

## EVAPORATION MEMO No 18

by B G Wales-Smith

### Comparisons of estimates and measurements of monthly totals of potential evaporation/transpiration

#### Estimates

The estimates used in this investigation were made with the Penman formula, using the version specified in Hydrological Memorandum No 39 (of the Meteorological Office). Duration of bright sunshine was used as the measure of incoming radiation, with albedo value 0.25, appropriate to much green vegetation. Estimates were made for nine stations. The wind data for Kew were obtained by "reducing" the wind speed at anemometer height to 2 metres and the temperature and humidity data were averages of several observations per day made in the North Wall screen. The wind data for the other eight stations were actually measured at a height of 2 metres: wind speeds for Alice Holt Lodge were extremely low, probably due to shelter, and were doubled in an attempt to make them area - representative. The temperature data for all stations except Kew were monthly averages of daily maxima and minima and the humidity data were averages from daily measurements at 0900 hrs GMT. For three stations, included in the investigation, complete climatological data for Penman calculations were not readily available.

#### Measurements

The measurements were made with British Standard evaporation tanks and with irrigated (non-weighing) lysimeters.

#### Period

The Penman estimates were for the period 1961-1970 except for Edgbaston for which the period was 1963-1970. The tank and lysimeter measurements were for the whole or parts of the decade 1961-1970.

#### Measures of evaporation and station details

Fig 1. shows the stations used, their heights above Sea Level and the measures of evaporation obtained: P = Penman, L = irrigated (non-weighing) lysimeter and T = British Standard Tank. The dashed line indicates the inter-station comparisons made in the investigation.

#### Analysis

The monthly measures of evaporation were plotted as scatter diagrams in two ways; pairs of measures of evaporation at the same station and the same measures of evaporation at pairs of stations. Monthly averages (for the months individually compared) are plotted as ringed crosses.

On each diagram the 1:1 line has been drawn, together with two lines of the same slope through  $x = \frac{1}{2}$  and  $y = \frac{1}{2}$ . This simple construction helps in forming a visual impression of the general relationships shown by the points. A rough\* process of correlation assessment was carried out with an overlay as shown in Fig 2 (a single stray, point falling beyond a pair of boundary lines was ignored). The various sets of pairs of points may be punched onto card or paper tape and analysed by a statistical programme at a later date, when time and labour permit.

The single-station comparisons of measures of evaporation and the inter-station comparisons were "ranked" very good, good, moderate, poor and bad and the rankings tabulated (Tables 1 and 2).

\*The method tends to over-emphasise a few points remote from an otherwise tight cluster.



### Inter-station comparisons

For periods as long as a month there should be no great difference between totals of potential evaporation at pairs of stations as close together as those used in this study\*. Large differences would be expected only if there were important topographical, geographical and land-use differences between the pairs of sites and between their surroundings.

The factors controlling potential evaporation are:

- (i) incoming radiation received at the earth's surface, dependent on ground slope and aspect and reduced by cloud which, in turn, is partly the result of topographical and geographical influences;
- (ii) outgoing radiation, reduced when cloud is present (the cloud owing its existence, in part, to topographical and geographical influences) and dependent on the local albedo (reflective power) of the earth's surface and upon the extent to which that surface radiates as a "black body";
- (iii) air temperature, a complex function of radiation balance (involving absorption and radiation of heat by the earth's surface), of evaporation itself and of air-mass history;
- (iv) air humidity, an air-mass characteristic partly controlled by the moistness of the surface over which the air flows and by topographical and geographical influences;
- and (v) the wind speed, much influenced by friction and by natural and man-made obstacles to wind flow.

### Use of the Penman estimates

The Penman formula (for potential evaporation) has terms including radiation balance, temperature, albedo (included explicitly or implicitly, depending on type of radiation input) humidity and wind speed. The formula attempts to include (through sunshine duration and humidity) a measure of nocturnal cloudiness when net radiation measurements are not available.

Table I shows four inter-stations comparisons of Penman P.E classified as one "very good" and three "good", Figs 3, 4, 5 and 6. The physically realistic character of the formula, the above comparisons and the wealth of reported studies demonstrating the validity of Penman estimates, are held to justify the use of monthly P.E estimates as a standard of comparison for studying evaporimeters.

### The tank measurements

Wales-Smith (Hydrological Memorandum No 39) compared Penman estimates and tank measurements over periods of 1, 5 and 10 days at one station and over 5 days at two additional stations. Using duration of bright sunshine as the measure of radiation, correlation coefficients were .86 at a windy site on high ground and .96 at a relatively sheltered, low ground site for 5-day estimates the correlation coefficient was improved to .97, at the low ground site when the period was increased to 10 days.

\*reference to Table I and Figures shows this to have been the case for most comparisons.



Fig 7 shows that monthly Penman P.E estimates and British Standard tank measurements at Kew (the station at which the 5-day .96 and 10-day .97 coefficients were obtained) are very well correlated. This result is supported at Wallingford Fig 8, Slaidburn Fig 9, Rosewarne Fig 10 and at Cawood Fig 11. The Penman estimates and tank measurements at Edgbaston Fig 12 are rather poorly correlated but the good inter-station, Penman correlation with Sutton Benington Fig 5 suggests that the (Edgbaston) tank record may contain some errors.

The comparisons are set out in Table II.

The generally good correlation between Penman estimates and tank measurements is held to justify comparison between tank and lysimeter measurements even though some tank evaporation occurs by night.

It will be noticed (Table I and Figs 22, 23, 40 and 41) that three out of four inter-station tank correlations were good.

Lysimeter measurements were not used as a check on corresponding Penman estimates and tank measurements because of the known difficulties of operating these instruments.

#### Comparisons of monthly Penman Estimates and monthly tank measurement totals with monthly lysimeter measurement totals.

These comparisons are summarised in the second and third columns of Table II.

#### Inter-station lysimeter comparisons

These are summarised in the second column of Table I 4 good, 3 moderate, 1 poor and 1 bad.

#### "Rating" of tanks and lysimeters

This has been attempted, roughly, in Table III. The "correlation letters" are listed, awarded a point score, totalled and averaged. The Edgbaston tank record has been excluded in calculating scores, on the basis of its poor correlation with the Penman estimates and only moderate correlation with the Wellesbourne tank.

#### Examination of cases of "Poor" and "Bad" correlation between measures of evaporation at the same station.

##### 1. Wallingford. Penman vs. lysimeter (Fig 13)

Nine points lying well away from the main cluster were identified by month and examined. In every case the values given by the lysimeter were high, whereas the Penman estimates appeared reasonable. (Lysimeter suspect).

##### 2. Edgbaston. Penman vs. tank (Fig 12)

Eight points were examined. In two cases the tank values were clearly too low and in five cases too high. In the eighth case the low tank value was a total of only 22 days of evaporation in July and would have been reasonable if multiplied by  $3\frac{1}{2}$ . (Tank suspect)

##### 3. Edgbaston. Tank vs. lysimeter (Fig 21)

Twelve points were examined. Four out of seven of the month-points which appeared to have been displaced from the main cluster by high tank totals were the same as those regarded as too high when compared with Penman estimates. The remaining three tank values appear rather too high for the months concerned. Of the three months in which the tank values appear to have been too low, the June tank value was the one which appeared suspect in comparison with the Penman estimate. (Tank suspect)



4. Rosewarne. Penman vs. lysimeter Fig 17

Thirteen points were examined. In ten of these, there was little or no doubt that the lysimeter values were too high. (lysimeter suspect).

5. Rosewarne. Tank vs. lysimeter Fig 18

Sixteen points were examined. Ten of these were for the months when the lysimeter was regarded as reading too high in the comparison with Penman estimates; three more were the other three points regarded as due to wrong lysimeter values in the same comparison. (lysimeter suspect).

6. Everton. Tank vs. lysimeter (Fig 25)

Six points were examined. Two points appeared displaced as the result of very high tank values, one by a very high lysimeter value, one by a combination of a high lysimeter value and a low tank value and two by low tank values. (Tank and lysimeter sometimes suspect).

