Evaporation Memorandum No 46

EVAPORIMETER DESIGN - MODIFICATION TO MINIMISE ACCIDENTAL WATER LOSS AND TO PROVIDE A THOROUGHLY WET EVAPORATING MEDIUM

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Summary

Data from an experimental evaporimeter are compared with those from a black-painted, GG1 3000 (buried) evaporation tank and with four sets of calculated evaporation estimates. It is shown that the experimental evaporimeter performed well, giving results usefully comparable with those obtained from the tank and in very good agreement with the most appropriate set of calculated estimates of evaporation from a flat, wet body.

1. Introduction

The conventional evaporation tank has a number of well-known shortcomings. In windy conditions the level of the water has to be reduced to avoid losses by splash and spray. This means that the tank has to be operated with an eye on the weather forecast and that the aerodynamic characteristics of the evaporimeter are not constant. Birds splash in convenient bodies of water and animals drink from them. It is not unknown for humans to remove water from evaporation tanks for such purposes as mixing cement!

From the point of view of representativeness the evaporative loss of water from a buried or exposed vessel of given dimensions, construction and colour cannot be regarded as typical, for example, of lesses from lakes or from freely transpiring vegetation even though useful empirical correlations can often be established.

A simple, inexpensive evaporimeter, effectively free from interference problems, of constant characteristics and representing evaporation from a flat, wet surface has a number of attractions for practical use.

2. Design of apparatus and experiment

Kew Observatory is equipped with two standard GGI 3000 evaporimeters (water surface area 3000 cm^2, diameter 61.8 cm, maximum depth 68.5 cm), installed with their rims approximately 3-4 cm above the ground. A pad of dark green felt approximately 2 cm thick, marginally smaller than the water surface, with a cut-out section to accommodate the stilling well, was supported in the water of one tank by polystyrene floats, to bring its topside slightly above the water surface. Water levels were maintained approximately at ground level.

Previous experiments had been carried out with the two tanks to determine if there was any systematic difference in evaporation; at that time both tanks were painted white. It had been found (Wales-Smith, 1973) that the eastern tank was systematically warmer than the other, and produced higher evaporation in the ratio of 1.031. Since there is no difference in the exposure of the two tanks, and they are only a few feet aparat, it is assumed that the difference in evaporation was caused by different characteristics of the surrounding soil. (It is understood that one tank is set in the remains of the foundations of an old building, and that the soil contains much rubble).

For this experiment the western tank was painted black and the pad was used in the eastern tank. It was assumed that the albedo of the wet felt would approximate to that of wet vegetation.

The meteorological elements required by Penman's equation for potential transpiration (Penman, 1948) are observed, regularly, at Kew.

The pad evaporimeter was brought into use in June 1975.

3. Comparisons of pad evaporimeter data with tank evaporation and with two forms of estimated transpiration and wet surface evaporation

Thirty, monthly scatter diagrams were plotted comparing daily pad evaporimeter and black GG1 3000 tank evaporation totals. These diagrams are summarised in Table 1 which contains (a) the slopes of the regression lines through the origin, (b) the pairs of daily data giving the greatest differences, (c) the differences, (d) the percentages of daily values within 0.5 mm of one another and (e) the monthly totals of evaporation from both evaporimeters.

Most of the slopes are close to the 1:1 line, most daily differences are small and even the greatest daily differences are $\leqslant 2.0$ mm.

The monthly totals are plotted in Figure 1. The months are numbered and it can be seen that the black tank values were mostly above the 1:1 relationship in winter and below it in summer.

The distribution of values of the quantity E_{PAD}/E_{TANK} is shown in Figure 2.

Monthly totals of evaporation from the pad evaporimeter are compared with Penman potential transpiration (E_t) with adjusted Penman potential transpiration (E_t') following Thom and Oliver (1977) and Wales-Smith and Bader (1978) and with estimates of evaporation from thoroughly wet, flat surfaces, based on the two versions of potential transpiration, derived from Wales-Smith and Bader (1978) as follows.

The term "adjusted Penman E_t" is taken to mean

$$E_t' = (\Delta Q_n - \Delta G + m\gamma E_{ap})/\{\Delta + \gamma(1+n)\}$$

where

Δ = the slope of the saturation vapour pressure vs temperature curve, for water, at air temperature.

