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THE RELATIONSHIP BETWEEN ANNUAL RAINFALL AND PAN EVAPORATION IN AUSTRALIA

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ABSTRACT

Annual totals of pan evaporation and rainfall are shown to be inversely correlated over much of inland Australia. The slope of the regression line is most negative in the interior of the continent and becomes less negative or zero near the coast. Over much of inland Australia the year to year variation in pan evaporation is greater than the corresponding rainfall variation. The relationships found may be used to determine the annual pan evaporation associated with annual rainfall totals.

INTRODUCTION

A knowledge of pan evaporation, rainfall, and their interrelationship is important for many studies in applied meteorology and hydrology, particularly those where the availability of surface moisture is not a major limitation on evaporation. An example of the use of these data is the determination of the difference of annual rainfall minus annual pan evaporation at a particular location. For this purpose climatic mean pan evaporation is often used with observed rainfall data because of the general shortage of long periods of pan evaporation records in many areas and the difficulties of reliably estimating pan evaporation data from other meteorological variables. While the inverse spatial relationship of rainfall and pan evaporation is fairly well established from climatic surveys (e.g. Gentilli 1972) there is little information available on the variability and extremes of pan evaporation with corresponding rainfall fluctuations from year to year at a particular location. Hunt et al. (1913) present annual totals of pan evaporation and rainfall for four stations in drought years but failed to observe any significant differences in evaporation between drought years and the long-term average. They did not comment on the relationship between pan evaporation and rainfall implicit in their data for Alice Springs. Studies such as Penman (1948) or Louw and Kruger (1967) that have related pan evaporation to other meteorological variables do not provide any direct means of determining the relationship between pan evaporation and rainfall on an annual or monthly basis. This study examines the relationship between annual and monthly totals of pan evaporation and rainfall for Australia. A significant correlation between annual totals is found over much of inland Australia and provides a means of extending the limited information available on pan evaporation.

DATA

Observations of pan evaporation for this study were selected from data available for the Australian evaporimeter network. Details of instrumentation and station location are described in Bureau of Meteorology (1974). The original evaporimeter used in the network was the Australian Sunken Tank (abbreviated as AST) described by Hounam (1961), but this has been progressively replaced since 1967 with the Class A pan. Data from stations with at least 10 years of reliable AST evaporation records were selected from Hounam (1961). These were then supplemented with data (AST or more recent pan Class A) from further stations with at

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least 5 years of reliable record to obtain as representative a spread of stations as possible over Australia. The corresponding rainfall totals were obtained using a gauge with a 20 cm (8 inch) diameter collecting area mounted 30 cm (1 foot) above ground level. In all, some 887 station years from 67 stations in Australia were found suitable for this study. Of the total stations years, 598 consisted of data from the AST.

As data from three evaporimeters (AST, Class A pan, Class A pan with bird guard) were used in this study, it was decided to present the results in terms of the Class A pan equivalent as this is a recognised standard instrument. Evaporation data for the AST were converted to the equivalent Class A pan evaporation using conversion factors derived from Hounam (1965) except at Rockhampton and Charleville where ratios of AST to Class A pan evaporation of 0.74 and 0.72 were deduced from station observations. Evaporation data from Class A pans with bird guards were converted to equivalent Class A pan evaporation by multiplying by the factor 1.07 (Van Dijk 1975). The bird guard is important in inland Australia to prevent birds and animals drinking the pan water and hence rendering the data unreliable.

METHOD

The relationship between annual pan evaporation and rainfall may be obtained by determining the line of best fit of the observations by the method of least squares. The regression equation has the form

$$E = mP + b \qquad \ldots 1$$

where E and P are the annual totals of evaporation and precipitation and m and b are the regression coefficients to be determined. In order to best determine m and b the least squares regression procedure was performed twice using both P and E as the independent variable and then a mean value of m and b obtained for use in Eqn 1. The difficulties of least squares regression analysis where both variables contain significant errors are further discussed in Morgan (1960). Also calculated were the correlation coefficient (r) and the standard errors in m and b, σ_m and σ_b, respectively.

