Estimation of Daily Potential Evaporation for Input to Rainfall-Runoff Models

T.G. Chapman

School of Civil and Environmental Engineering,
The University of New South Wales, Sydney 2052, Australia (tomc@civeng.unsw.edu.au)

Abstract: Simple linear regression models have been used to relate daily potential evaporation (PE) at 19 sites in Australia to pan evaporation and maximum and minimum temperature data. In most cases, forcing the regressions through the origin resulted in significantly lower coefficients of determination and increased bias. In general, maximum temperature was a better predictor of PE than mean temperature, and at one site only was there a significant improvement resulting from including the difference between maximum and minimum temperatures as an additional predictor. Pan evaporation was a better predictor of PE than maximum temperature at all but one site. In an attempt to regionalise the results within Australia, empirical equations have been developed to relate the parameters of the regressions to latitude and altitude of the data sites. When PE data are not available for a given catchment, careful consideration needs to be given to the available options for estimation of the input to daily rainfall-runoff models.

Keywords: Potential evaporation; Daily temperatures; Pan evaporation; Rainfall-runoff; Linear regression

1. INTRODUCTION

Soil water balance models, including most conceptual rainfall-runoff models, require as inputs both rainfall data and estimates of potential evaporation (PE). The actual evaporation is usually calculated as a function of PE and computed soil water, and the difference between rainfall and evaporation is partitioned between runoff, groundwater recharge, and change in soil water storage.

PE can be calculated at climate stations which record solar radiation (or sunshine hours), temperature, humidity and wind run, but Table 1 shows that there are probably only 60-70 locations in Australia where this is currently feasible. Use of pan evaporation as a predictor for PE increases the number of currently available sites to 90, but many of these will be co-located with climate stations. The much larger number of stations which record maximum and minimum temperatures provides the incentive to determine the extent to which such data can be used as predictors for PE.

A recent paper [Jeffrey et al., 2001], describes the use of spatial interpolation to develop patched data sets for approximately 4600 locations, using all available Australian daily climate data from 1957 onwards. The data sets include pan evaporation and maximum and minimum temperatures, but not PE.

Most Australian studies of rainfall-runoff models have used calculated PE or observed pan evaporation from locations which may be well outside the catchment being modelled. For the data base of 28 unregulated Australian catchments compiled by Chiew and McMahon [1993], the mean distance of the temperature stations from the centroid of the catchment was 35 km, while the corresponding mean distance of the sunshine recording stations was 110 km (the authors used Morton's model for PE [Morton, 1983], which does not require wind data).

Table 1. Numbers of locations for which evaporation-related data are available, extracted from Bureau of Meteorology web site (www.bom.gov.au).

Variable	Total sites	Current sites
Solar radiation	78	12
Sunshine duration	180	60
Wind run	326	77
Pan evaporation	529	90
Temperature	1493	353

In adapting the IHACRES rainfall-runoff model to a water balance approach, Evans and Jakeman [1998] assumed PE to be proportional to mean daily temperature. It should be noted that mean daily temperature is calculated as the average of maximum and minimum temperature, and thus evaporation, Figures 4 and 5 show that the parameters A_p and B_p can be expressed in terms of latitude, leading to

Model 2:

$$PE = A_p * Epan + B_p \quad (2)$$

where $A_p = 0.17 + 0.011 * Lat \quad (3)$

and $\log_{10} B_p = 0.66 - 0.0211 * Lat \quad (4)$

Lat being the latitude in degrees South.

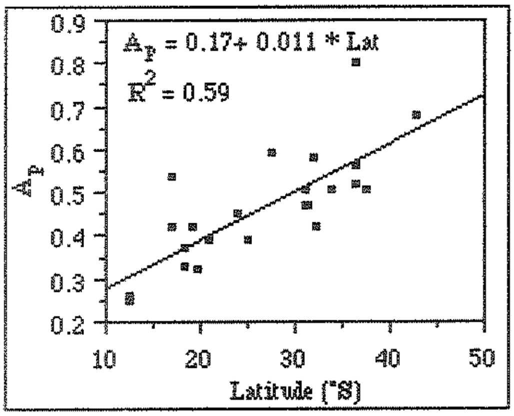

Figure 4. Relation between slope parameter of (2) and latitude.

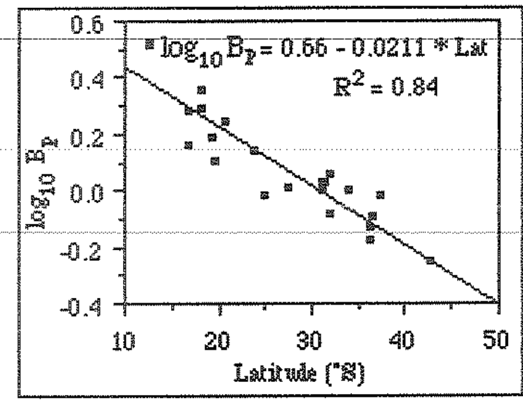

Figure 5. Relation between offset parameter of (2) and latitude.