Q_n = the evaporation equivalent of the net flux of radiant energy to the surface. In estimating this quantity the Penman-Brunt long-wave radiation term is seasonally adjusted, following Wales-Smith and Bader (1978) and multiplied by 0.95 following Budyko (1950) (see Grindley, 1970)

G = the evaporation equivalent of the net soil heat flux

m = an aerodynamic roughness factor (defined by Thom and Oliver, 1977)

E_{ap} = Penman's aerodynamic term

n = r_s/r_a, where

r_s = the resistance to the diffusion of water from some saturated region below or within a surface and

r_a = the aerodynamic resistance to the diffusion of water from a surface.

m was taken as 2.5 and the all-year value of n=1.4, approximated by Thom and Oliver, was considered appropriate for comparisons with the pad evaporimeter. Wales-Smith and Bader obtained approximate values of E_{wet}/E_t' (where E_{wet} is the evaporation from a thoroughly wet English lowland catchment of moderate aerodynamic roughness), following Thom and Oliver, as follows

E_{wet}/E_t' = 1.0 for December to February
1.3 for March and November
1.7 for April to October

The results are set out in Table 2. The E_{wet} values were obtained by multiplying the corresponding E_t or E_t' by arbitrarily damped values of E_{wet}/E_t' (above), to recognise the fact that the pad is a flat and not "naturally" rough surface, as follows

March and November	1.1
April to October	1.3

The monthly E_t and E_t' values are compared with E_{PAD} totals in Figure 3(a and b). It can be seen that the regression lines through the origin are significantly different from a 1:1 relationship and that there is a strong suggestion of seasonal bias.

When the E_t and E_t' values are multiplied by the arbitrarily damped E_{wet}/E_t' values (Figure 4) the 1:1 line is a very good approximation to a regression line through the origin in both cases. Each individual month's comparison is compared (between Fig 4(a) and Fig 4(b)) and the closer relationship marked with a tick (✓). It can be seen that if values of $\leqslant$ 20 mm are ignored the E_{wet} values derived from E_t' are superior to those derived from E_t on 15 occasions out of 21.

This suggests that the pad evaporimeter usually gives a good approximation to E_{wet} derived from E_t' on a monthly basis.

The monthly totals of E_{PAD} and monthly values of E_t and E_t' are plotted, sequentially, in Figure 5. It is noticeable that the E_{PAD} values were very much larger than both E_t and E_t' in the extremely hot, dry summer of 1976 than in the summers of 1975 and 1977. It is suggested that this may be due to the conditions Penman stipulated in obtaining the numerical value of the multiplying factor in his aerodynamic term. The grass surrounding the evaporimeter dried out and hence the condition that the evaporating surface be surrounded by a 10 mile radius circular area of freely transpiring vegetation was not satisfied and oasis effect resulted.

4. Conclusions

On the basis of the simple comparisons described, it is proposed that the experimental evaporimeter appears to have been an efficient device and to have given results which can be shown to be in reasonable agreement with carefully calculated estimates of evaporation from a wet surface.

Assuming that the accidental water losses from the black-painted GG1 3000 tank were not serious, it appears that the pad evaporimeter gave useful estimates of tank evaporation.

April 1978

References

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Thom, A S and Oliver, H R	1977	On Penman's equation for estimating regional evaporation. Q. J. Roy. Met. Soc., 103, pp. 345-357
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Table 1. Summary of 30 scatter diagrams E_{PAD} vs E_{TANK}

Daily Evaporation Totals from Pad. Evaporimeter and Black Tank.

