

Problems in comparisons between measures of potential evaporation.

The purpose of this memorandum is to bring together a number of results obtained in earlier memoranda in this series and the results of some other work not previously written up. The work is intended to support advice given to the users of evaporimeters, also the quality-control of evaporimeter data.

The measures (of potential evaporation, p.e.) considered are (i) measurements with British Standard tanks, (ii) measurements with Russian GGI 3000 tanks, (iii) measurements with irrigated, non-weighing lysimeters (grass covered) and (iv) estimates made by Penman's formula for a well-watered lawn.

1. Penman formula estimates of potential evaporation.

1.1. Obtaining averages of the meteorological variables.

The effects upon calculated estimates of p.e. of various methods of obtaining average values of the required meteorological variables have been investigated in Memos. 4, 6a, 7, 9, 12, 16 and 17.

1.1.1. Average air temperature. Averages of readings taken at regular intervals four or more times in 24 hours and the means of daily maximum and minimum temperatures both gave acceptably close results. The mean of the max. and min. is, on average, slightly higher than the average of temperatures at 03, 09, 15 and 21 hours GMT.

1.1.2. Average vapour pressure. The use of the 09 GMT vapour pressure as an estimate of the 24-hour average usually slightly over-estimates the true average in the summer months. Averages of values at 03, 09, 15 and 21 hrs. GMT give better approximations to the averages of sets of 24 hourly values.

1.1.3. Wind speed. Run of wind measured at 2 metres was compared with an estimate thereof obtained from (anemometer) measurements at greater heights above ground, at Kew, Cardington and Rothamsted (Memorandum 17); a comparison for Eskdalemuir has also been made.

The "adjustments" were made by power law, using the accepted effective heights of the instruments. At Kew the adjustments were over-estimates of measured values by some 25 % (a later comparison, with 10 years of data, gave 31 % - Memo. 26); at Cardington there was an under-estimate by some 5% and at Rothamsted an under-estimate by some 7%. Monthly averages of hourly mean wind speed at 10 m. at Eskdalemuir in 1970 multiplied by .78 (to "adjust" to 2 m.) gave estimates which exceeded the monthly averages of wind speeds actually measured at 2 m. by from 36 to 94 %, average 61%, of the 2 m. average values.

MET  
DUP 2A



It will be realised that the true Penman estimate is one made using the run of wind (or average speed) measured at 2m. above ground and that an estimate made with other (adjusted) wind data is not necessarily the same and must be shown to be accurate before being accepted. Fig.1 illustrates this point.

1.1.4. Radiation See Memo.7 and Hydrological Memorandum No.39.

## 2. Evaporation tank measurements.

Tank measurements are compared in Memos. 1,5,9,13a,14,18 and 27.

### 2.1. The tanks and their colour.

The tank measurements were made with British Standard (square-section) and Russian GGI 3000 (round-section) tanks both 2 feet (61 cm) deep. The British tank has some 11 times the free water surface area of the GGI 3000. The tanks were painted black or white but only at Kew were the tanks painted white and cleaned to keep them so. At most, if not all, the other sites the responsible authorities either favoured black on physical grounds or did not consider cleaning necessary or even desirable.

### 2.2. British Standard and GGI 3000 tanks compared.

In Memo.14 (for the period Sept.1969 to Sept.1970) it was shown that at Kew the smaller (GGI 3000) tank lost more <sup>depth of</sup> water than the larger (British) tank. Fig.2. compares monthly totals of measurements at Kew (both painted white). The line of best fit through the origin gives the relationship

$$R = 1.23B \quad (R = \text{Russian, } B = \text{British})$$

At Cardington the Russian tank certainly lost more <sup>depth of</sup> water than the British tank in the cooler months; at Eskdalemuir the British tank lost slightly more than the Russian. All of these <sup>GGI-3000 and the British tank at Kew</sup> tanks were painted white. The British tanks at Cardington and Eskdalemuir were left unpainted (galvanised finish).

### 2.3. Further comparisons.

Figs 3 to 6 compare Penman p.e. and tank evaporation at Cardington and Eskdalemuir. For the moment we are interested only in relationships between tanks. Combining regression equations we get:

$$\text{Cardington} \quad R = .784 + .983 B$$

$$\text{Eskdalemuir} \quad R = .004 + .906 B$$

for 5-day totals and measurements in mm. (R Russian, B British).

These comparisons covered a partly different period from those reported in 2.2. but yielded the same relationships.

### 2.4. Apparent cases of out-splash.

The comparisons of 2.3. for Eskdalemuir are of particular interest in respect of probable out-splash.

It will be noticed that pentads 60, 62, 72, 119, 120, 123 and 135 (counting 1-5 Jan 1969 as pentad 1) have considerably greater evaporation from the British than from



the Russian tank. The highest daily mean wind speeds (at 10 m) in these pentads were (60) 18.0 kt, (62) 25.9 kt, (72) 16.6 kt, (119) 23.1 kt, (120) 15.5 kt, (123) 18.8 kt and (135) 21.9 kt. There were, in all, 51 pentads out of the 109 when there was at least one day with mean wind speed 15 kt or more; in 31 of these pentads the British tank had a greater loss than the Russian.

It seems likely that more water splashes out of the larger, square tank than out of the much smaller, round one. Wind waves in the smaller tank would be smaller and there would be less chance for a gust to whip spray from a wave-top than in the larger tank. In the large tank waves would slap against the flat walls and, with suitable wind directions, be driven into the corners, in both cases loss of water by splashing and spray are likely. This may explain, at least in part, the comparatively large losses from the British Tank in a windy location.

#### 2.5. Apparent effects of thermal properties of the soil.

In Memo. 27, results from two GGI 3000 tanks at Kew, only 4.3 metres apart, are compared. During the first 34 months of the comparison both were painted white. The more easterly tank lost 3 % more water than the western one. The maximum water temperatures in the western tank were generally higher in December and January, there was little difference in November and the eastern tank (the more "evaporative") had generally higher maximum temperatures in all other months. This, together with what is known about inhomogeneities of soil type and condition in the Observatory grounds, suggests that tanks can only be compared if they are imbedded in exactly similar material and if all other local effects are similarly equalised.

#### 2.6. Comparison of white and black painted tanks.

Of the pair of tanks (2.5.) one, the western, was painted black (after the 34-month comparison). After the western tank had been painted black, maximum water temperatures were generally higher than in the eastern (white) tank throughout the year. It became the more "evaporative" of the pair. Rough calculations show that its average evaporative rate appears to have been increased by about 7 % by changing the colour from white to black.