7. Alice Holt Penman vs. lysimeter (Fig 28)

Seven points were examined. One May and two March anomalies were probably due to low lysimeter totals. The July, August and September anomalies were probably due to high lysimeter values. (Lysimeter sometimes suspect).

Evaporation and Altitude

Table I gives values of the difference between annual totals of average monthly measures of Penman or evaporimeter P.E at "adjacent" stations. Except for 4 of the lysimeter differences, all values are small (.14 to 2.14 inches). Four out of five of the Penman P.E differences, seven out of nine of the lysimeter differences and three out of four of the tank differences show decreasing P.E. with increasing altitude.

Conclusions

1. Five out of six comparisons between monthly Penman P.E estimates and tank evaporation totals showed good correlations. In the fifth case there are good reasons for suspecting the tank record.
2. Five out of eight comparisons between monthly Penman P.E estimates and lysimeter evaporation totals showed moderate correlation, two gave poor results and one comparison was definitely unsatisfactory.
3. Of eight comparisons between monthly totals of tank and lysimeter evaporation one was close, four were moderately close, one was poor and one was very unsatisfactory.
4. A rating system applied to eleven lysimeters placed one in the top tank, six in the second tank, one in the third tank and three in the fourth tank. The same system rated seven tanks highly and one moderately.
5. Cases of "poor" and "bad" correlation between measures of P.E at the same station were examined; the result was that four of the lysimeters and two of the tanks were shown to be almost certainly unreliable at times.
6. The investigation supports the view that buried evaporation tanks of the order of size of the British Standard tank give useful results if well sited and competently managed.



It appears that non-weighing, irrigated lysimeters give results of varying quality probably depending greatly upon condition of apparatus and expertness of management.

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COMPARISON OF THE SAME MEASURE OF  
EVAPORATION AT PAIRS OF STATIONS

TABLE I.

	PENMAN P.E.	LYSIMETER	TANK
EVERTON		Fig 31 P E > AH (23.10) (Mar 3.51 (19.59) (Oct	
ALICE HOLT			
ALICE HOLT	Fig 6 V.G. AH > WA 18.83 1.20	Fig 32 B WA > AH 20.71 3.05 23.76	
WALLINGFORD			
WALLINGFORD		Fig 33 M WE > WA 21.13 5.32 26.45	Fig 23 G WA > WE 20.27 1.36 18.91
WELLESBOURNE			
WELLESBOURNE		Fig 34 G WE > E 25.30 7.70 17.60	Fig 22 M WE > E 19.06 .53 18.53
EDGBASTON			
EDGBASTON	Fig 5 G SB > E 18.78 .74 19.52	Fig 35 M SB > E 18.77 .53 19.30	
SUTTON BONINGTON			
SUTTON BONINGTON		Fig 36 G SB > H 17.98 1.86 16.12	
HOLLINSCLOUGH			
HOLLINSCLOUGH		Fig 37 G S > H 16.12 1.41 17.53	Fig 40 G S > H 16.58 2.14 18.72
SLAIDBURN			
SLAIDBURN	Fig 4 G C > S 16.41 1.84 18.25	Fig 38 G C > S 17.46 .54 18.00	Fig 41 G C > S 18.65 .14 18.79
CAWOOD			
CAWOOD	Fig 3 G C > HM 18.25 .48 17.77	Fig 39 M HM > C (16.15) 1.86 (18.01) MAR	
HIGH MOWTHORPE			

Correlation  
VG = very good  
G = good  
M = moderate  
P = poor  
B = bad

Annual totals of  
monthly evaporation  
and differences are  
given. Part-year  
totals are indicated.

A = higher station  
has lower evaporation  
A = lower station has  
lower evaporation



COMPARISON OF PAIRS OF MEASURES OF  
EVAPORATION AT THE SAME STATION.

TABLE II

	PENMAN vs TANK	PENMAN vs LYSIMETER	TANK vs LYSIMETER
WALLINGFORD	Fig 8 G T>P P 17.54 3.00 T 20.54	Fig 13 P L > P P 17.77 5.82 L 23.59	Fig 14 M L>T T 20.94 3.22 L 24.16
EDGBASTON	Fig 12 P T>P P 19.59 1.11 T 20.70	Fig 24 M E > L P 19.56 .79 L 18.77	Fig 21 P T>L T 20.56 1.79 L 18.77
SLAIDBURN	Fig 9 G T>P P 16.44 2.32 T 18.76	Fig 15 M L > P P 16.46 .94 L 17.40	Fig 16 M T>L T 18.77 1.37 L 17.40
ROSEWARNE	Fig 10 G T>P P 20.17 4.27 T 24.44	Fig 17 B L > P P 20.02 10.94 L 30.96	Fig 18 B L>T T 24.33 6.67 L 31.00
CAWOOD	Fig 11 G T>P P 18.71 .08 T 18.79	Fig 19 M P > L P 18.30 .34 L 17.96	Fig 20 M T>L T 18.71 .89 L 17.82
EVERTON			Fig 25 B L>T T(21.81)(Mar 1.49 L(23.30)(Oct
WELLESBOURNE			Fig 26 M L>T T 20.43 5.77 L 26.20
HOLLINSCLOUGH			Fig 27 G L>T T 14.04 1.83 L 15.87 Jan Dec
ALICE HOLT		Fig 28 P L > P P 18.80 1.87 L 20.67	
HIGH MOWTHORPE		Fig 29 M L > P P 16.25 1.76 L 18.01 MAR	
SUTTON BONINGTON		Fig 30 M P > L P 19.55 .14 L 19.41	
KEW	Fig 7 G P>T P 23.85 1.55 T 22.30		

Notes to Table I refer. (except "A-index").



TABLE III

Tank and lysimeter ratings on the basis of station and inter-station comparisons

Station	Tank	Lysimeter	Class	Points
WALLINGFORD	$G_P G_T$ 4	$P_P M_T B_L$ $2\frac{1}{4}$	G	4
EDGBASTON	$P_P M_T$ $2\frac{1}{2}$	$M_P P_T^* M_L$ $3.1/3$	M	3
SLAIDBURN	$G_P G_T$ 4	$M_P M_T G_L$ $3\frac{1}{2}$	P	2
ROSEWARNE	$G_P -$ 4	$B_P B_T -$ 1	B	1
CAWOOD	$G_P G_T$ 4	$M_P M_T M_L$ $3\frac{1}{4}$	<u>Suffixes</u>  P = w.r.t. Perman T = w.r.t. Tank L = w.r.t. Lysimeter	
EVERTON		$- B_T P_L$ $1\frac{1}{2}$ (Plus)		
WELLESBOURNE	$- * M_T$ (4)	$- M_T G_L^+$ $3.1/3$	P comparisons are at same station	
HOLLINSCLOUGH	$- G_T$ 4	$- G_T G_L$ 4	T comparison is at same station for Kew, only.	
ALICE HOLT		$P_P - P_B$ $1.2/3$	L comparisons and all except Kew	
HIGH MOWTHORPE		$M_P - M_L$ 3	"T-comparisons" are inter-station.	
SUTTON BONINGTON		$M_P - M_G$ $3.1/3$	(The Kew comparison was with another, identical, tank at Kew).	
KEW	$G_P (G_T)$ 4			

\* Edgbaston tank comparisons ignored in rating.

+ Wallingford lysimeter suspect



Fig. 1. Stations, heights (a.s.l.) in metres, measures of evaporation (P= Tenman P.E., L= Lysimeter, T= B.S. Evaporation Tanks) and inter-station evaporation comparisons (---).