		PAD/BLACK	Values giving max. differences: Black	Pad	Black−Pad	All pairs % within ± 0.5mm
July	1975	.87	7.8	6.0	1.8	81%
Aug.		.95	6.4	5.4	1.0	84
Sept		.87	6.2	4.7	1.5	80
Oct		.86	2.4	1.4	1.0	81
Nov		.75	2.4	.7	1.7	77
Dec.		.75	.9	.4	.5	100
Jan	1976	.73	3.9	1.9	2.0	80
Feb		1.06	1.7	1.0	.7	90
Mar		1.03	3.02	1.6	1.42	94
April		1.03	4.6	5.8	−1.2	65
May		1.0	2.2	3.9	−1.7	74
June		1.04	6.6	8.0	−1.4	73
July		1.0	5.4	3.7	1.7	58
Aug		1.02	7.0	7.8	−0.8	81
Sept.		1.0	1.3	2.4	−1.1	86
Oct.		.95	2.3	1.5	.8	71
Nov.		.65	1.2	1.5	−0.3	93
Dec		.45	.6	0	.6	92
Jan	1977	1.0	1.1	.6	.5	100
Feb		1.0	1.1	.6	.5	100
Mar.		1.2	1.9	.5	1.4	90
April		1.26	1.6	2.7	−1.1	87
May		1.13	2.4	3.4	−1	90
June		1.18	4.0	5.3	−1.3	73
July		1.08	5.0	3.9	1.1	84
Aug		1.07	4.5	5.5	−1	81
Sept		1.11	2.0	3.3	−1.3	80
Oct.		1.0	3.9	3.3	.6	97
Nov.		.75	3.0	1.9	1.1	87
Dec.		.8	1.2	.8	.4	100

Monthly Totals for Pad Evaporimeter & Black Tank.

PAD	BLACK
138.1	154.9
131.5	140.5
77.4	86.3
37.9	42.7
20.2	27.0
7.2	11.4
19.3	24.8
16.1	14.6
52.1	52.1
88.6	80.4
129.8	128.2
177.8	168.7
209.1	204.5
168.8	161.1
70.4	69.6
28.0	32.5
10.0	16.9
1.8	6.4
6.8	8.0
17.4	17.2
37.0	32.3
65.7	52.6
112.4	100.5
91.1	78.6
138.9	129.8
79.2	71.7
66.1	57.1
incomplete readings	
24.3	33.8
9.7	12.2

Average pad/black ratio in periods March – October = 1.0325

Table 2. Monthly evaporation totals obtained (a) from the pad evaporimeter, (b) from Penman's equation, (c) from Penman's E_t adjusted to give E_{wet}, (d) from Penman's (adjusted) equation and (e) from (d) adjusted to give E_{wet}.

		PAD (a) Evap	PENMAN (b) P.E. E_t	pad/penman	E_{wet} (c) from E_t	PAD (a)	Adjusted (d) PENMAN E_t'	pad/rev pen.	E_{wet} (e) from E_t'
July	1975	138·1	117·8	1·17	153·1	138·7	115·1	1·20	149·6
Aug		131·5	98·3	1·34	127·8	131·5	99·3	1·32	129·1
Sept		77·4	50·2	1·54	65·3	77·4	56·9	1·39	72·7
Oct		37·9	20·2	1·88	26·3	37·9	29·2	1·30	38·0
Nov		20·2	4·1	(4·92)	4·5	20·2	15·6	(1·29)	17·2
Dec.		7·2	2·9	(2·48)		7·2	13·8	(0·52)	
Jan	1976	19·3	14·6	(1·32)		19·3	31·6	(0·61)	
Feb		16·1	13·7	(1·17)		16·1	19·3	(0·83)	
Mar.		52·1	37·7	1·38	41·5	52·1	44·6	1·17	49·1
April		88·6	62·5	1·42	81·3	88·6	61·0	1·45	79·3
May		129·8	100·3	1·29	130·4	129·8	89·9	1·44	116·9
June		177·8	118·8	1·50	154·4	177·8	119·4	1·49	155·2
July		209·1	138·1	1·51	179·5	209·1	132·9	1·57	172·8
Aug.		163·8	98·1	1·67	127·5	163·8	108·6	1·51	141·2
Sept.		70·4	45·3	1·55	58·9	70·4	52·6	1·34	68·4
Oct		28·0	20·4	1·37	26·5	28·0	28·5	·98	37·1
Nov		10·0	6·7	(1·49)	7·4	10·0	13·4	(·75)	14·7
Dec		1·8	0·2	(9·0)		1·8	7·0	(·26)	
Jan	1977	6·8	4·6	(1·48)		6·8	12·2	(0·56)	
Feb		17·4	12·3	(1·41)		17·4	20·6	(0·85)	
Mar		37·0	32·2	1·15	35·4	37·0	35·5	1·04	39·1
April		65·7	58·5	1·12	76·1	65·7	57·7	1·14	75·0
May		112·4	92·5	1·21	120·3	112·4	86·9	1·29	113·0
June		91·1	80·5	1·13	104·7	91·1	69·8	1·31	90·7
July		138·9	107·9	1·29	140·3	138·9	102·3	1·36	133·0
Aug		79·2	67·5	1·17	87·7	79·2	62·3	1·27	81·0
Sept		66·1	46·6	1·42	60·6	66·1	51·8	1·28	67·3
Oct		incomplete readings	19·7			incomplete readings	26·4		
Nov		24·3	10·4	(2·34)	11·4	24·3	27·2	(0·86)	29·9
Dec.		9·7	13·5	(0·72)		9·7	29·8	(0·33)	