#### 2.7. Other problems in comparisons.

Tank management, observational technique (including working up data) and tank watertightness are all of the greatest importance and if neglected the data are useless. Where the data from pairs of tanks are compared, at the same place or at places some distance apart it is, of course, essential to standardise site characteristics, especially exposure to insolation and air-flow and the quality of the associated rain-gauging.



### 3. Irrigated, non-weighing lysimeters.

Lysimeter measurements are compared on an inter-station basis and with tank data and Penman estimates in Memos. 18 and 19.

#### 3.1. Percolation hang-ups.

Experience has shown that hang-ups often occur in some soils and that these have to be smoothed out by subjective or objective graphical analysis techniques or prevented by the use of specially prepared soil mixes.

#### 3.2. Other problems in comparisons.

Management, observational techniques (including working up data) and the water-tightness of the apparatus are of the greatest importance and if neglected the data are useless. Where data from pairs of lysimeters are compared at the same place or at places some distance apart it is, of course, essential to standardise site characteristics, especially exposure to insolation and air-flow, vegetation type and cover and the quality of the associated rain-gauging.

### 4. Comparisons between evaporimeter data and Penman estimates on a monthly basis.

#### 4.1. Tanks and Penman p.e.

##### 4.1.1. Wind input and Penman estimates.

Comparisons have already been shown (Figs 3 to 6) for Cardington and Eskdalemuir. The Penman estimates at both places were made for consecutive 5-day periods and were based (for wind input) on estimates of 2 metre winds derived from measurements made by anemometers at higher levels. It was shown in 1.1.3. that the Cardington wind estimates are probably of good quality, but that those for Eskdalemuir are not good. Thus whilst the Penman p.e. for Cardington is probably realistic the estimates for Eskdalemuir are over-estimates at all seasons.

The degree of over-estimation is probably of the order of 15% (based on independent calculations by Waggoner, Seaton and Wales-Smith). Thus, taking the regression equations of Fig. 5

$$PE = .473 + .950 B$$

we write  $1.15 PE = .473 + .950 B$

$$\text{or} \quad B = 1.21 PE - .498$$

instead of  $B = 1.05 PE - .498$  for values in mm

##### 4.1.2. Comparisons at Kew.

Comparisons of 10-year averages of monthly values are shown in Figs 7 and 8 and of the



individual monthly values in Fig.9. It can be seen that the Penman p.e. estimates based on real 2 m. wind data are much closer to the (white British Standard) tank data than those using "adjusted" speeds measured by the main anemometer.

#### 4.1.3. Comparisons at other stations.

From Table 2 of Memo. 18 one can obtain the following annual average values of  $\bar{T} - \bar{P}$  (here  $\bar{T}$  is average annual (white, British) tank evaporation and  $\bar{P}$  is average annual Penman p.e. for grass)

Station.	$\bar{T} - \bar{P}$ (mm)	$\bar{T} - \bar{P}$ as % of $\bar{P}$
wallingford	76.2	17
Edgbaston	28.2	6
Slaidburn	58.9	14
Rosewarne	108.5	21
Cawood	2.0	0
Average	54.8	12 (approx).

giving the rough relationship for tanks not kept white

$$\bar{T} = 1.12 \bar{P}$$

#### 4.2. Lysimeters and penman p.e.

From the same Table (in Memo.18) and from Fig.25 of Memo. 19 one can obtain a similar table to that of 4.1.3. , where  $\bar{L}$  is average annual lysimeter evaporation.

Station.	$\bar{L} - \bar{P}$	$\bar{L} - \bar{P}$ as % of $\bar{P}$
wallingford	147.8	32
Edgbaston	- 20.1	- 4
Slaidburn	23.9	6
Rosewarne	277.9	55
Cawood	- 8.6	- 2
Alice Holt	47.5	10
High Mowthorpe	44.7	11
Sutton Bonington	- 3.6	- 1
Yeovilton	355.6	59
Average	96.1	20 (approx)

giving the rough relationship  $\bar{L} = 1.2 \bar{P}$

#### 4.3. Tanks and lysimeters.

From the same source as above one can obtain the following table



Station	$\bar{L} - \bar{T}$	$\bar{L} - \bar{T}$ as % of $\bar{T}$
wallingford	81.8	15
Edgbaston	- 45.5	- 9
Slaidburn	- 34.8	- 7
Rosewarne	169.4	27
Cawood	- 22.6	- 5
Everton	37.9	7
wellesbourne	146.6	28
Hollinsclough	46.5	13
Average	47.4	9 (approx)

giving the rough relationship  $\bar{L} = 1.09 \bar{T}$

It is, perhaps, worth noting that although the lists of stations change, somewhat, from comparison to comparison, we can obtain the last result (approximately) by substituting for  $\bar{T} = 1.12 \bar{P}$  in  $\bar{L} = 1.2 \bar{P}$

this gives  $\bar{L} = 1.07 \bar{T}$

or we can use absolute units

$$\bar{P} = 54.8 - \bar{T}$$

$$\bar{P} = 96.1 - \bar{L} \quad \text{thus } \bar{L} - \bar{T} = 41.3$$

and we have  $\bar{L} - \bar{T} = 47.4$  from the last table.

The very low quality of these rough relationships is obvious from the manner in which they have been obtained and the many other pitfalls already examined; the tables and the rough results do, however, summarise the results of available comparisons and show what may occur in practice.

July 1973.

Exception may be taken to the treatment of regression equations as algebraic equations. Fig.10 compares the data from pairs (Brit.Std. and GGI 3000) of tanks at Cardington and Eskdalemuir. The data are those used in Figs. 3 to 6 and the dashed lines are those obtained in 2.3. It will be seen that they are quite acceptable as regression lines.

Nov 1973.



Fig. 1.

EFFECT OF ESTIMATING RATHER THAN  
MEASURING 2-METRE WINDS UPON

PENMAN P.E. AT KEW 1961-1970

X = 10-year monthly averages

• = comparisons of estimates for 1961-64.