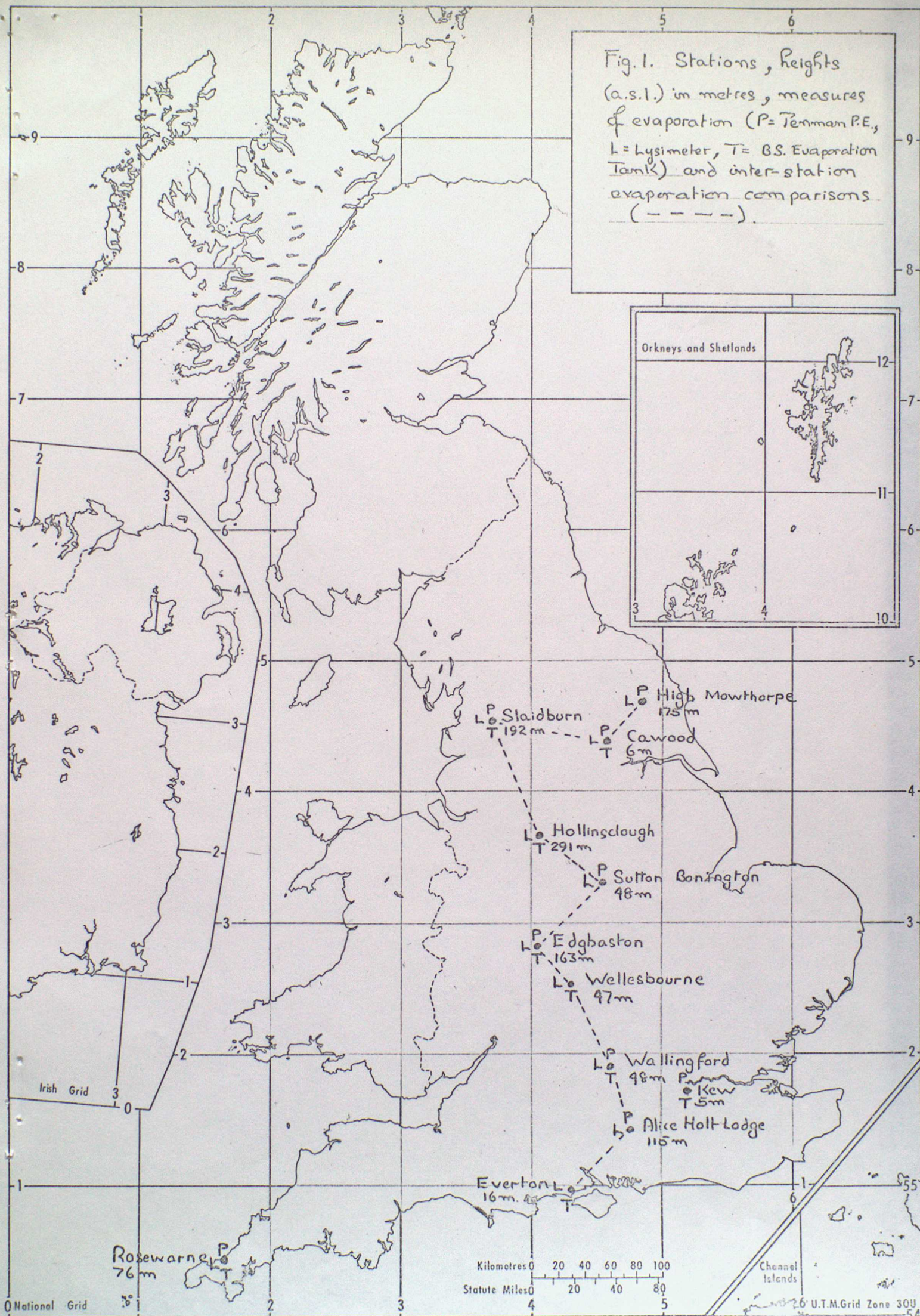
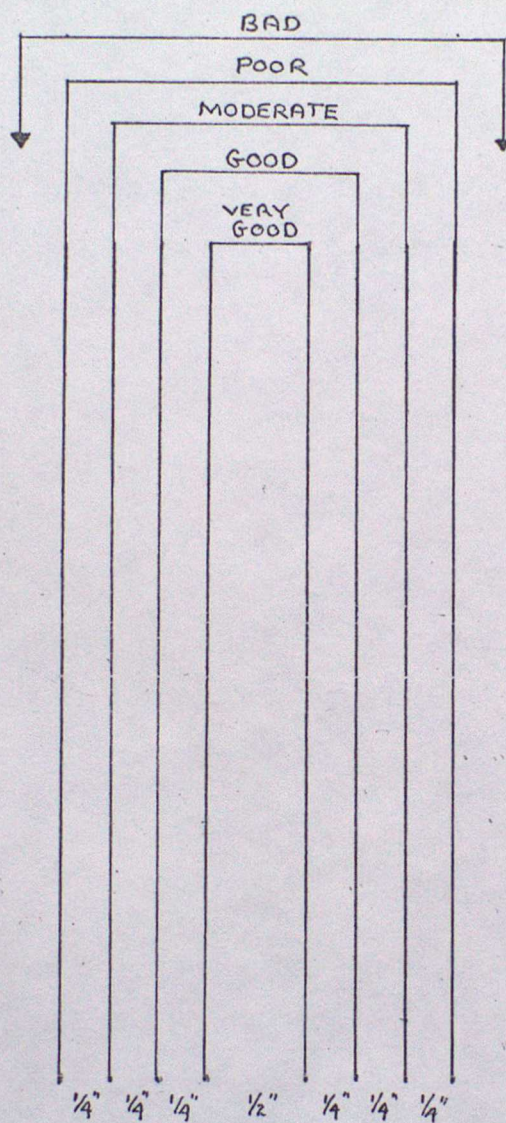