Mar–Oct average 1·37

Mar–Oct average 1·3.1

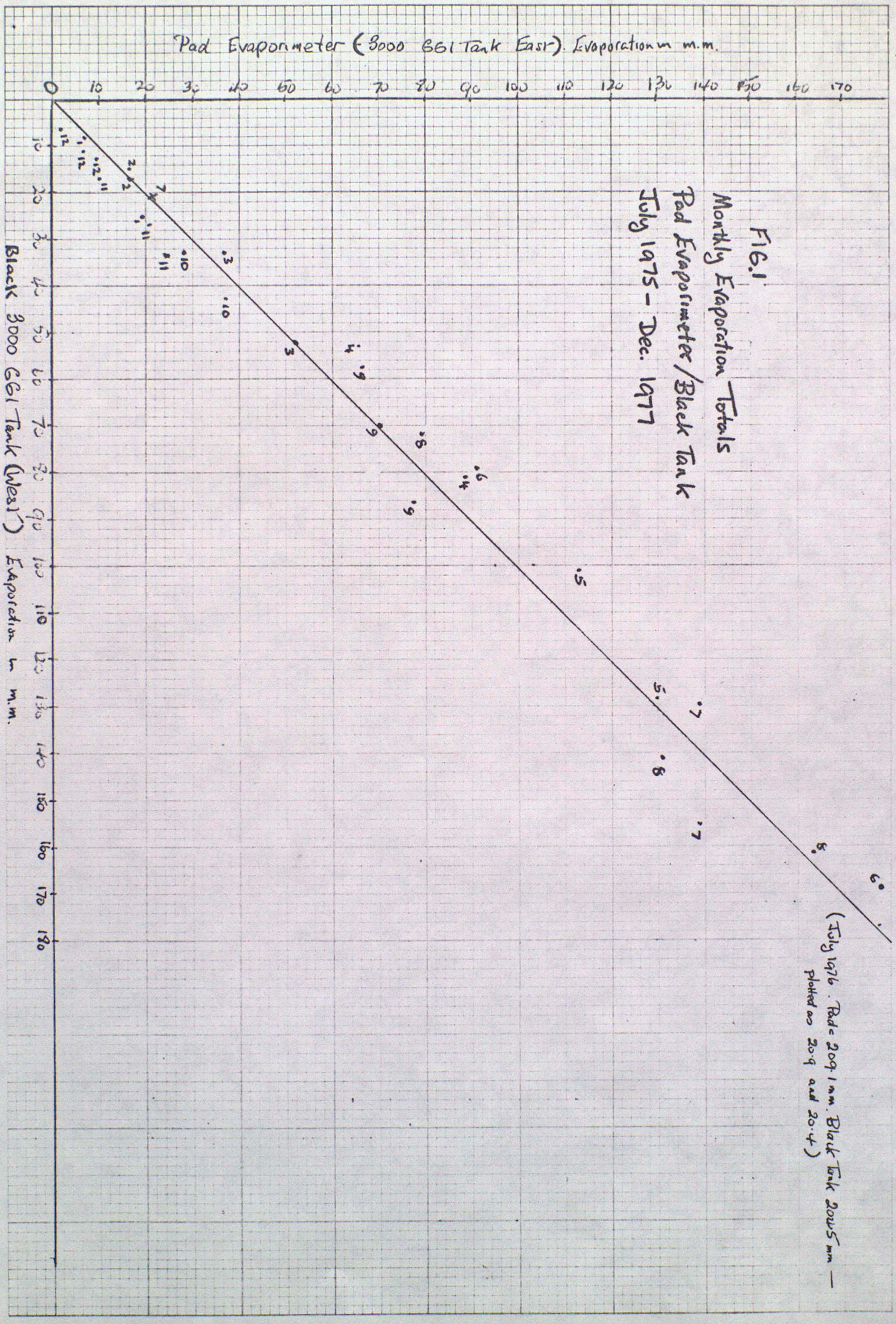
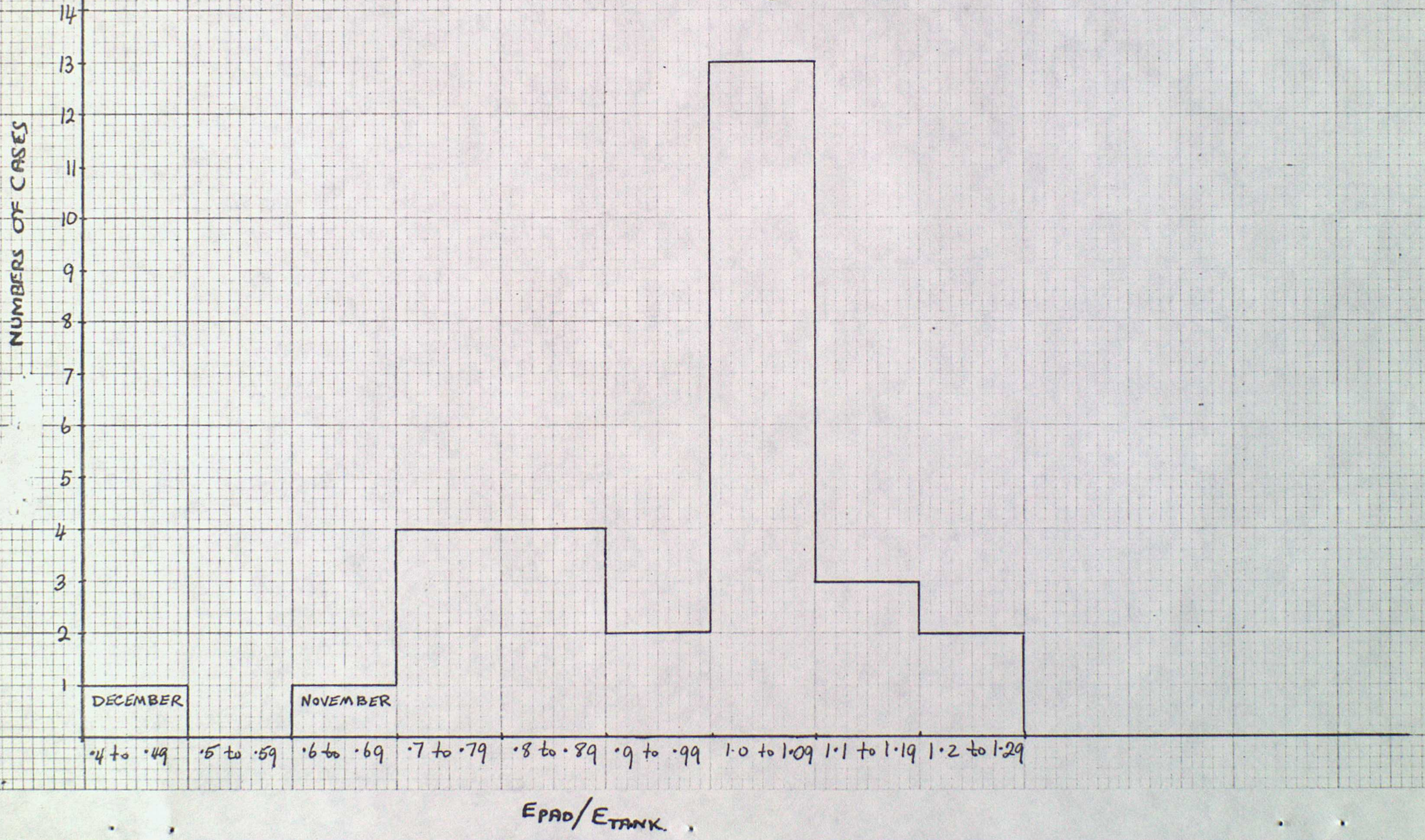