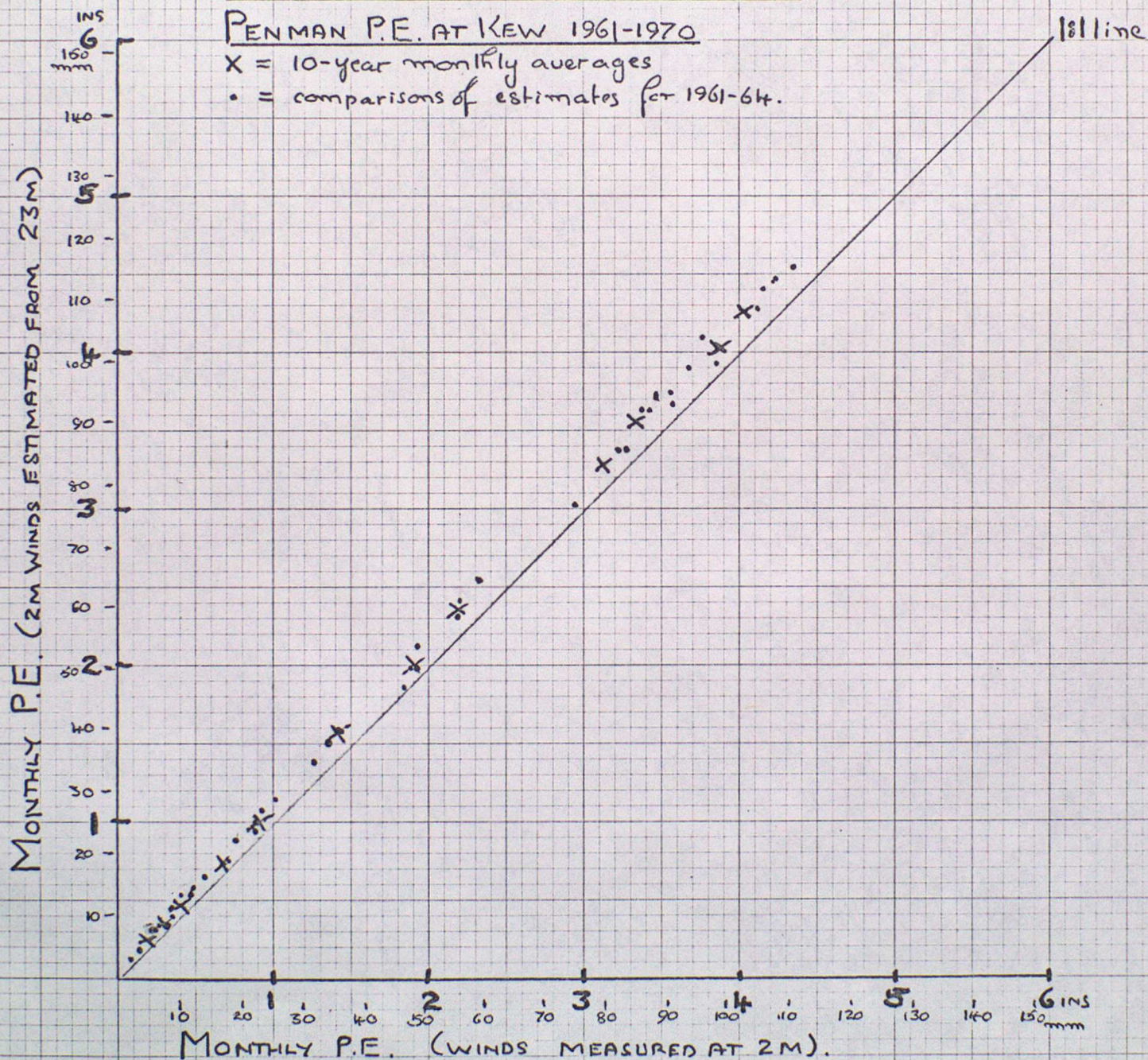
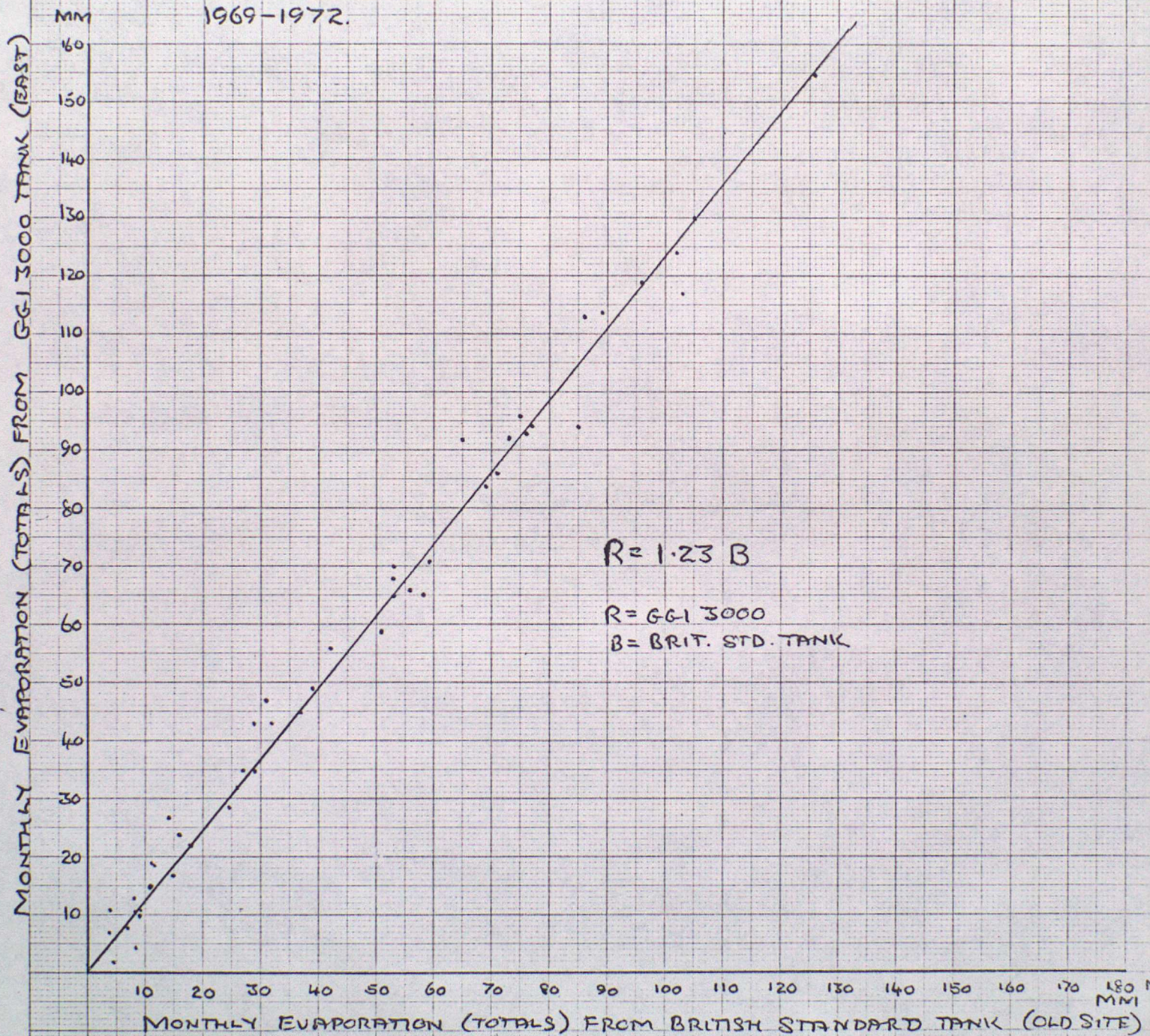