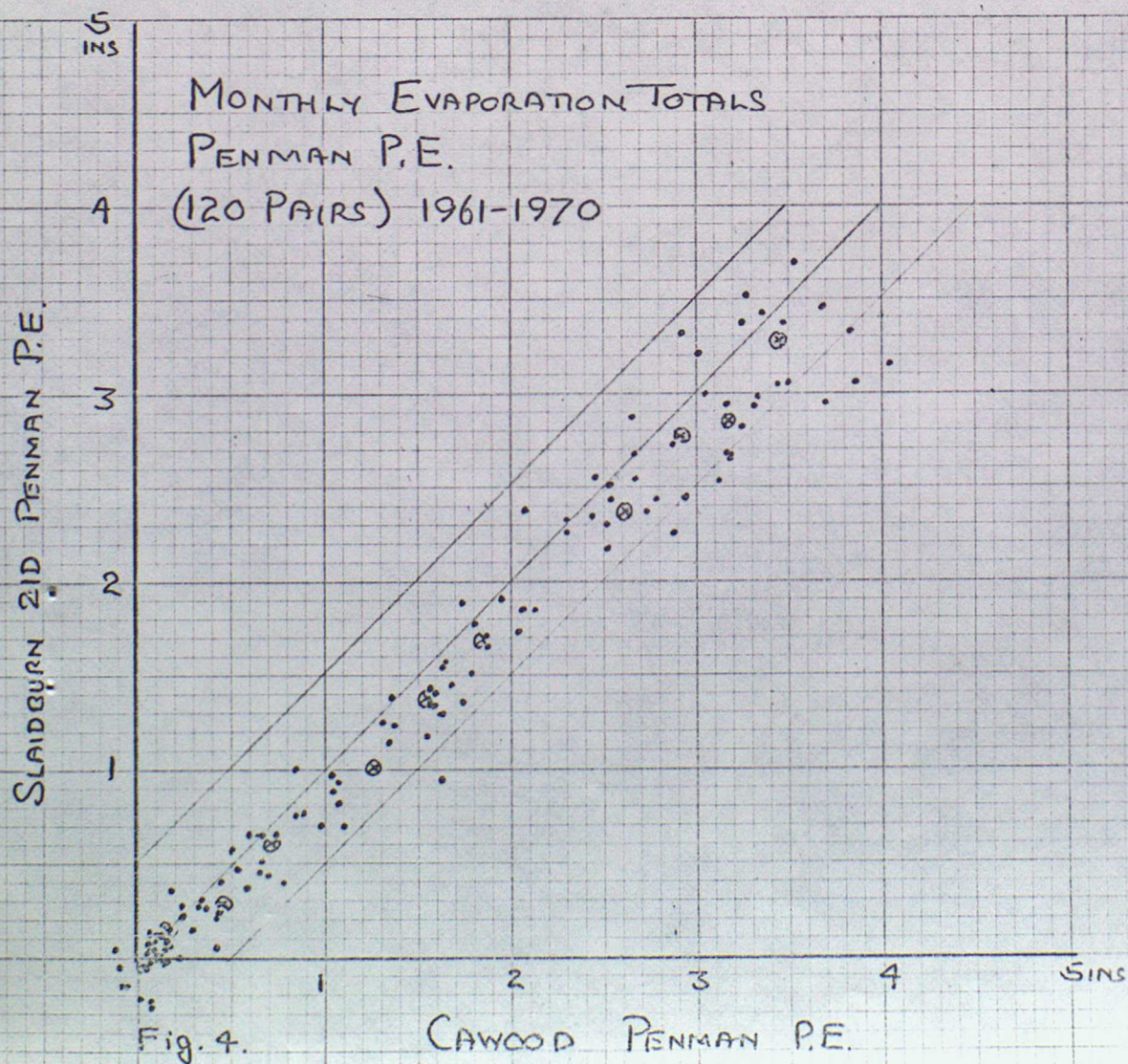
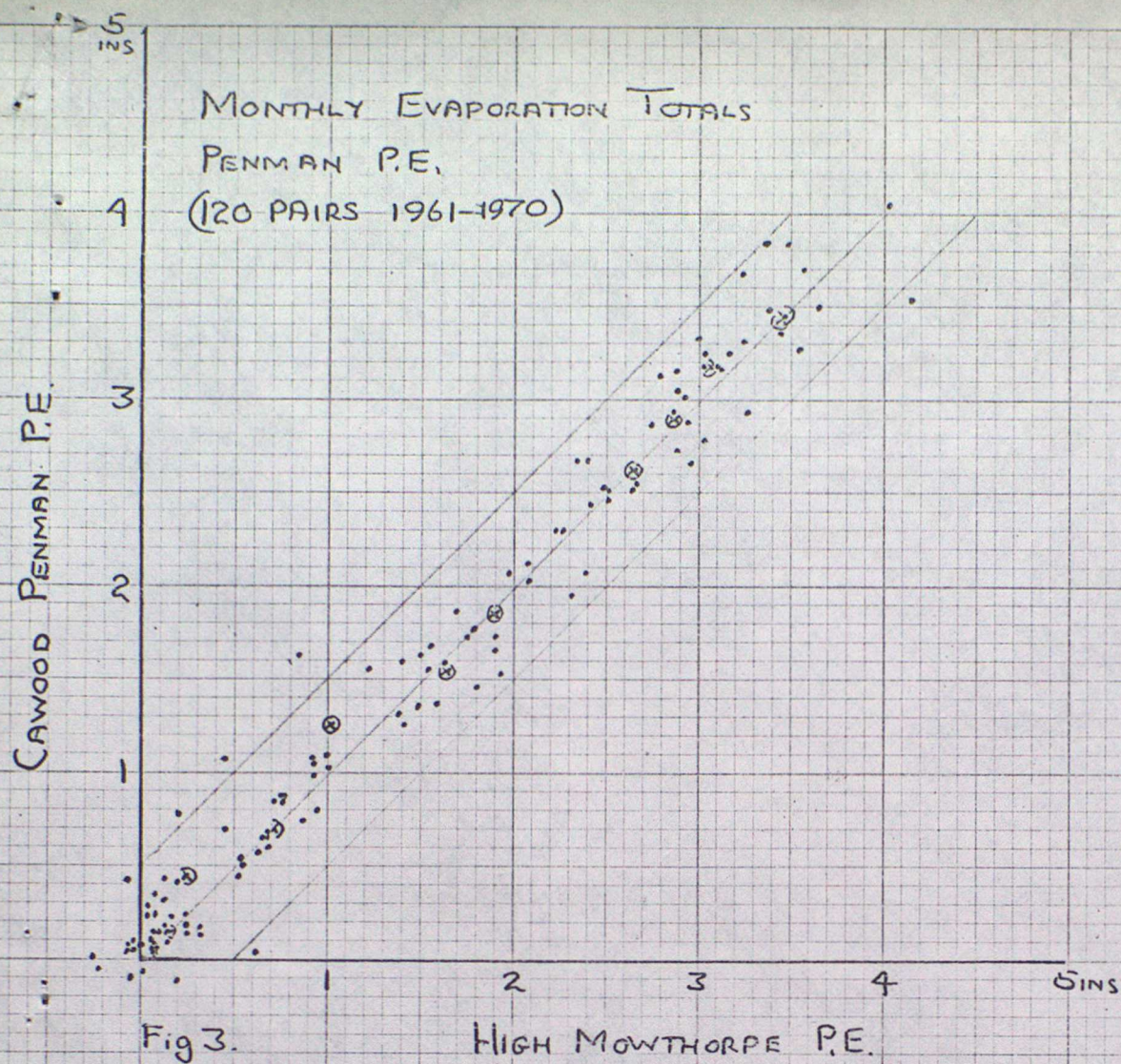