RESULTS

Regression analysis results for those stations where the correlation coefficient was significant at the 5 per cent confidence level are given in Table 1. All results are presented in terms of Class A pan equivalent. Of the 67 stations examined, 37 were found to have correlation coefficients significant at the 5 per cent confidence level. At a confidence level of 1 per cent, 24 of the 67 stations were still found to have significant correlation coefficients. Although from a statistical viewpoint some of the Class A pan evaporation records are rather short (between 5 and 9 years) for regression analysis, this is offset for much of central Australia by the unusually large variation in annual rainfalls observed in the period 1967 to 1975, notably the very high rainfalls of 1974 and 1975. This tended to produce more reliable results than would otherwise have been expected. The regression coefficients obtained for Tennant Creek and Longreach (indicated by an asterisk) in Table 1 are considered doubtful as they are much larger in absolute magnitude than those obtained from nearby stations and they are based on observations from Class A pans without bird guards. In these low rainfall regions birds and animals drinking from the unguarded pans may result in significant overestimations of pan evaporation. The effect would tend to be greater in the drier years, resulting in an overestimation of the value of b and an underestimation (more negative) value for m. While the values of m and b for these two stations were not used in subsequent analyses, the significance of the correlation coefficient seems correct. Table 2 lists those stations examined that were found to have non-significant correlation coefficients at the 5 per cent confidence level. Stations of Table 1 tend to have inland locations, whereas stations of Table 2 tend to be located near the coastline.

Table 1 Regression results for stations with correlation coefficients significant at the 5 per cent confidence level. PO and RS indicate Post Office and Research Station, respectively. Results from stations marked by an asterisk (*) are doubtful as discussed in the test.

Station Name	Number of years	r	m	σ_m (%)	b (mm)	σ_b (mm)
Halls Creek	7	-0.77	-1.38	37	4300	800
Kununurra	5	-0.99	-0.86	7	3500	230
Meekatharra	9	-0.87	-2.74	22	4760	300
Mt Magnet	7	-0.81	-1.87	32	3120	410
Albany	7	-0.85	-0.78	28	2030	470
Merredin RS	41	-0.51	-2.57	27	3030	150
Forrest	8	-0.74	-2.38	37	3220	350
Kalgoorlie	9	-0.68	-1.83	41	3340	490
Giles	14	-0.75	-1.87	25	4230	420
Darwin Aerodrome	16	-0.69	-0.31	28	3220	1840
Katherine	9	-0.67	-1.34	41	3940	800
Alice Springs PO	32	-0.74	-2.02	17	3780	272
Alice Springs Aerodrome	9	-0.96	-2.29	11	4090	170
Newcastle Waters	7	-0.83	-1.42	30	3800	550
Tennant Creek*	6	-0.94	-4.30	19	6120	350
Rabbit Flat	6	-0.97	-2.22	13	4420	200
Woomera	9	-0.78	-2.94	30	3720	270
Yudnapinna	14	-0.69	-2.52	30	3190	250
Oodnadatta	7	-0.94	-2.98	16	4610	220
Cloncurry	8	-0.81	-1.66	29	4490	550
Townsville	6	-0.94	-0.89	18	4000	600
Longreach*	8	-0.93	-3.61	17	4720	250
Birdsville	5	-0.92	-1.81	25	4350	530
Rockhampton Aerodrome	24	-0.79	-0.72	17	3010	450
Brisbane	32	-0.61	-0.61	24	2320	480
Charleville Aerodrome	21	-0.79	-1.80	18	3900	260
Thargomindah	5	-0.98	-1.17	12	3320	300
Wilcannia	28	-0.39	-1.52	46	2300	350
Bourke	8	-0.88	-1.15	22	2140	300
Gunnedah	15	-0.78	-1.06	22	2710	350
Inverell	10	-0.89	-0.65	18	2010	410
Bathurst	28	-0.64	-0.90	24	1950	310
Sydney	16	-0.52	-0.31	44	1570	1270
Canberra Aerodrome	16	-0.71	-1.03	27	2190	370
Tatura	13	-0.70	-0.58	31	1920	760
Melbourne	32	-0.45	-0.84	37	1800	400
Hobart	30	-0.44	-0.84	39	1510	330

Table 2 Stations found to have non-significant correlation coefficients at the 5 per cent confidence level. PO indicates Post Office station.