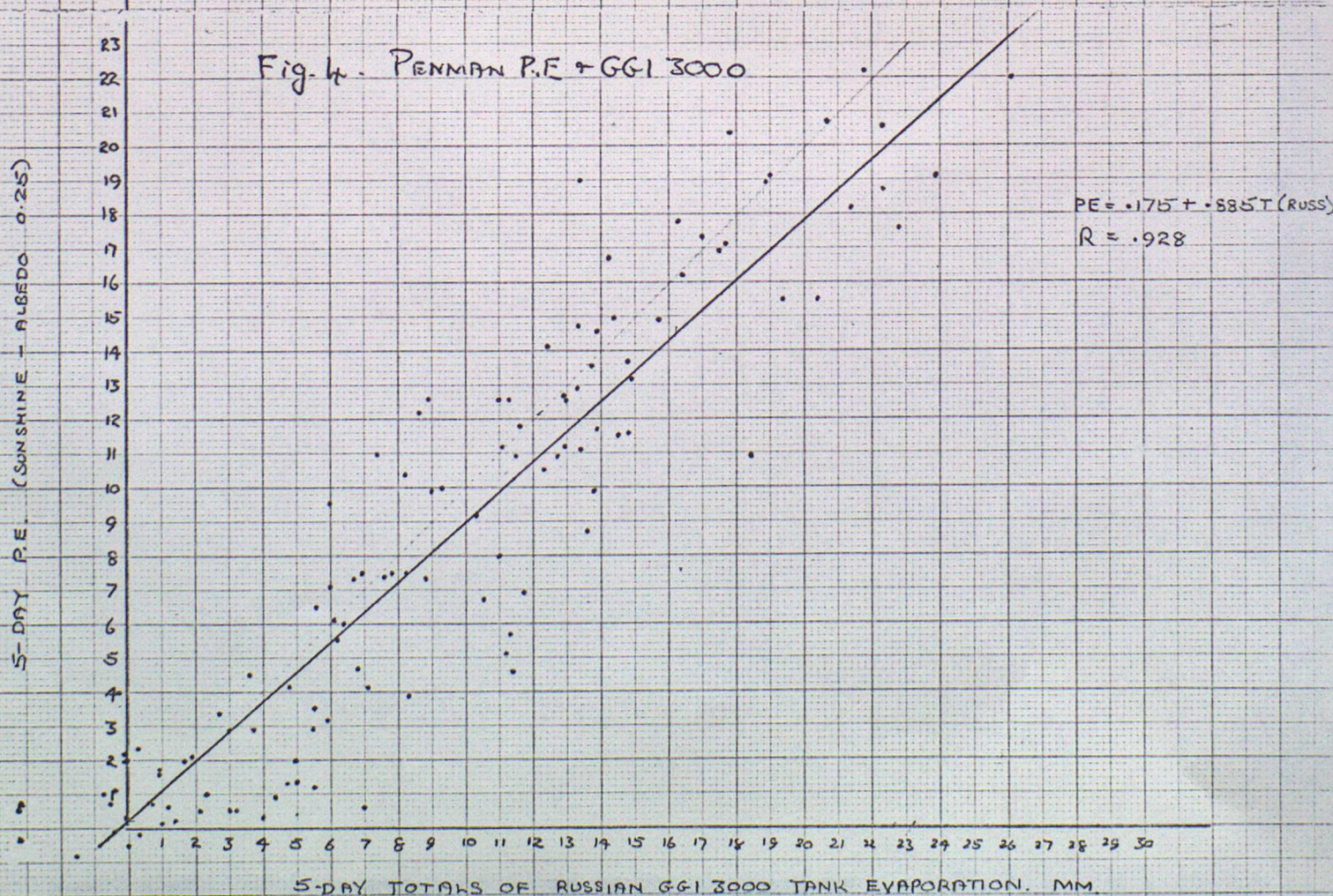
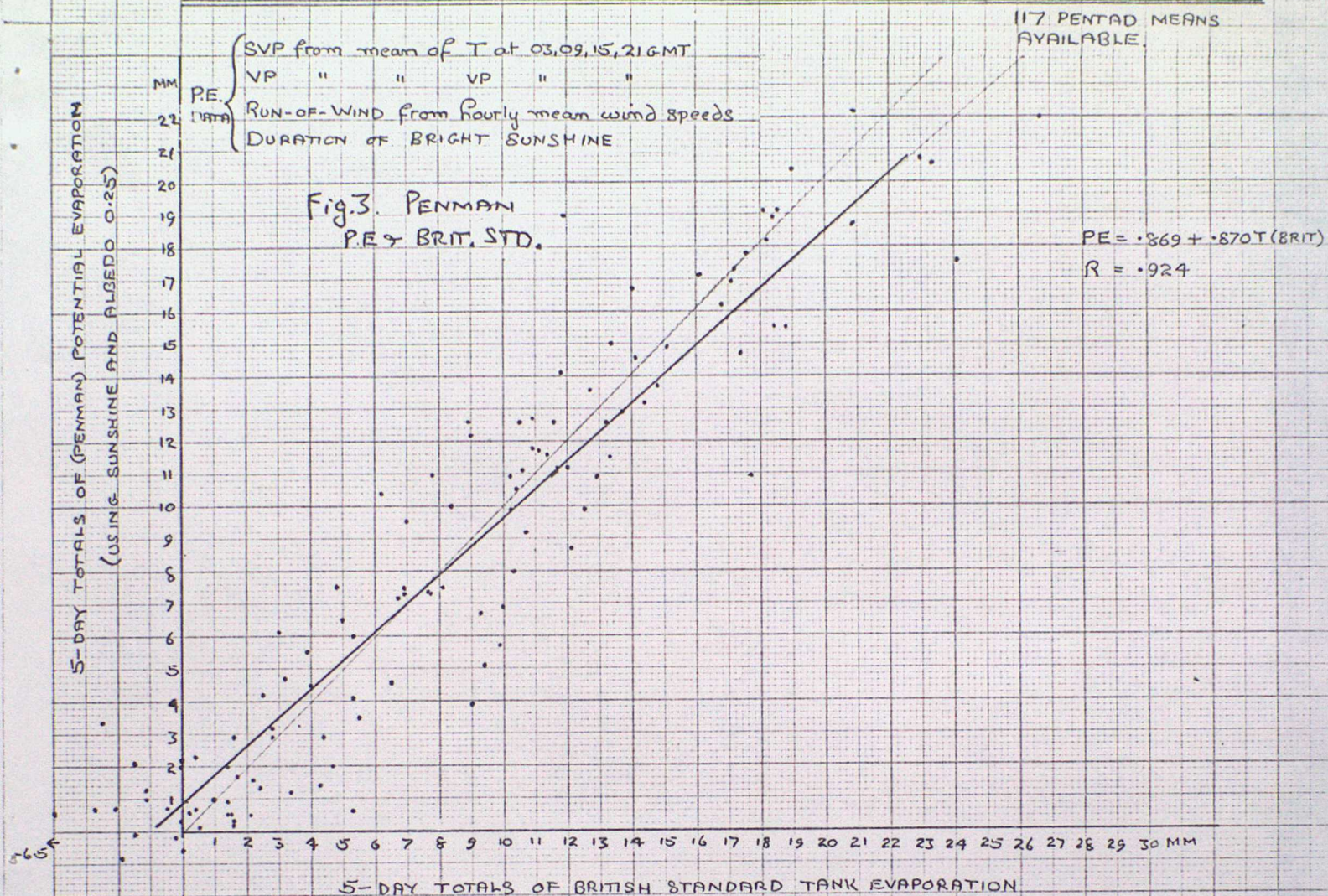