Fig. 2. Overlay used with Figs 3-41 to provide a rough measure of correlation









EDGBASTON PENMAN P.E.

INS

MONTHLY EVAPORATION TOTALS  
PENMAN P.E.  
(96 PAIRS) 1963-1970

4

3

2

1

1 2 3 4 5 INS

Fig. 5.

SUTTON BONINGTON PENMAN P.E.

ALICE HOLT LODGE PENMAN P.E.

INS

MONTHLY EVAPORATION TOTALS  
PENMAN P.E.  
(120 PAIRS) 1961-1970.

4

3

2

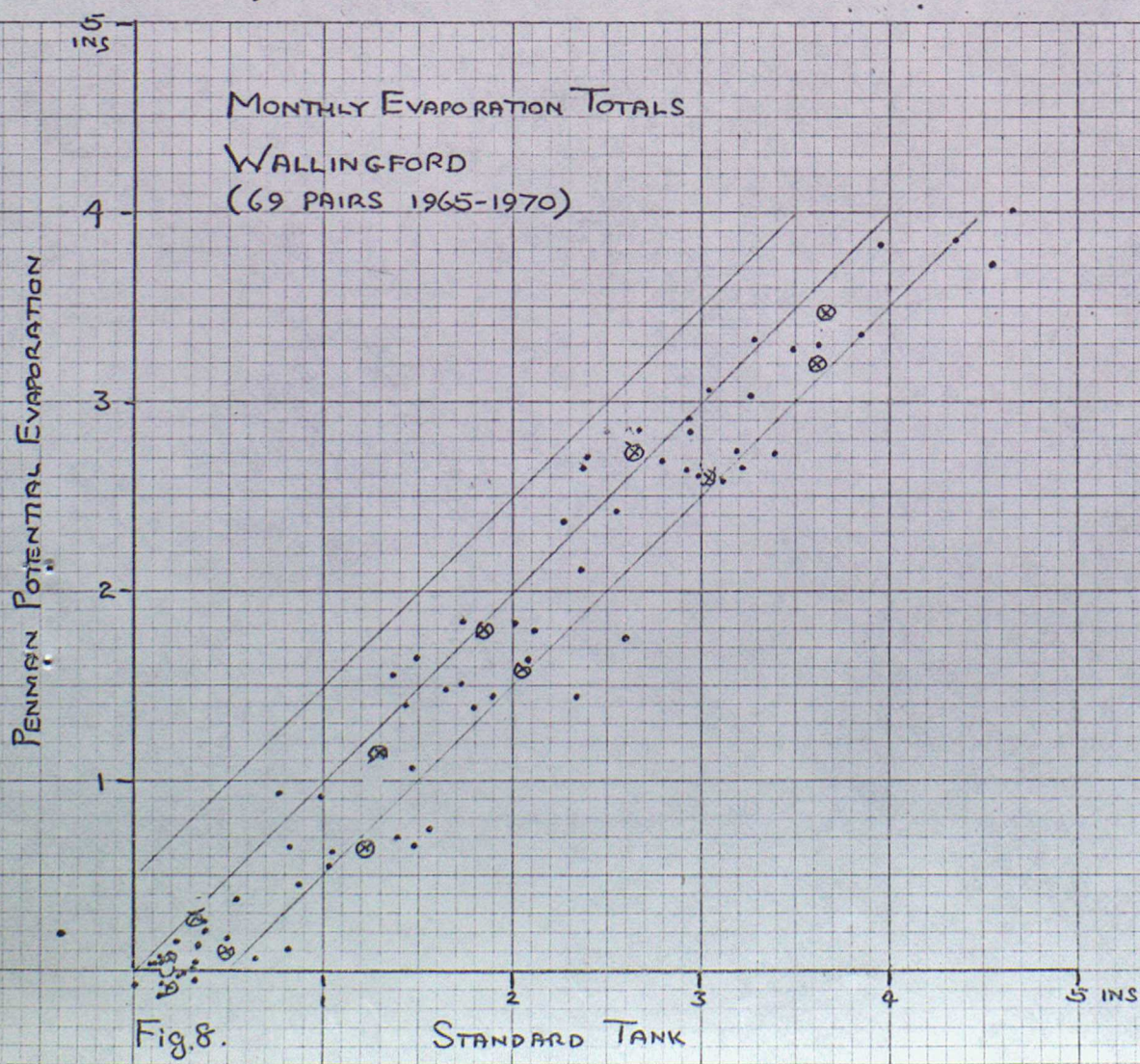
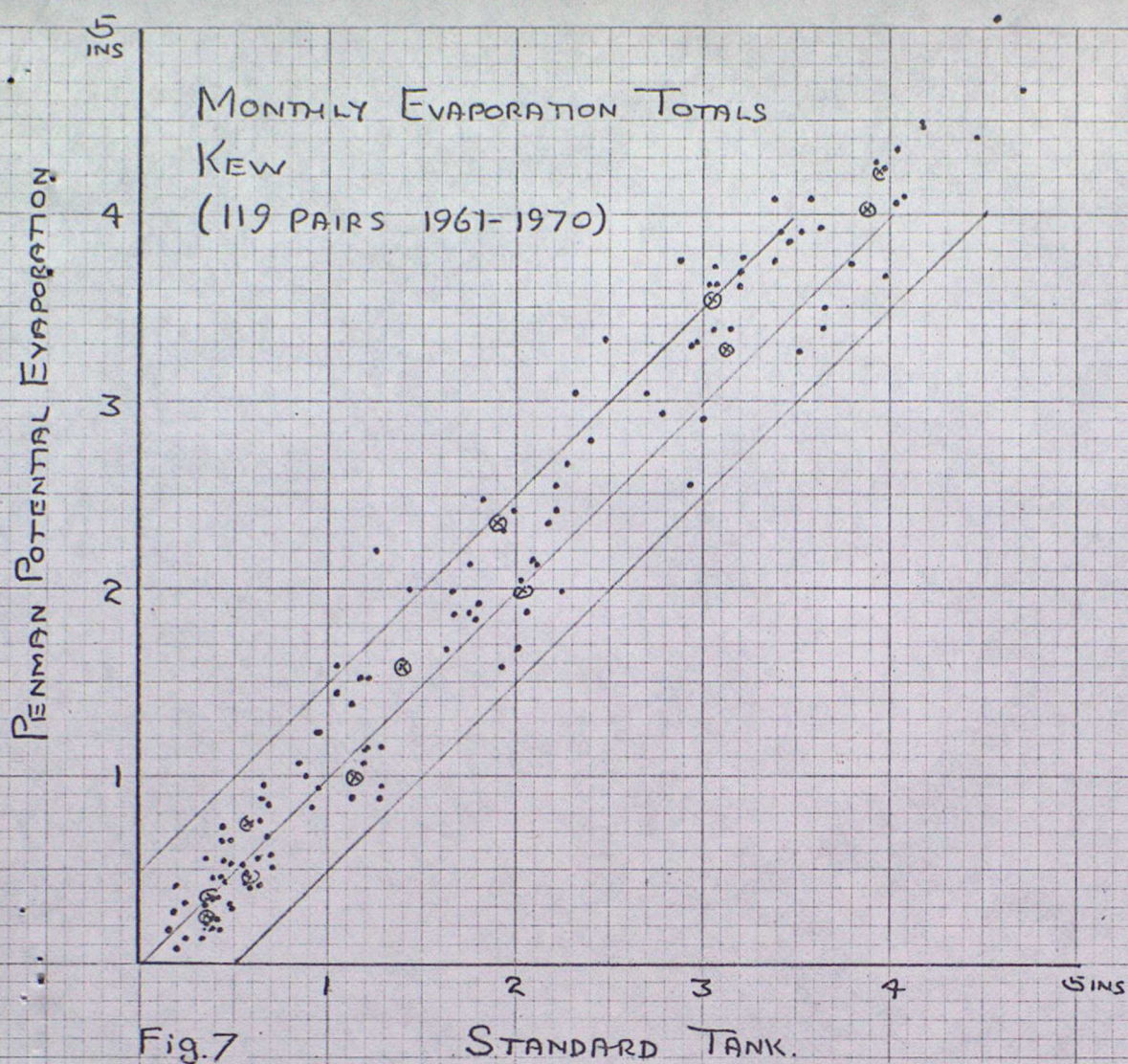
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1 2 3 4 5 INS