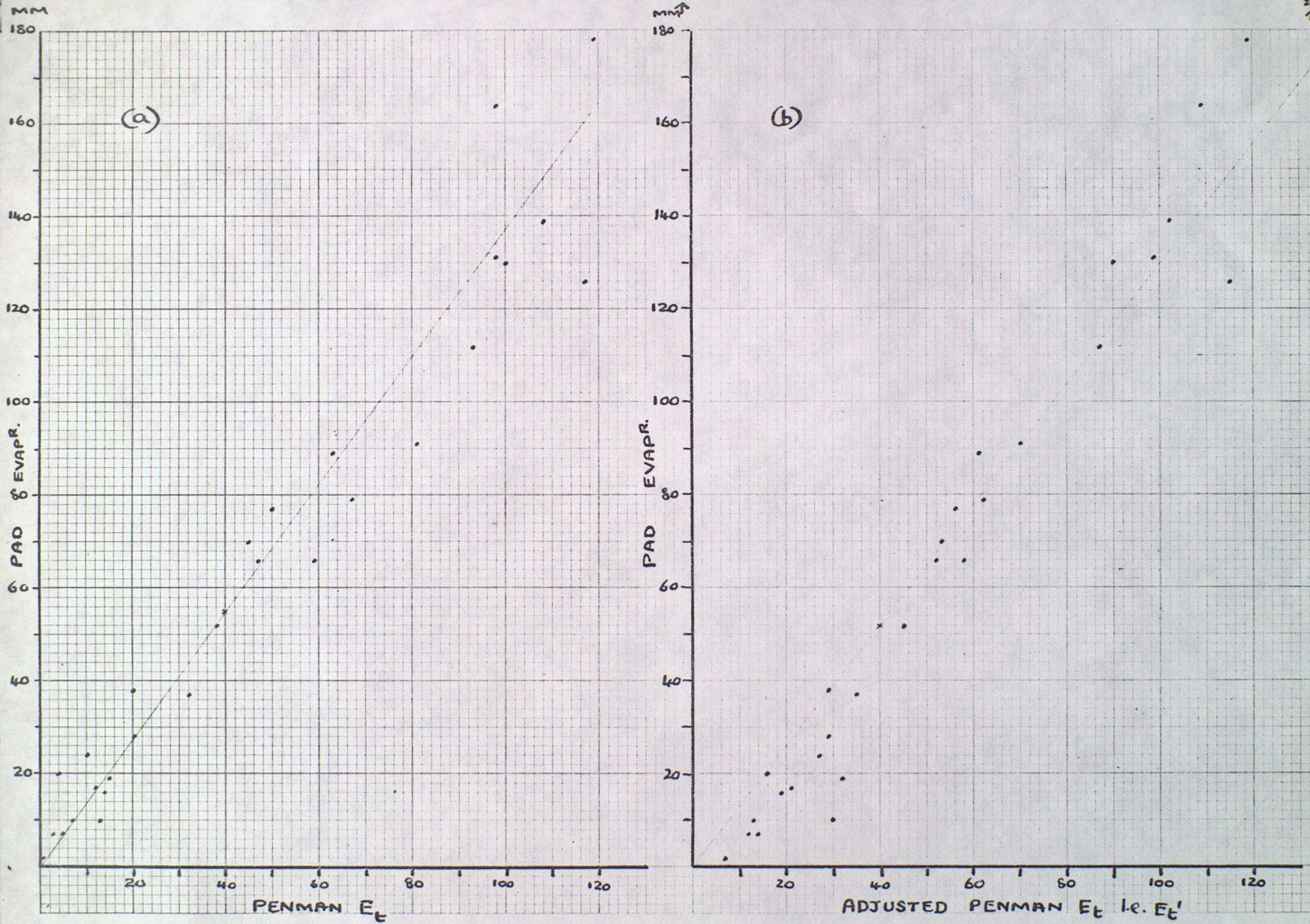
FIG. 1
Monthly Evaporation Totals
Pad Evaporimeter / Black Tank
July 1975 – Dec. 1977

FIG. 2. FREQUENCY DIAGRAM

Pad Evaporimeter/Black Tank Coeficients

July 1975 – December 1977.