Fig. 2. TANK EVAPORATION AT KEW  
1969-1972.





# CARDINGTON - COMPARISON OF PENMAN P.E. AND TANK E. MAY 1969 - DEC. 1970



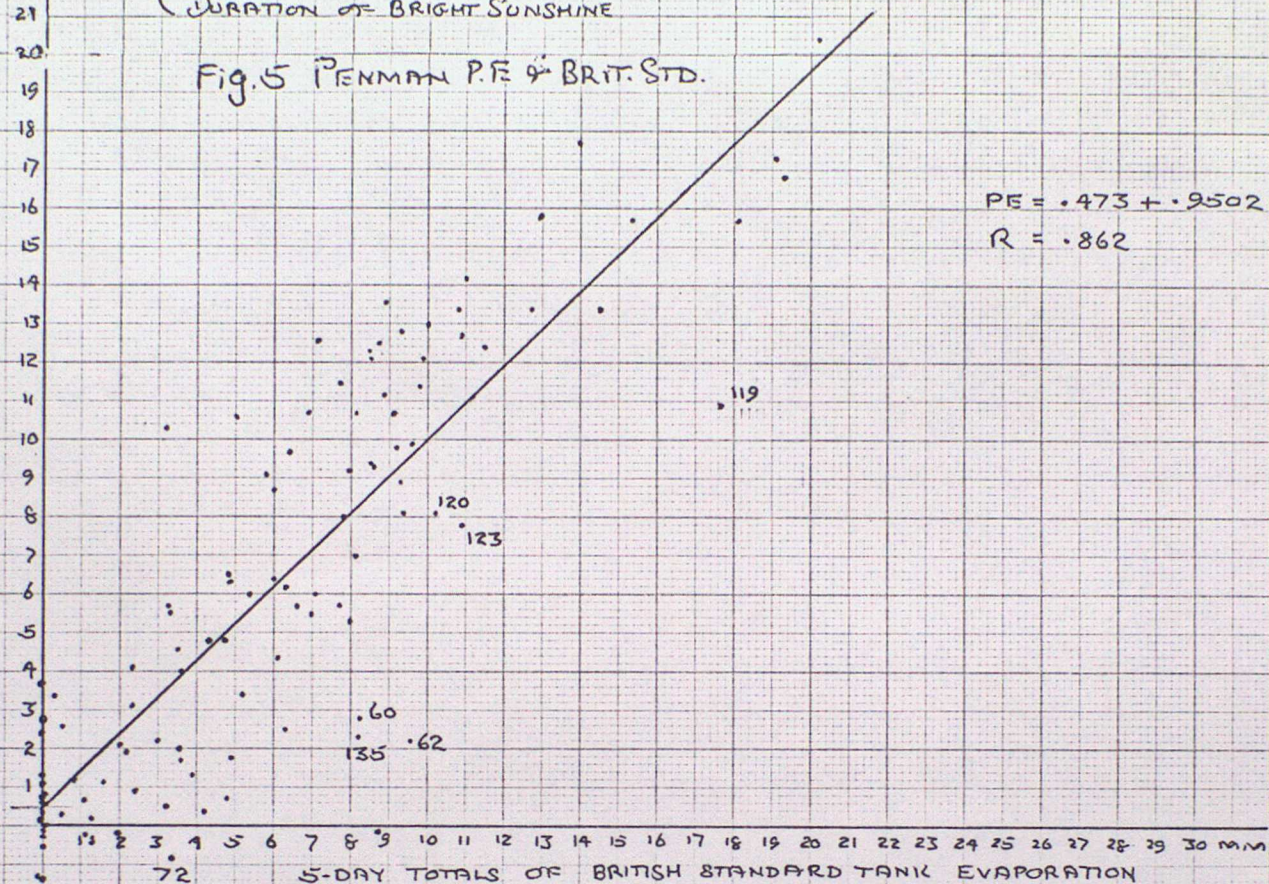


109 PENTAD MEANS  
AVAILABLE.

5-DAY TOTALS OF (PENMAN) POTENTIAL EVAPORATION  
(USING SUNSHINE AND ALBEDO 0.25)