Broome
Port Hedland
Onslow
Wittenoom
Carnarvon Aerodrome
Brickhouse
Chapman
Geraldton
Perth
Esperance
Narrogin PO
Eucla
Ceduna
Adelaide
Waite
Kybybolite
Cairns
Walkamin
South Johnstone
Monto
Gladstone
Applethorpe
Coffs Harbour
Prospect Reservoir
Cataract Reservoir
Griffith
Merbein
Rocklands Reservoir
Glenmaggie Reservoir
Cressy

An example of annual totals of pan evaporation and rainfall data for the Alice Springs area in central Australia is shown in Fig 1. The Post Office record is based on AST observations whereas the aerodrome record is based on observations from a Class A pan with bird guard. The values of the regression coefficients m and b in Table 1 for Alice Springs aerodrome, although based on 9 years observations between 1967 and 1975, are not significantly different from the values of the regression coefficients for Alice Springs Post Office, even though the latter are based on 32 years of AST data between 1891 and 1924. This suggests that results in Table 1 based on less than 10 years Class A pan data are reasonably reliable compared with the results from the generally much longer AST records and that the results of Table 1 are not dependent on the type of evaporimeter used, provided the known conversion factors are applied.

The variation of m (the slope of the regression line) over Australia is shown in Fig 2. Those stations where pan evaporation and rainfall were found to be uncorrelated at the 5 per cent confidence level were considered to have an m of zero. The coefficient m has its greatest reliable negative magnitude at Oodnadatta ($m = -2.98$) in the arid interior of Australia. Along the coastline values of m range from zero to -1.0. Qualitatively therefore in regions where $m \leqslant -1.0$ the absolute change in pan evaporation from year to year is greater than the corresponding variation in rainfall.

The spatial variation of b over Australia is shown in Fig 3. No values are shown where there was no significant correlation between pan evaporation and rainfall. The contour pattern of b is similar to the variation of mean annual evaporation (Bureau of Meteorology 1975), although the absolute values are somewhat larger. In arid areas where rainfall may be close to zero in dry years, b may be considered an estimate of the maximum expected annual evaporation.

DISCUSSION

The results of Table 1 suggest certain factors that favour the significant correlation of annual pan evaporation and rainfall and these will now be considered in more detail. Station locations were considered to be either coastal, mountainous, or inland. A station was considered coastal if it was located within 50 km of the sea, mountainous if station elevation was above 300 m in a region of rugged terrain, and inland if it was neither coastal nor mountainous. Stations were also categorised according to their seasonal rainfall distribution, one of summer maximum, winter maximum, uniform, or arid according to Australian Water Resources Council (1969). By this definition a location has a summer rainfall maximum if the ratio of (median rainfall from November to April) over (median rainfall from May to October) is greater than 1.3, a winter rainfall maximum if this ratio is less than 0.77, and a uniform distribution if this ratio is between 0.77 and 1.3. A location is considered arid if median annual rainfall is less than 380 mm for a summer rainfall maximum or less than 255 mm for a winter rainfall maximum or uniform distribution.