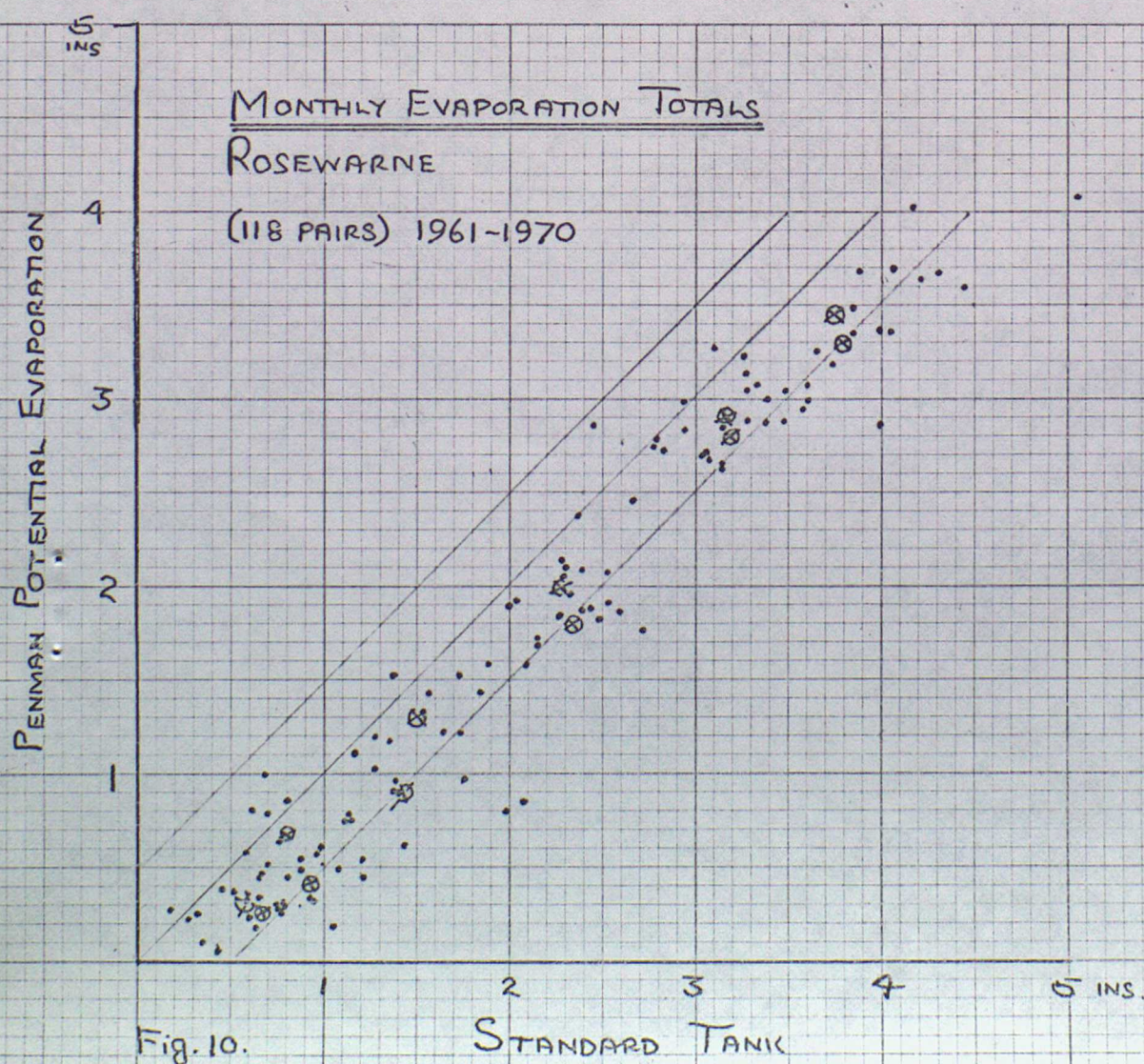
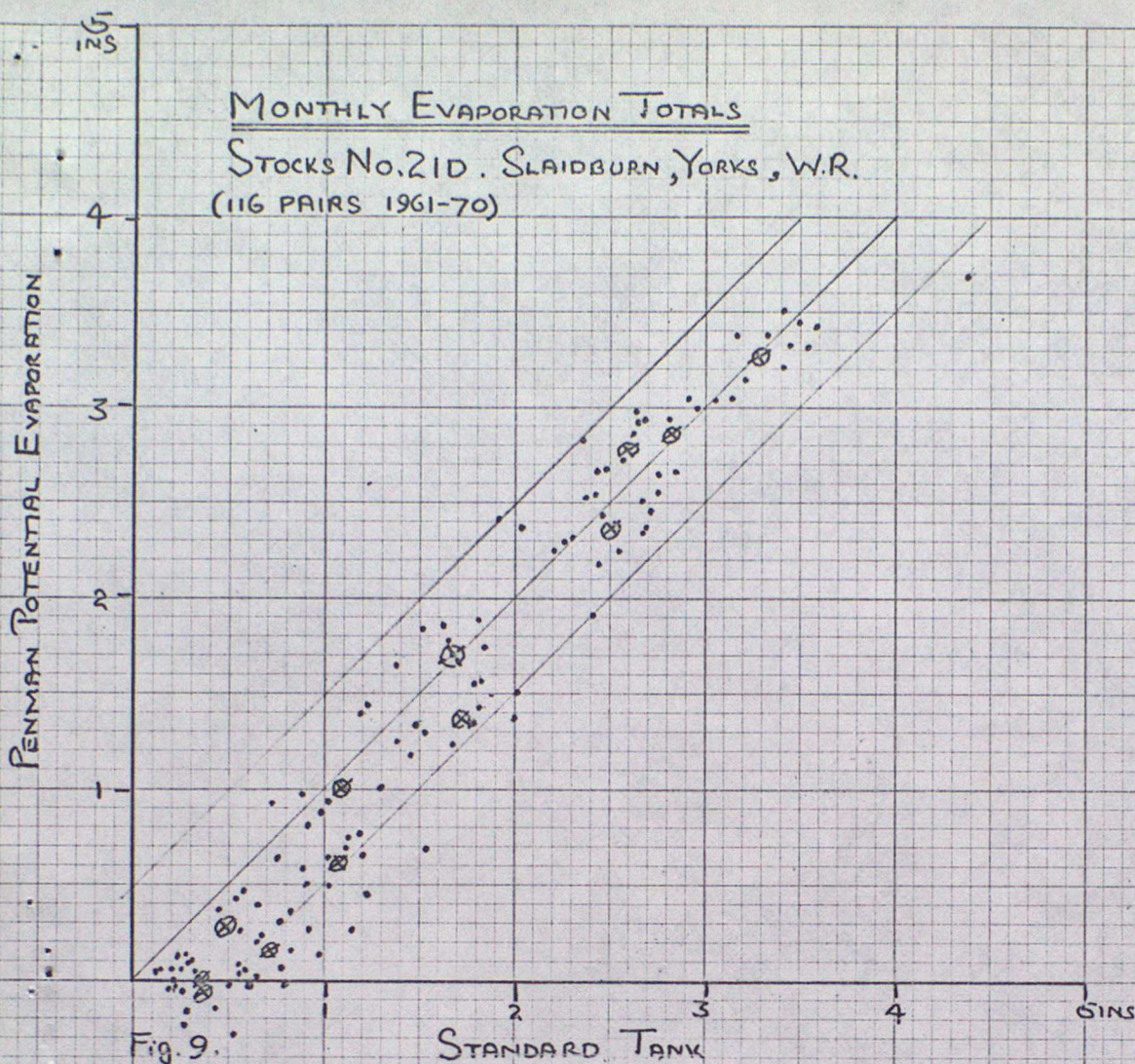
Fig. 6.

WALLINGFORD PENMAN P.E.