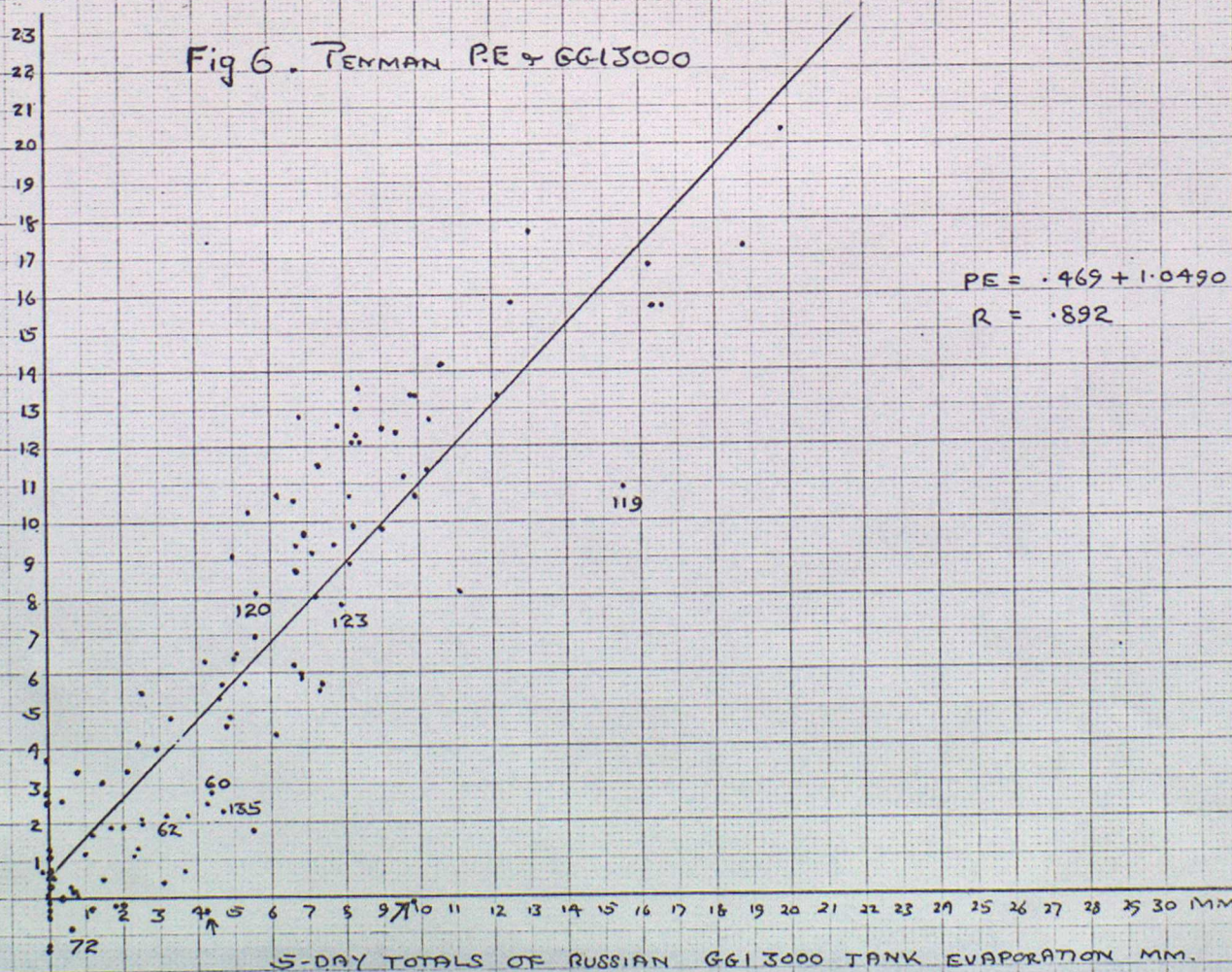
P.E. DATA { SVP from  $\bar{T}$  (mean of 24 hourly  $T_s$ )  
VP as mean of 24 hourly  $V_s$ .  
RUN-OF-WIND from hourly mean wind speeds  
DURATION OF BRIGHT SUNSHINE

Fig. 5 PENMAN P.E. & BRIT. STD.



5-DAY P.E. (SUNSHINE - ALBEDO 0.25)

Fig. 6. PENMAN P.E. & GG13000





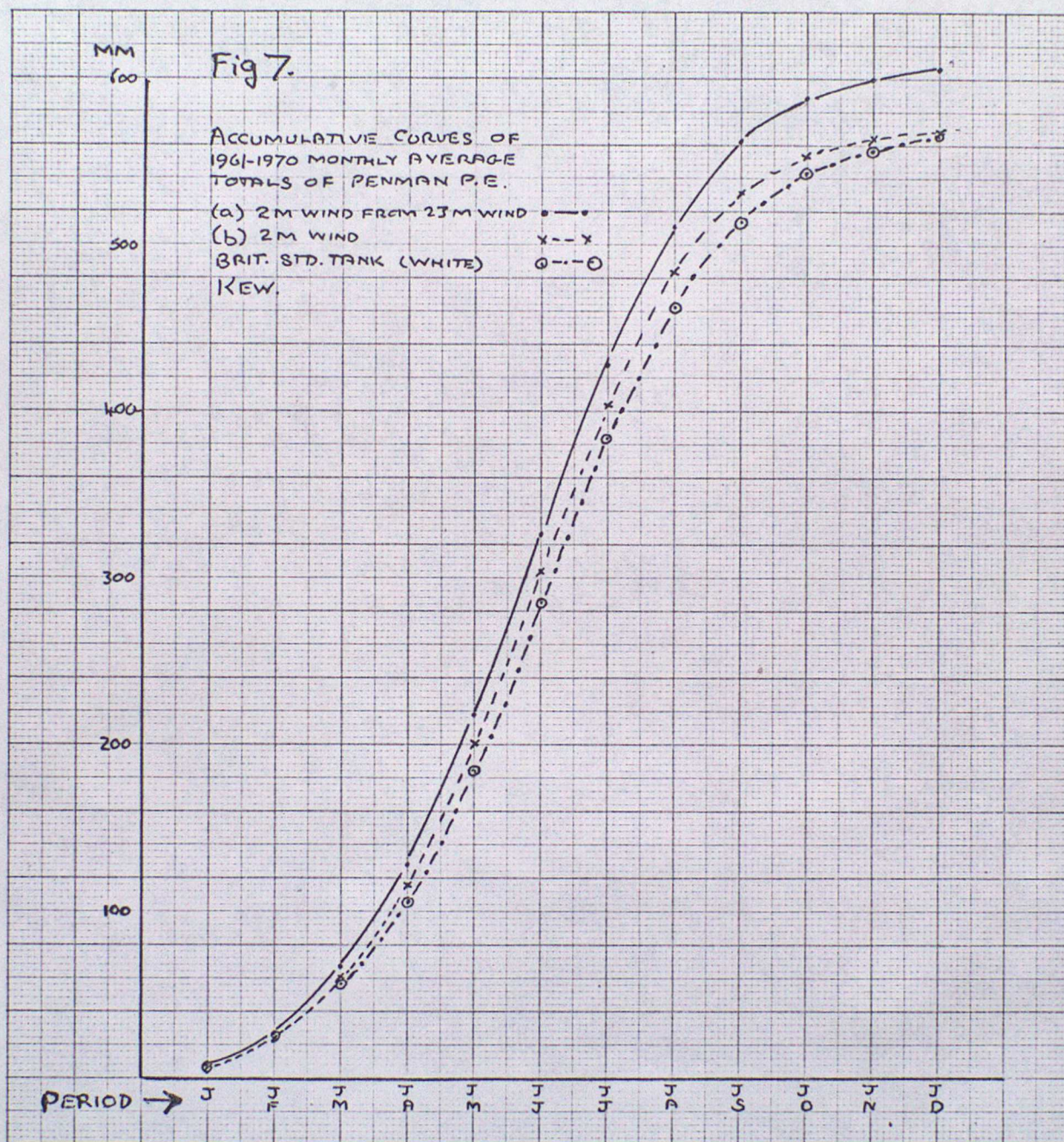




Fig. 8.