MM
(a)
PAD EVAPR.
PENMAN E_t
20
40
60
80
100
120
140
160
180
(b)
PAD EVAPR.
ADJUSTED PENMAN E_t i.e. E_t'

Figure 3

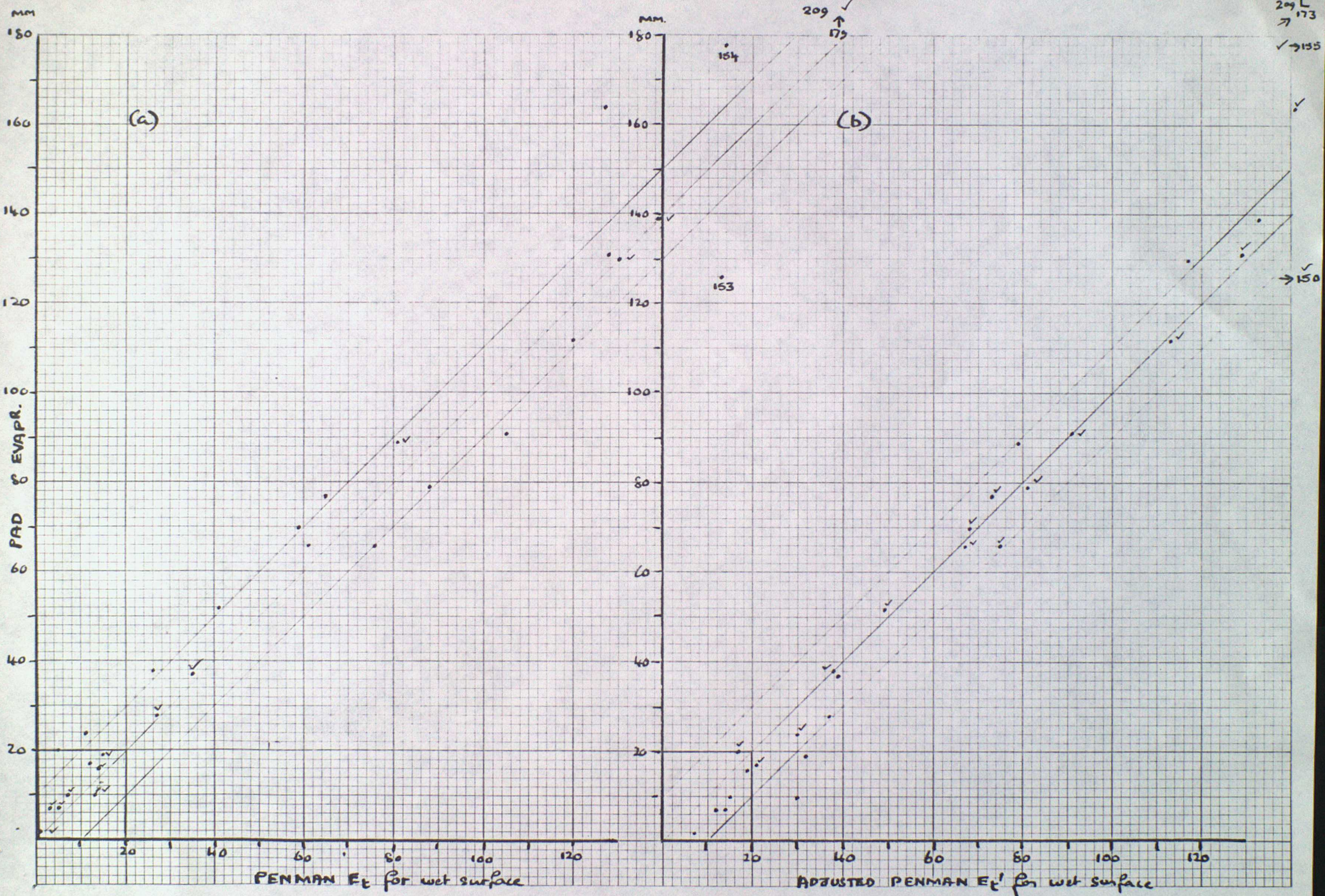

mm
PAD EVAPR.
(a)
PENMAN Et for wet surface
mm.
(b)
ADJUSTED PENMAN Et' for wet surface
209
179
154
153
209 L
173
155
150

Figure 4.