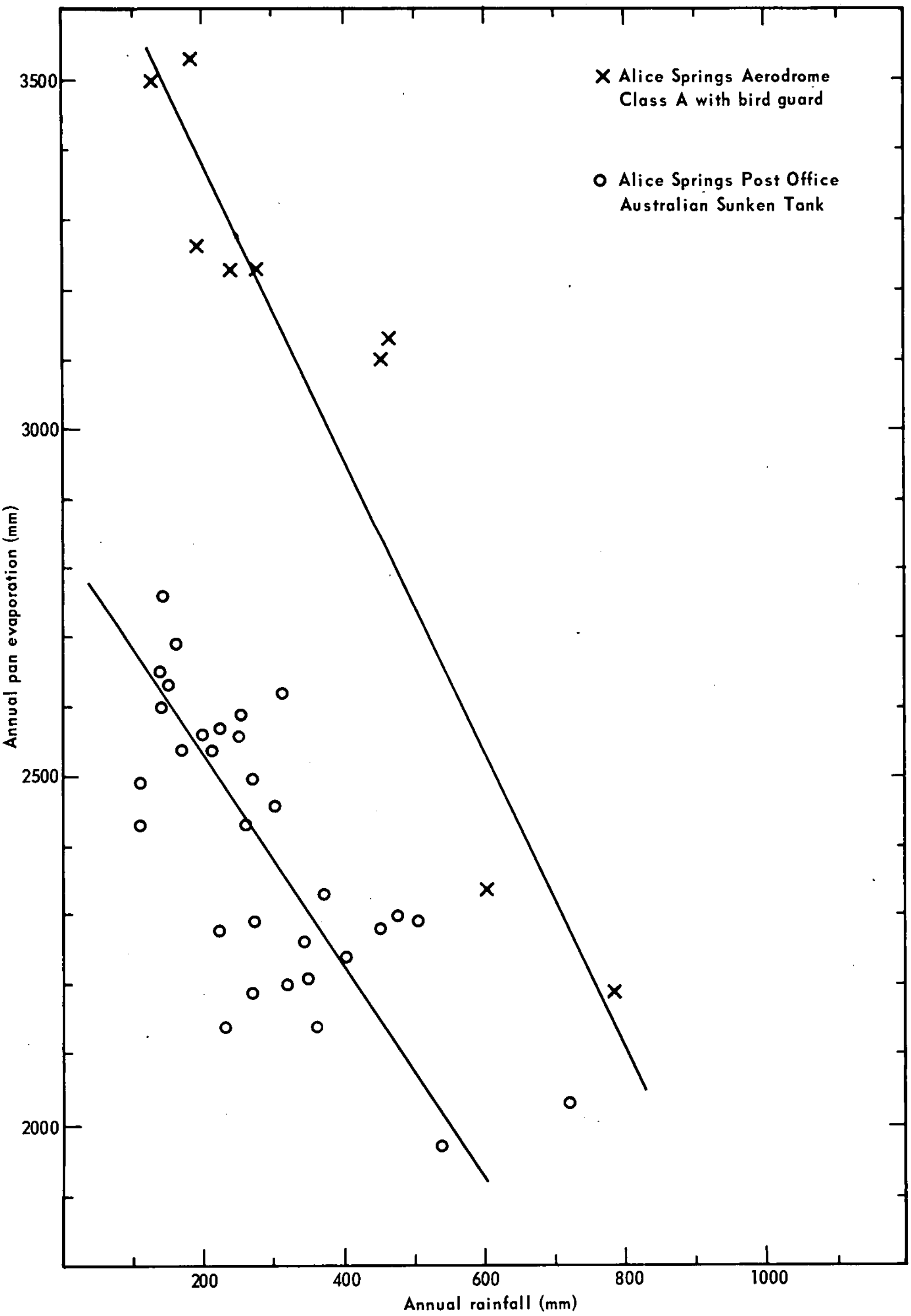

Fig 1 The relationship of annual totals of pan evaporation and rainfall for Alice Springs Aerodrome and Post Office and the corresponding least squares regression lines.