TEN YEAR (1961-70) AVERAGE MONTHLY EVAPORATION TOTALS - PENMAN P.E. (a) WITH WIND SPEED AT 2M ESTIMATED FROM 23M (PE2') AND (b) MEASURED AT 2M (PE2) ALSO BRITISH STANDARD TANK PAINTED WHITE (TBW) - KEW OBSERVATORY

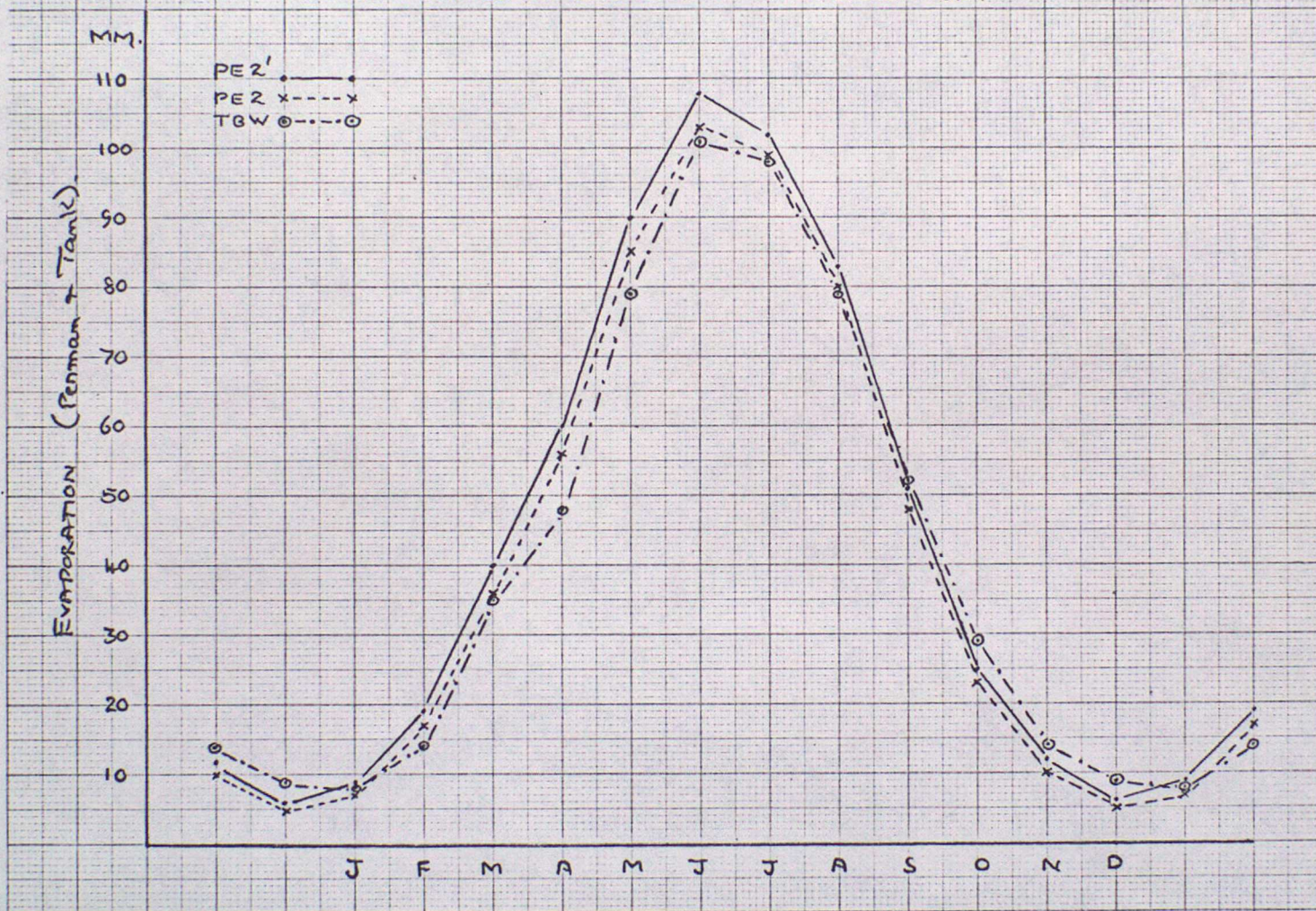




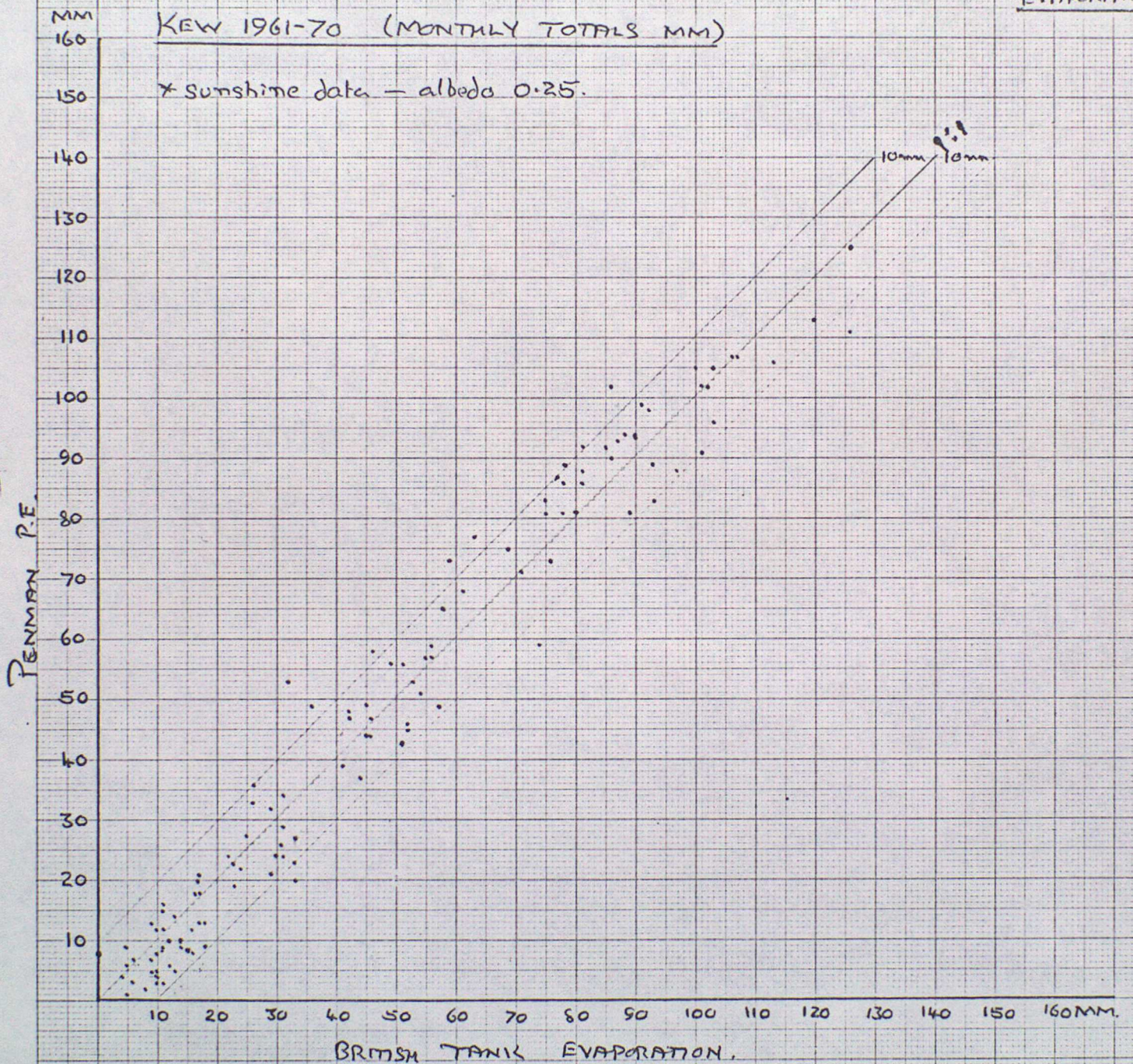
Fig-9.

PENMAN P.E.\* (2M WIND DATA) AND BRITISH TANK (WHITE)