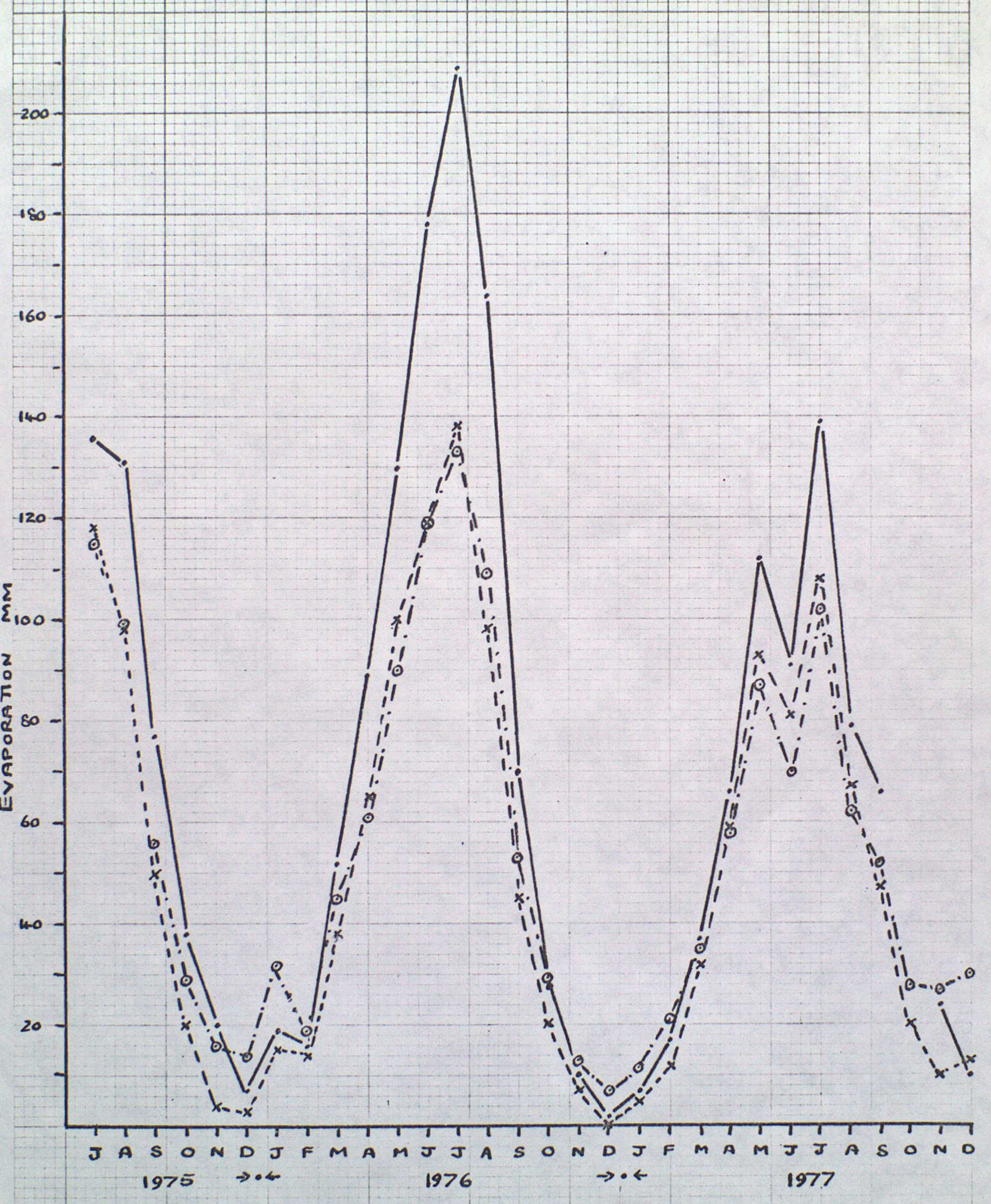


Figure 15

E_{PAD} •—• E_t x---x E_t' ⊙-·-⊙