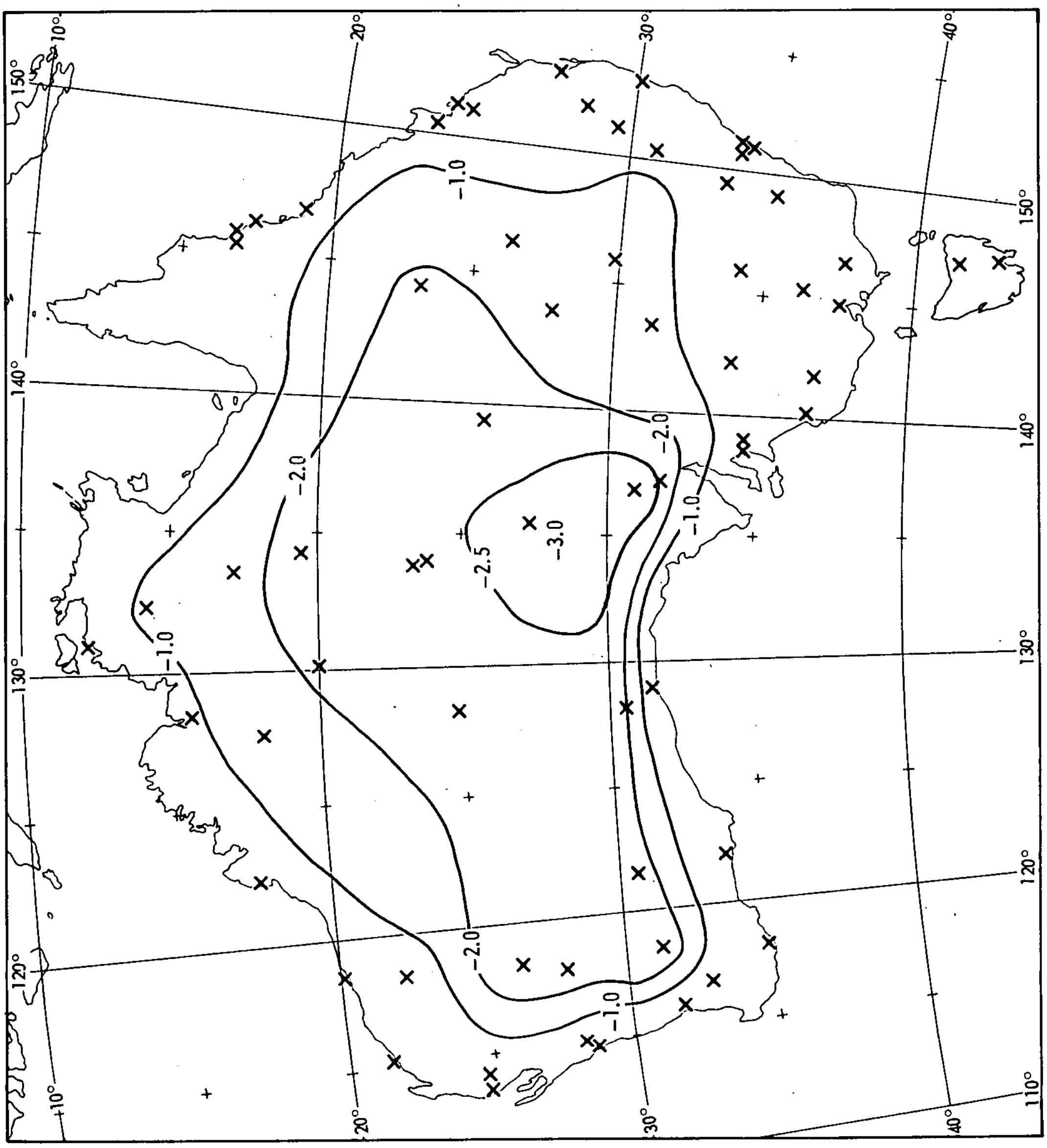

Fig 2 The spatial variation of the regression coefficient m. The locations of stations examined are shown by a cross (x).