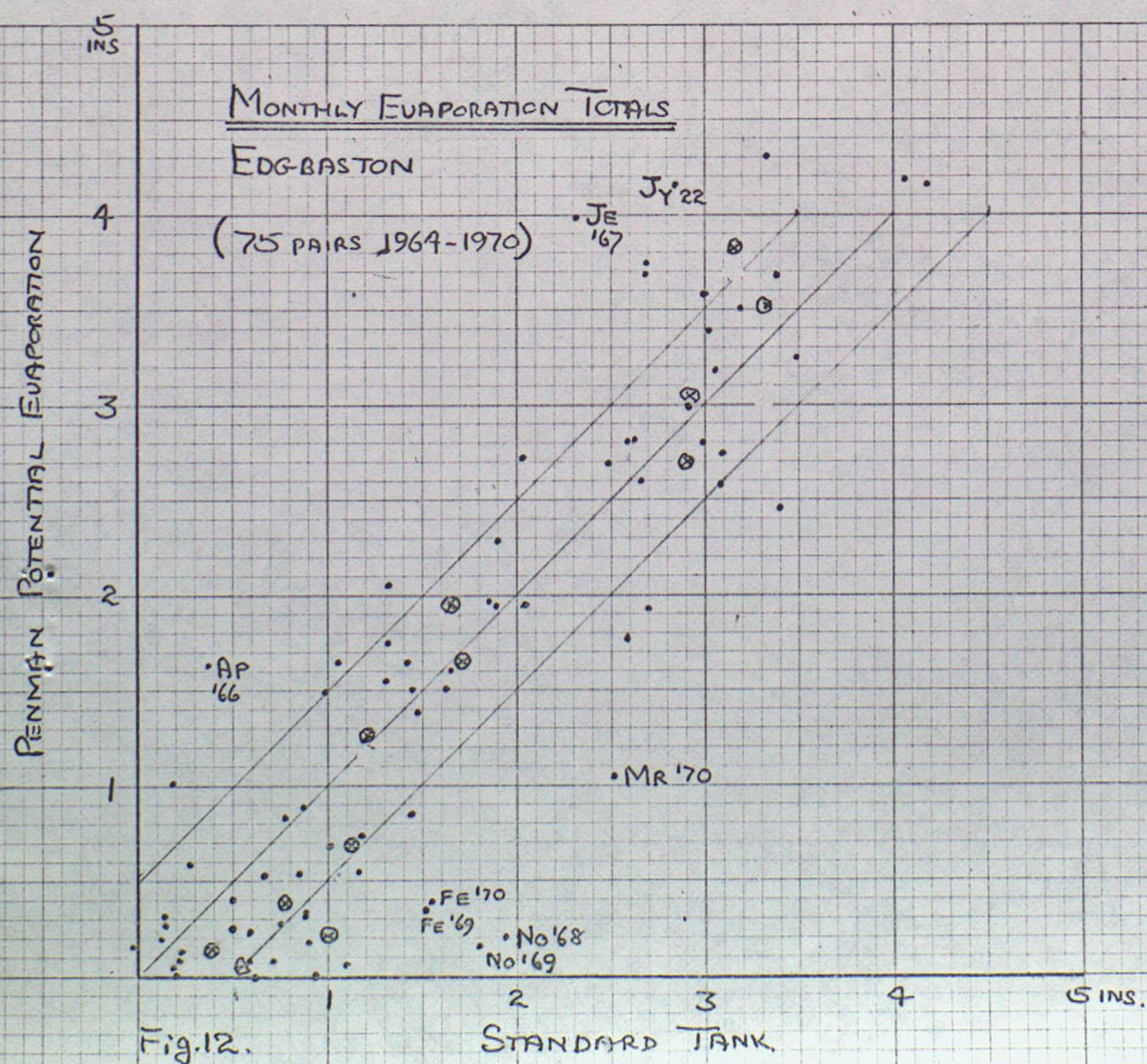
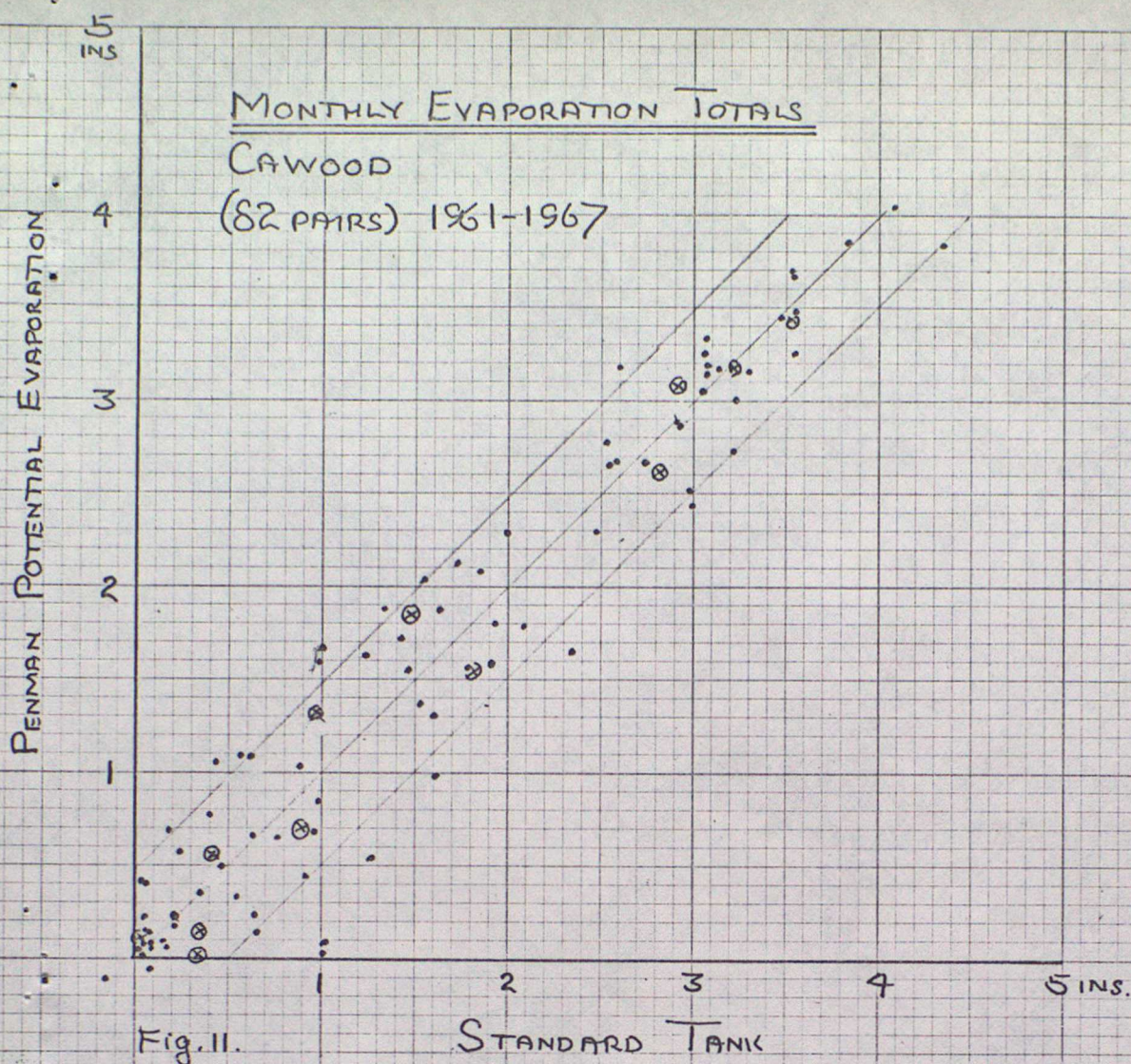