The parameters of the regression between PE and maximum temperature are strongly related to each other and to both latitude and altitude, as shown in Figures 6 and 7. This results in

Model 3:

$$PE = A_t * Tmax + B_t \quad (5)$$

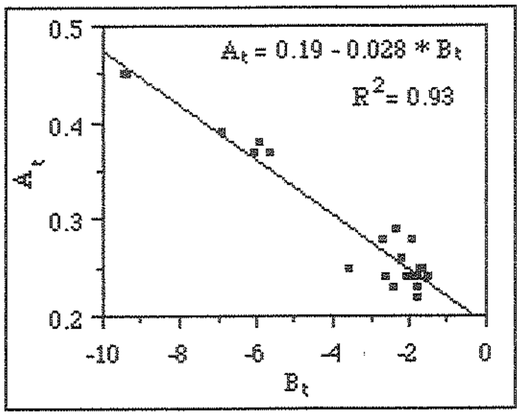

Figure 6. Relation between the slope and offset parameters of (5).

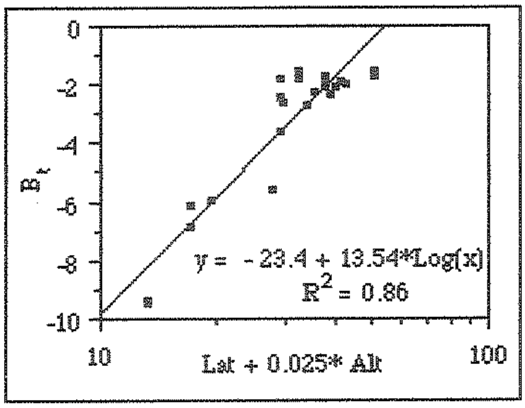

Figure 7. Relation between offset parameter of (5) and function of latitude and altitude.

where $A_t = 0.19 - 0.028 * B_t \quad (6)$

and

$B_t = -23.4 + 13.54 * \log_{10}(Lat+0.025*Alt) \quad (7)$

Alt being the altitude of the station in m AHD.

Table 3 shows the degradation of R^2 when these models are used in place of the regressions based on the station data. Model 1, with only 1 parameter, performs reasonably at all locations, but the coefficient of determination is generally below those for the other models. Models 2 and 3 show a relatively small decrease in R^2 for most stations, but each performs very badly at one location. However, the general level of the coefficient of determination compares very favourably with the corresponding statistics for pan evaporation in the study by Jeffrey et al. [2001], which range from <0.2 to >0.6, with a median around 0.4.

Table 3. Values of R^2 for predictions of PE from the variables shown, using the regressions from the data and the linear predictions from the regionalised models. Values of mean absolute error (MAE) in mm are also shown for each model. See text for definitions of variables. Stations are ordered by decreasing latitude.

Variables			Tmax			Epan, C			Tmax, C		
	Latitude		Data	Model 1		Data	Model 2		Data	Model 3	
Location	(°S)	Period	R^2	R^2	MAE	R^2	R^2	MAE	R^2	R^2	MAE
Hobart	42.8	1987-89	0.49	0.48	1.13	0.81	0.80	0.63	0.57	0.54	1.02
Laverton	37.4	1977-79	0.58	0.58	1.02	0.70	0.68	0.77	0.66	0.64	0.86
Tatura	36.4	1973-75	0.63	0.60	1.16	0.82	0.63	1.02	0.73	0.67	0.98
Canberra	36.3	1970-72	0.64	0.64	0.90	0.73	0.70	0.77	0.71	0.63	0.92
Canberra	36.3	1987-89	0.65	0.64	1.02	0.79	0.78	0.72	0.72	0.66	0.99
Sydney	33.9	1974-76	0.45	0.44	1.09	0.63	0.62	0.84	0.55	0.51	0.93
Ceduna	32.1	1970-72	0.57	0.54	1.17	0.78	0.63	0.91	0.61	0.48	1.13
Perth	31.9	1970-72	0.46	0.46	1.27	0.75	0.74	0.81	0.51	0.47	1.17
Cobar	31.5	1975-77	0.70	0.70	0.94	0.85	0.82	0.68	0.78	0.77	0.79
Tamworth	31.1	1973-75	0.67	0.67	0.88	0.79	0.79	0.64	0.75	0.74	0.75
Woomera	31.1	1972-74	0.64	0.63	1.14	0.85	0.82	0.72	0.72	0.71	0.92
Brisbane	27.4	1970-72	0.46	0.33	1.14	0.67	0.61	0.79	0.64	0.62	0.81
Giles	25.0	1970-72	0.71	0.69	0.92	0.88	0.62	1.07	0.78	0.76	0.81
Alice Springs	23.8	1974-76	0.63	0.61	0.90	0.71	0.71	0.73	0.69	0.57	0.91
Mount Isa	20.7	1976-78	0.62	0.61	1.67	0.63	0.63	0.41	0.70	0.58	0.83
Tennant Creek	19.6	1970-72	0.64	0.55	0.93	0.75	0.01	1.48	0.68	0.64	0.81
Townsville	19.2	1970-72	0.41	0.38	1.03	0.62	0.61	0.76	0.58	0.46	0.90
Halls Creek	18.2	1974-76	0.58	0.34	0.91	0.59	0.59	0.71	0.70	0.03	1.14
Halls Creek	18.2	1987-89	0.64	0.58	0.68	0.54	0.52	0.73	0.71	0.14	1.03
Cairns	16.9	1974-76	0.34	0.27	0.92	0.59	0.56	0.67	0.51	0.48	0.76
Cairns	16.9	1987-89	0.37	0.34	0.93	0.68	0.52	0.76	0.58	0.56	0.75
Darwin	12.4	1978-80	0.29	0.28	0.70	0.30	0.21	0.73	0.48	0.48	0.61
Darwin	12.4	1987-89	0.30	0.29	0.70	0.26	0.11	0.80	0.52	0.51	0.59
Averages			0.54	0.51	1.01	0.68	0.60	0.79	0.65	0.55	0.89