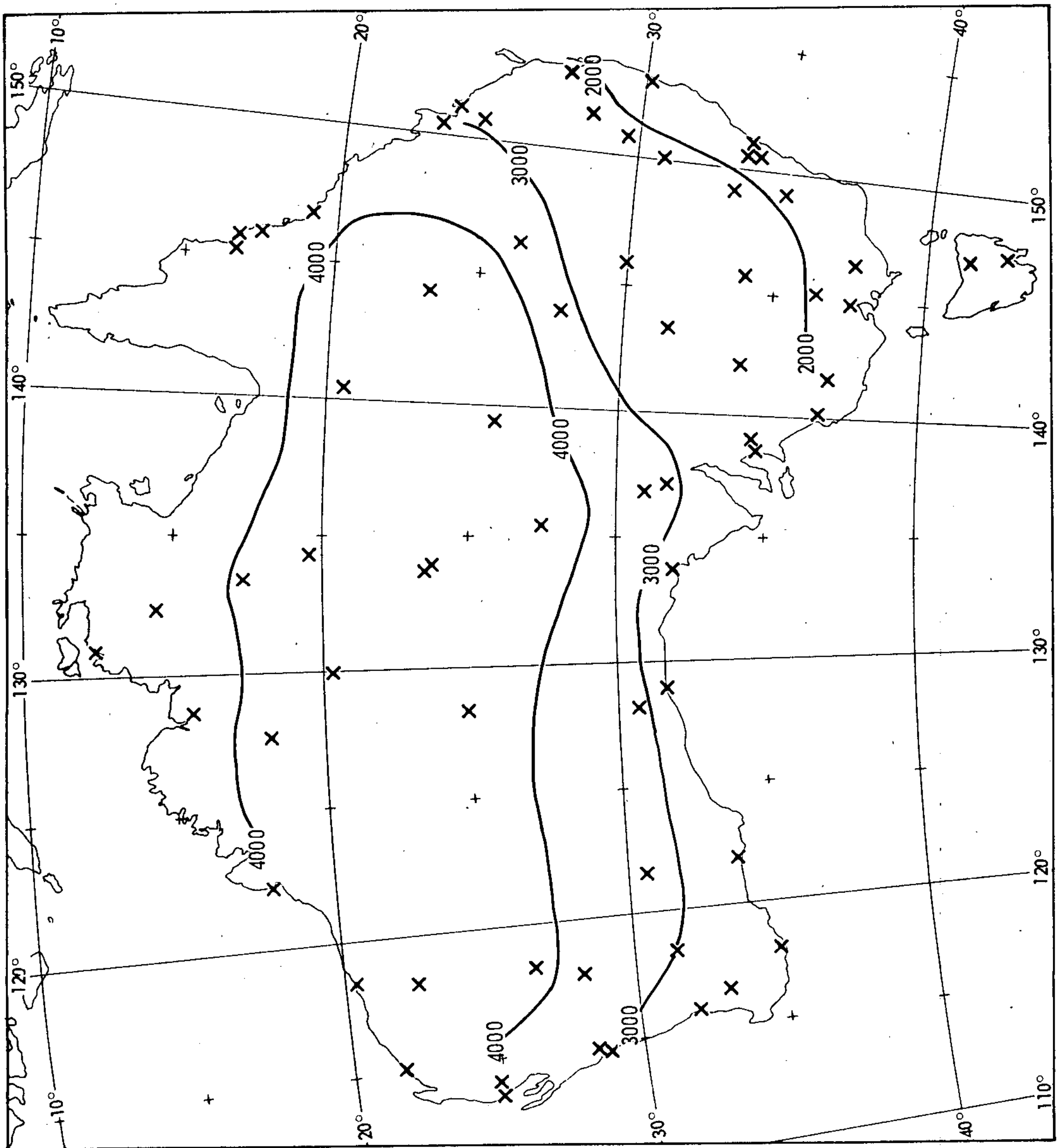

Fig 3 The spatial variation of the regression coefficient b. The locations of stations examined are shown by a cross (x).

Table 3(a) shows that coastal or mountainous locations are not associated with significant correlations between annual pan evaporation and rainfall whereas inland stations are associated with significant correlations. Table 3(b) shows that winter rainfall maximum regions are not associated with significant correlations between pan evaporation and rainfall whereas the other three seasonal rainfall types are associated with significant correlations. While stations in the arid area with significant correlations all have values of $m \leq -1.0$, only about half the stations with a summer rainfall maximum have values of $m \leq -1.0$ and only one station out of five with a uniform rainfall distribution has a value of $m \leq -1.0$. Table 3(c) shows that stations with an inland location and a rainfall maximum not in the winter show a high association with significant correlation between annual pan evaporation and rainfall; whereas other stations are associated with non-significant correlations. Considering only those stations which have significant correlation coefficients together with a value of $m \leq -1.0$ further improves this association.

Table 3 . Association of significant correlation between annual pan evaporation and rainfall with station location and seasonal rainfall distribution.

