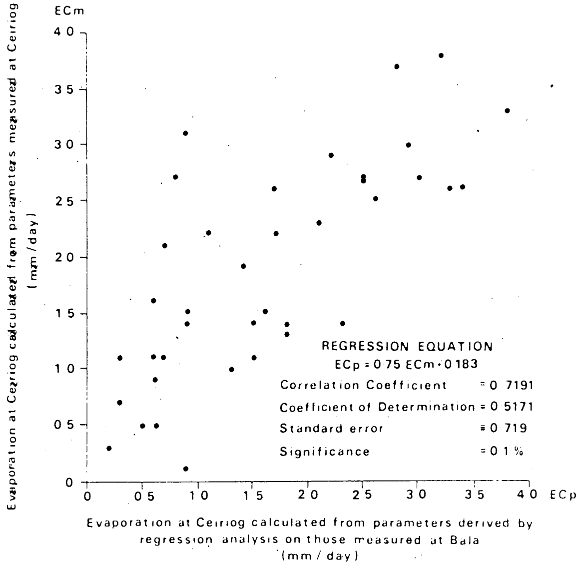

Fig. 3. Scatter diagram of evaporation calculated from on site recordings and from equivalent predicted recordings.

In order to give some consideration to the macroclimatic variations it was decided to use published upper-air data and hence to derive parameters which could be used to represent atmospheric turbulence. Thornthwaite and Holzman (1942) used lakeside measurements on a small scale to examine the role of turbulence on the evaporation process. Such measurements were not possible in this work and so the following parameters were used.

a) an assessment of the vertical rate of change of potential temperature, $\partial\theta/\partial z$ used as a measure of thermal stratification (Webb 1965)

This is taken as

$$\frac{(\theta_s - \theta_{850})}{\Delta z}$$

where

$$\theta_s \equiv T_s \left(\frac{1000}{P_s}\right)^{0.288}$$

and

$$\theta_{850} = T_{850} \left(\frac{1000}{850}\right)^{0.288}$$

when

θ_s	is the potential temperature of the earth's surface
θ_{850}	is the potential temperature at 850 mbs
P_s	is the surface pressure in mbs
T_s	is the surface temperature in degrees Kelvin
T_{850}	is the temperature at 850 mbs in degrees Kelvin
Δz	is the height of the 850 mb pressure level in geopotential metres

b) the vertical rate of change of specific humidity $\partial q/\partial z$ between the surface and the height Δz

c) the vertical wind shear, taken (after Webb 1965) as: –

$$\frac{\partial u}{\partial \ln z} = \frac{u_{850} - u_s}{\ln z}$$

where

u_{850}	is the wind speed at 850 mbs
u_s	is the surface wind speed
$\ln z$	is the natural logarithm of the height of the 850 mb pressure surface

d) the component of the geostrophic wind speed resolved along the estimated orientation of the catchment area on which the recording station is situated, taken as the average wind speed between the surface and the 850 mb level, multiplied by the absolute value of the cosine of the angle between the long axis of the valley and the wind direction at 850 mb. (This parameter is intended to give some weighting to the importance of valley winds common in this area).

These four "turbulence parameters" were calculated for each day in a randomly selected sample, from radiosonde ascents at Aughton (53° 33'N; 2°55'W; 57 m altitude) and Camborne (50° 13'N; 5°19'W; 89 m altitude). A linear variation was assumed between these stations in order that a weighted average could be extracted from the two sets of data to represent the expected values at the test area in North Wales, which lies geographically between Aughton and Camborne. The four turbulence parameters so derived were introduced, together with the Penman calculated evaporation at the base and one satellite station (Ceiriog), into a partial correlation coefficient analysis, in order to obtain the partial correlation between evaporation at Bala and Ceiriog, with the turbulence parameters being considered as held constant. The results are shown in Table 2.

The introduction of upper air parameters is seen (Table 2) to give a correlation coefficient of calculated evaporation between sites at Bala and Ceiriog of almost 0.7 under conditions when the turbulence factors are held (statistically) constant. The multiple correlation coefficient, a measure of the goodness of fit of a regression equation between the inter-site evaporation, taking into account turbu-

Table 2 – Results of the partial correlation analysis on evaporation with atmospheric turbulence – year round results

		Evaporation at Bala (X2)	Potential Temp. Lapse Rate (X3)	Specific Humidity Lapse Rate (X4)	Vertical Wind Shear (X5)	Component of geostrophic wind (X6)
Zero order partial correlation coefficients	Evaporation at Ceiriog (X1)	0.6119	0.2481	0.3774	0.4036	0.1103

4-fold multiple correlation coefficient, $R_{1\,(2\ldots6)} \equiv 0.7649$
partial correlation coefficient, $r_{12.3456} \equiv 0.6971$
standardised partial regression coefficients: $a \equiv +0.639$ $b_5 \equiv -0.193$
$b_2 \equiv -0.130$ $b_6 \equiv -0.084$
$b_3 \equiv -0.022$
$b_4 = +0.179$ all at .001

+ all significant at 0.001 level

lence over the area, is 0.76. These annual figures are nearly as good as the best monthly comparisons, namely a correlation of 0.81 (Table 1), and compare favourably with the annual polynomial correlation coefficient for the same pair of sites (Fig. 2) of 0.55, being an improvement of some 20%.

Conclusions

It is not clear why the accuracy of spatial correlations of evaporation rates between sites varies markedly from strong (Bala-Celyn) to unacceptably poor (Bala-Ceiriog), but this is probably due to microclimatic variations between sites and their surrounding environments. It has not been considered practical to approach the spatial correlation problem by a direct consideration of microclimatic anomalies; for even if such work was undertaken, it would preclude generalised applications.

Instead, the introduction of easily obtainable data from which can be calculated parameters representing turbulence produced an improved correlation between sites, and a more accurate regression equation.

There is considerable scope for the development of the parameters representing turbulence used in this investigation, and such improved parameters may prove useful in future investigations of this type.

Acknowledgements

Thanks are due to the Welsh National Water Authority for the data, and in particular to Mr. A. O. Lambert for his interest and co-operation.

References

Pegg, R. K., and Ward, R. C. (1972) Evapotranspiration from a small clay catchment. *J. Hydrol.* 15, 149-65.

Penman, H. L. (1948) Natural Evaporation from open water, bare soil and grass. *Proc. Roy. Soc.* A. 193, 120-145.

Penman, H. L. (1956) Evaporation – an introductory survey. *Neth. J. Agric. Sci.*, 4, 9-29.

Thornthwaite, C. W., and Holzman, B. (1942) Measurement of evaporation from land and water surface. *U.S. Dept. Agric. Tech. Bull.* No. 817.

Udny Yule, G., and Kendall, M. (1964) *An Introduction to the Theory of Statistics'*.

Webb, E. K. (1965) Aerial Microclimate. *Meteorological Monographs* 6 (28), 27-58.

Received: 28 August, 1978

Address:
University of Liverpool,
Department of Geography,
Roxby Building,
P.O. Box 147,
Liverpool L69 3BX.
England