EVAPORATION

KEW 1961-70 (MONTHLY TOTALS MM)

\* sunshine data - albedo 0.25.





# CARDINGTON TANK EVAPORATION

MAY 1969 - DEC 1970 (117 PENTADS)

GGI 3000 5-DAY EVAPORATION (MM)

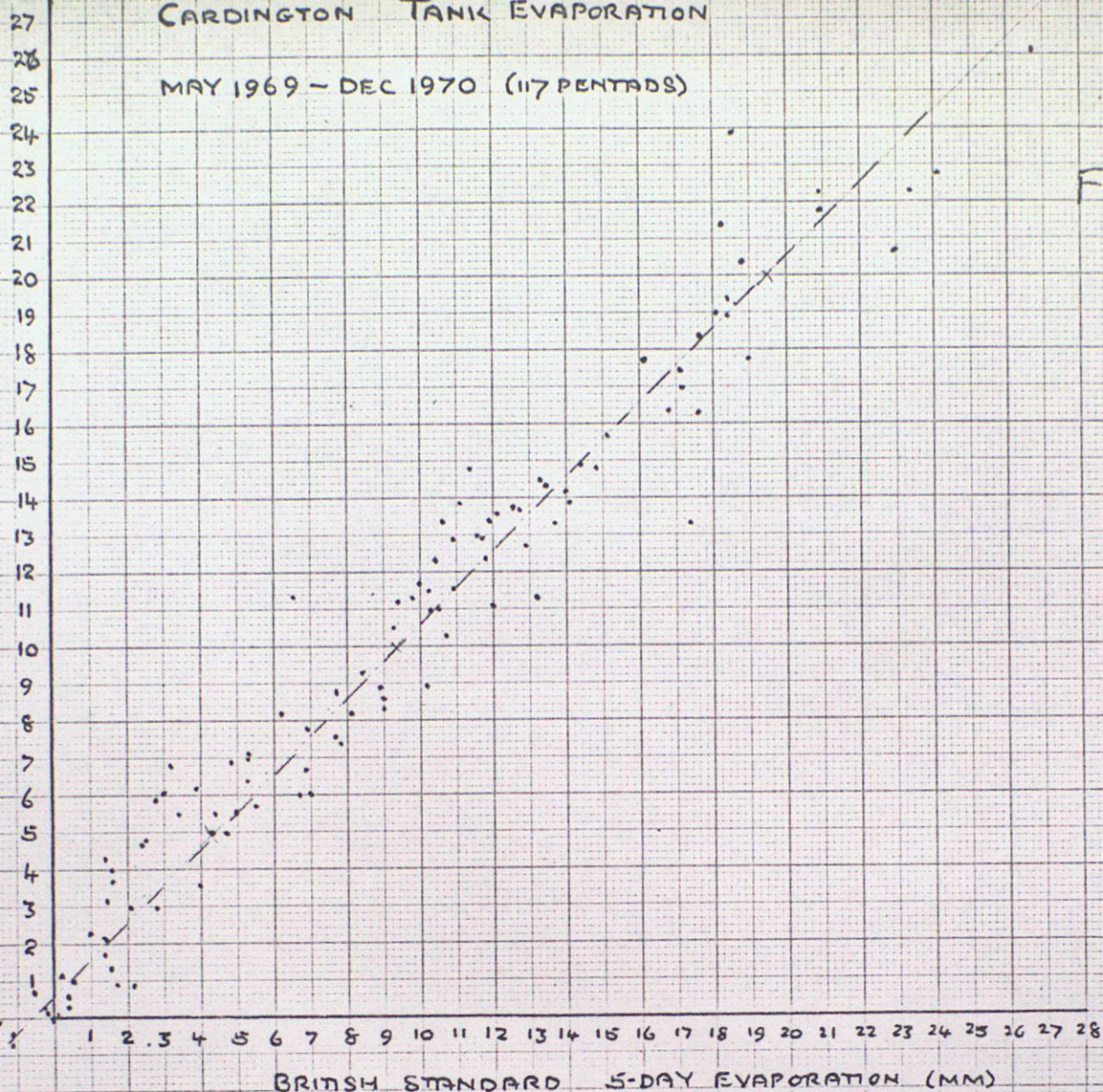


Fig-10.

# ESKDALEMUIR TANK EVAPORATION

JUN 1969 - DEC 1970 (109 PENTADS)

GGI 3000 5-DAY EVAPORATION (MM)