As a further measure of performance of the models, the mean absolute error has also been tabulated in Table 3, and the values can be seen to compare well with the values for pan evaporation in the above study, which ranged from 0.8 to 2.8 mm/d, with a median around 1.8 mm/d. As a qualification to these comparisons, it must be recognised that the data in the current study are restricted to 3 year periods, while those in the work by Jeffrey et al. [2001] extend over the available record since 1970.

5. DISCUSSION

When dealing with monthly or seasonal data, it has been common practice [Chiew et al., 1995] to force the regression between PE and pan evaporation through the origin, so providing a single coefficient relating the two variables. This study has shown that application of this approach to daily data generally results in a marked decrease in the coefficient of determination, and biased estimation of PE at high and low values.

This effect can be partly attributed to very high values of pan evaporation related to high advected sensible heat resulting from poor exposure when surrounded by bare soil. For example, the four values of pan evaporation above 18 mm shown in Figure 2 for Mount Isa are occasions of high maximum temperatures (>37°), low humidity, and high wind, while the four lowest points in Figure 3 relate to Tennant Creek, Giles, Ceduna and Halls Creek, all locations where advection is likely to be high [Fitzpatrick, 1968].

Another contributing factor, particularly relevant in tropical areas in the wet season, is that pan evaporation may be registered as zero or negative, and recorded as zero, due to the difference in catch between raingauge and pan in heavy rainfall and high winds.

The lack of sensitivity of PE to the difference between maximum and minimum temperatures can be seen as symptomatic of differences between northern hemisphere humid areas, where minimum temperatures are close to the dewpoint, and high evaporation conditions in Australia, where the minimum temperature is much higher than dewpoint. The one exception, Cairns, can be attributed to a moist onshore air stream which is maintained for most of the year.

It should be noted that all the regressions would be sensitive to seasonal variations, and higher coefficients of determination could be obtained by undertaking separate analyses for each month. However, regionalisation of such results would be difficult to achieve, and application would be subject to considerable uncertainty.

While the range in PE values calculated from the regressions will be less than the true site values, the impact on the performance of a daily rainfall-runoff model should not be serious, particularly when there are relatively long drying periods between runoff events. In such situations, where the PE is modulated by the simulated soil moisture to give the actual evaporation, the estimated catchment dryness before a runoff event will not be very sensitive to over or under estimation of the PE.

The study has demonstrated that, with the exception of Darwin, pan evaporation is a better estimator of PE than maximum temperature. However, a randomly selected site is likely to be closer to a temperature station than to a station where pan evaporation is measured, and a station where PE can be calculated is likely to be even further away. The appropriate balance between distance and data quality has yet to be determined.

6. CONCLUSIONS

The conclusions to be drawn from this study can be summarised as follows:

- Forcing regressions between daily PE and other climate variables through the origin results in generally significant reductions in R^2, and biased predictions at high and low PE.
- Maximum daily temperature is a better predictor of PE than mean daily temperature.
- The difference between maximum and minimum temperatures was a significant predictor of PE at only one location studied (Cairns).
- Pan evaporation was a better predictor of PE than maximum temperature at all but one location studied (Darwin).
- The parameters of the regressions between PE and pan evaporation, and between PE and maximum temperature, can be regionalised with generally minor degradation of the coefficient of determination and acceptable values of the mean absolute error.

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