Category	Number of stations		
	Not significant	Significant	
		All m	$m \leq -1.0$
(a) LOCATION			
Coastal	19	8	0
Mountainous	5	1	0
Inland	6	28	25
(b) SEASONAL RAINFALL DISTRIBUTION			
Winter	13	3	1
Uniform	3	5	1
Summer	8	13	7
Arid	6	16	16
(c) COMBINATION OF (a) AND (b)			
Inland and not winter rainfall maximum	1	26	24
Other	29	11	1

The association found in Table 3(a) may be explained qualitatively by considering the Penman (1948) equation for evaporation, which shows evaporation is a combination of a radiation term and an aerodynamic term. Considering year to year fluctuations at a given location the radiation term is largely controlled by the cloudiness and the aerodynamic term by the saturation vapour pressure deficit and wind speed. The cloudiness and saturation vapour pressure deficit are likely to be correlated with rainfall at inland locations but this is not likely to be so at coastal or mountainous locations. Here cloud and/or humidity changes may result from local circulation patterns such as a sea breeze without rainfall occurring. The association of wind speed and rainfall is not clear and therefore is has been assumed to be uncorrelated for the present argument. However, where the rainfall maximum occurs in winter it is less likely that cloudiness and saturation vapour pressure deficit changes associated with rainfall will have much influence on evaporation with its summer maximum. This is borne out by the results of Table 3(b). Combining both station location and seasonal rainfall distribution in Table 3(c) characterises those areas where a significant correlation between annual totals of rainfall and pan evaporation may be expected, especially where values of $m \leqslant -1.0$ are of most importance.

In regions where a significant correlation between annual pan evaporation and rainfall exists, Hoy (1977) has shown empirically that the expressions:

$$m = -0.93 \ln \bar{E}/\bar{P} \qquad \ldots 2$$

or

$$m = -\frac{350 + 0.12\,\bar{E}}{\bar{P}} \qquad \ldots 3$$

are both capable of explaining 79 per cent of the variance of m. Also the expression

$$b = 1.12\,\bar{E} + 350 \qquad \ldots 4$$

is capable of explaining 96 per cent of the variance of b. Some function of the ratio of $\bar{E}$ and $\bar{P}$ is frequently used as an indicator of climate (Gentilli 1972). While there is some similarity between values of m and climatic indicators in the interior of Australia, along the coast (especially the west coast of Australia), these climatic indicators do not suggest the lack of correlation observed in Table 1.

Preliminary examination of pan evaporation and rainfall totals for each month over many years at several stations from Table 1 showed that the monthly correlation was much less consistent than the annual correlation. Extreme rainfall events such as thunderstorms may influence monthly totals more than yearly totals, thus resulting in more erratic behaviour of the correlation coefficient. Also, individual monthly totals show greater climatic variability from year to year than do yearly totals, owing to the increased influence of variables not included in the regression. Thus the correlation between pan evaporation and rainfall totals for particular months is not sufficiently reliable to be generally useful.

The results outlined in this study enable variations of annual rainfall to be associated with corresponding variations in annual pan evaporation over much of inland Australia. Thus it is possible to estimate annual totals of pan evaporation from annual rainfall totals and the coefficients m and b in Eqn 1. Extreme values of annual rainfall minus evaporation may be calculated more reliably using evaporation from Eqn 1 rather than a mean annual evaporation.

Evaporation from large water bodies may also be obtained by applying annual lake to pan conversion coefficients as in Australian Water Resources Council (1970) or Hoy and Stephens (1977) to the annual pan evaporation totals.

CONCLUSIONS

From a least squares regression analysis of extensive evaporation and rainfall data, there exists a significant inverse relationship between annual totals of pan evaporation and rainfall over much of the interior of Australia. In particular, inland regions, either in the arid zones or with seasonal rainfall distributions that are uniform or have a summer maximum, are associated with significant correlations. Coastal or mountainous regions or those possessing winter rainfall maxima are associated with correlation coefficients that are either not significant or significant with a value of the slope of the regression line between 0 and -1.0. In general, the slope of the regression line is most negative in the interior of the continent near Oodnadatta and becomes less negative towards the coastline. The regression results obtained appear to be independent of the type of evaporimeter used, provided the known conversion factors between evaporation pans are applied. The results presented apply only for annual totals and should not be used with monthly totals, where correlations were found to be unreliable. Over much of inland Australia the year to year variation in pan evaporation is greater than the corresponding rainfall variation.

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