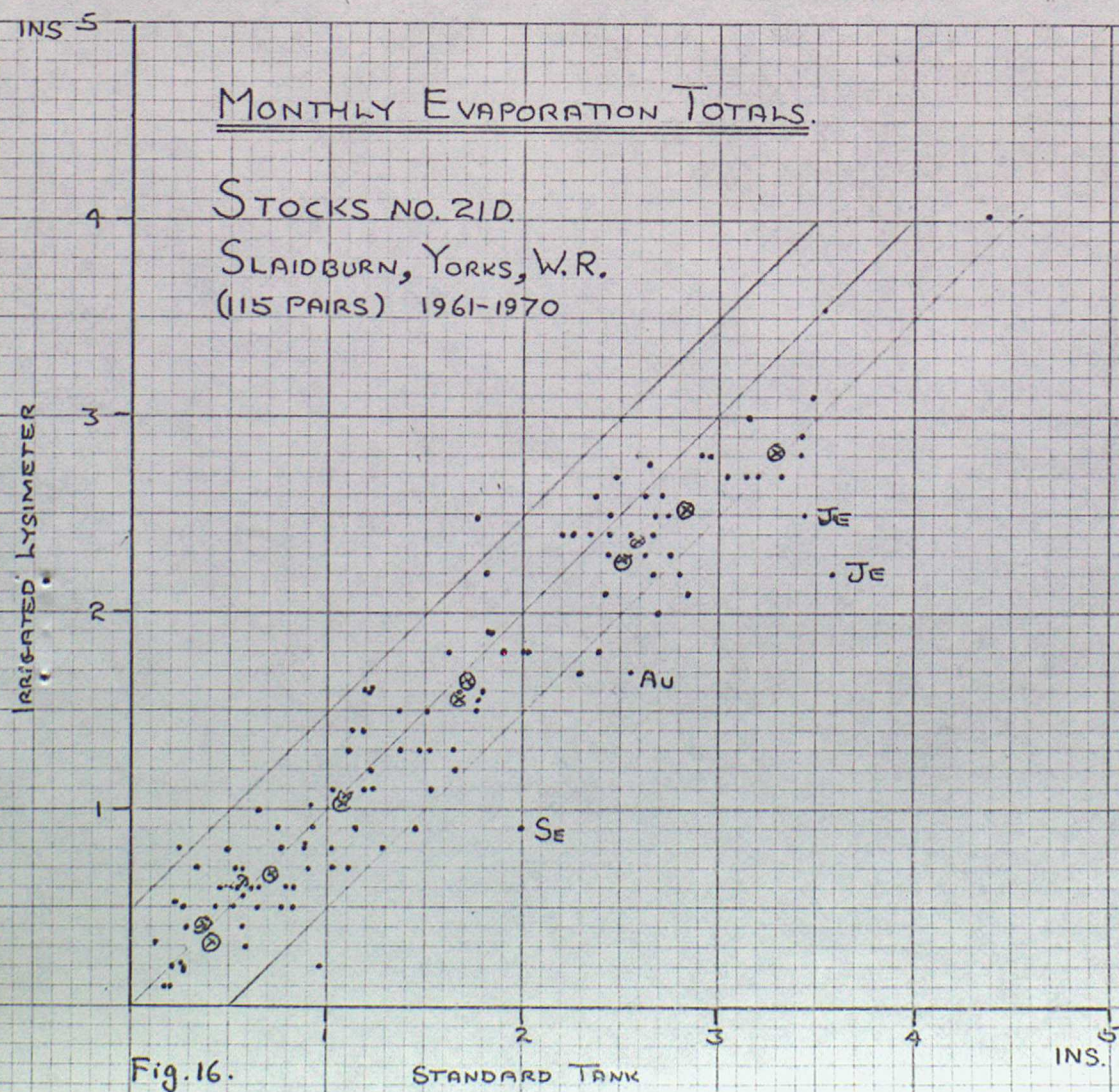
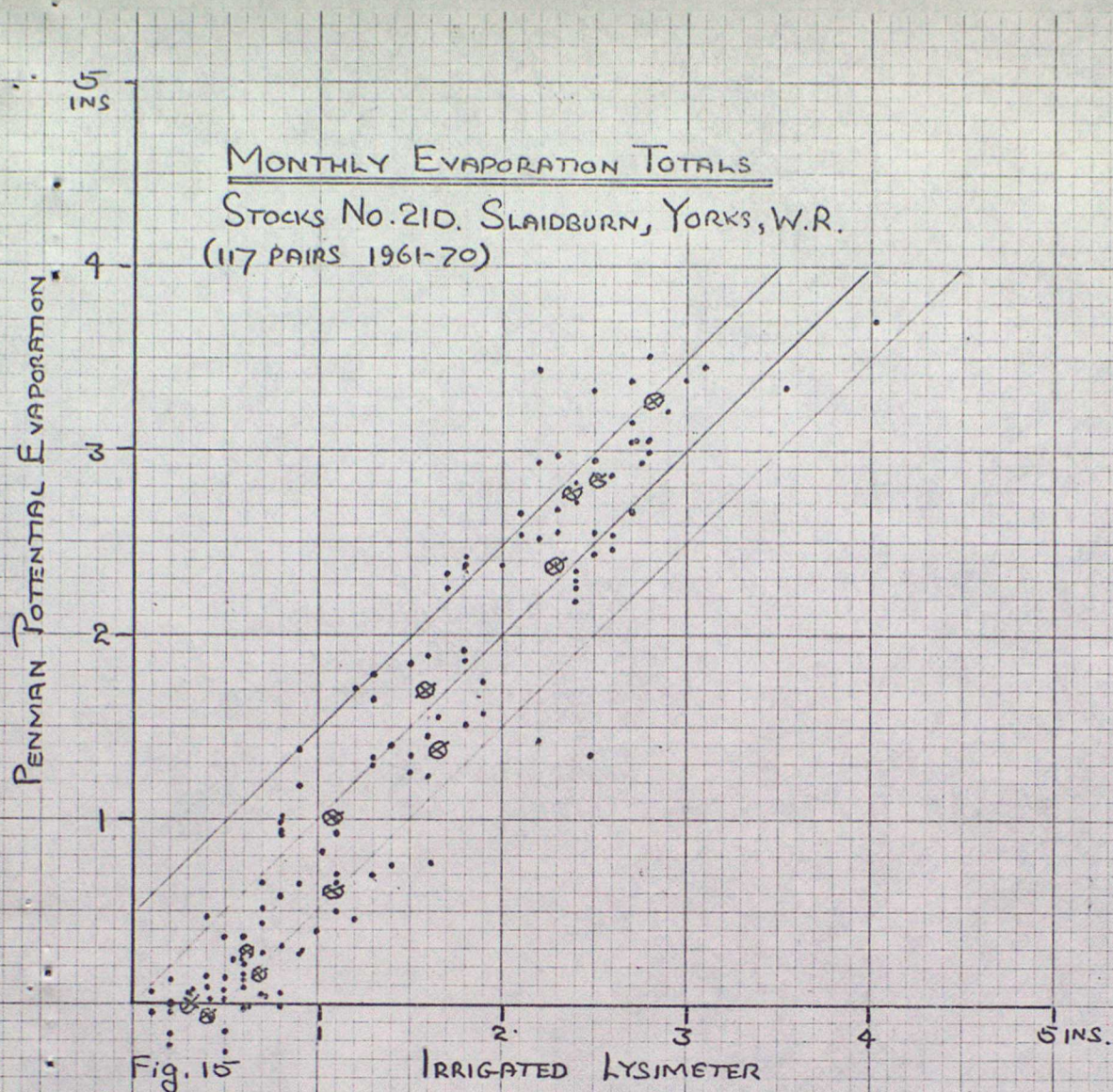




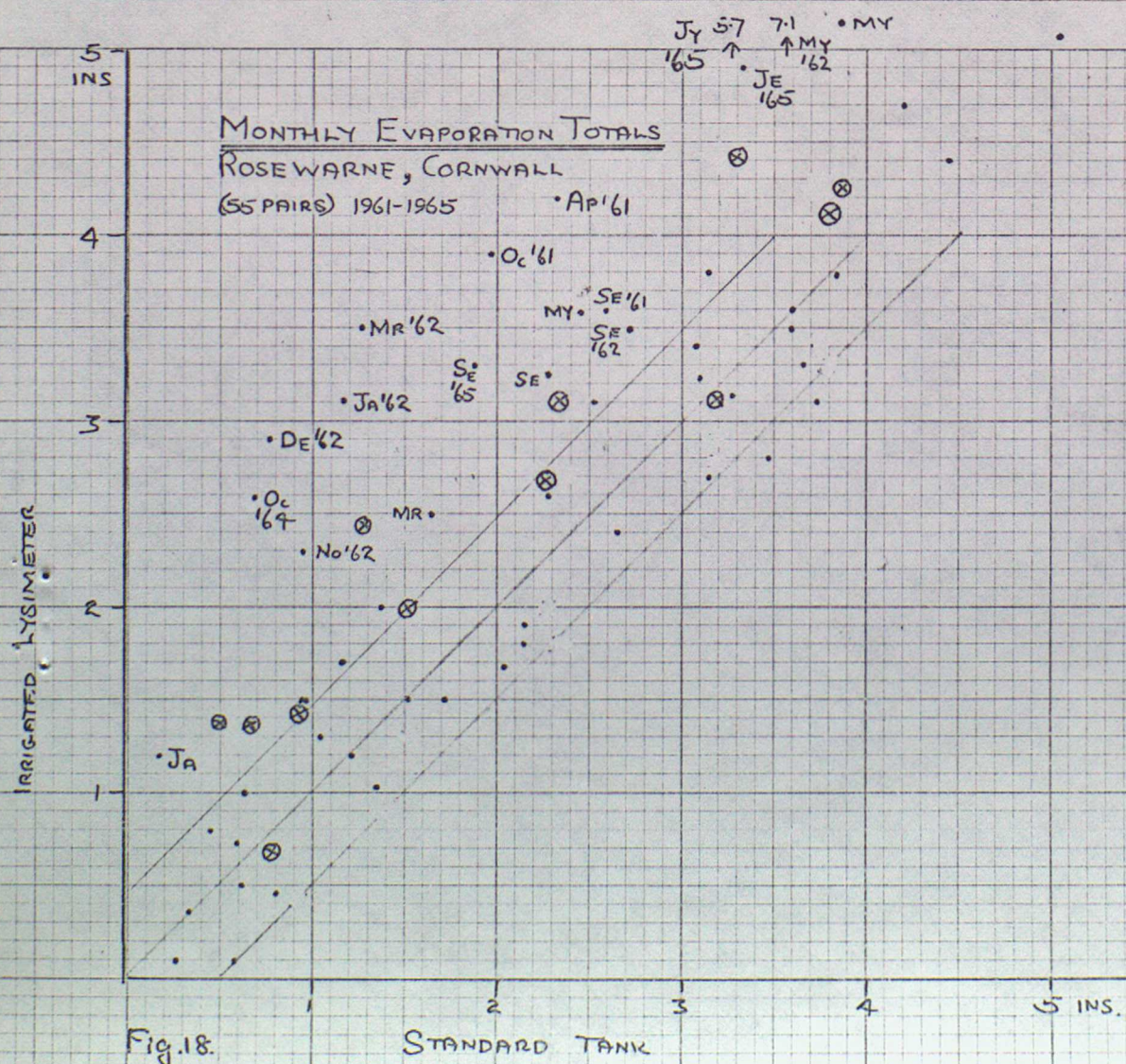
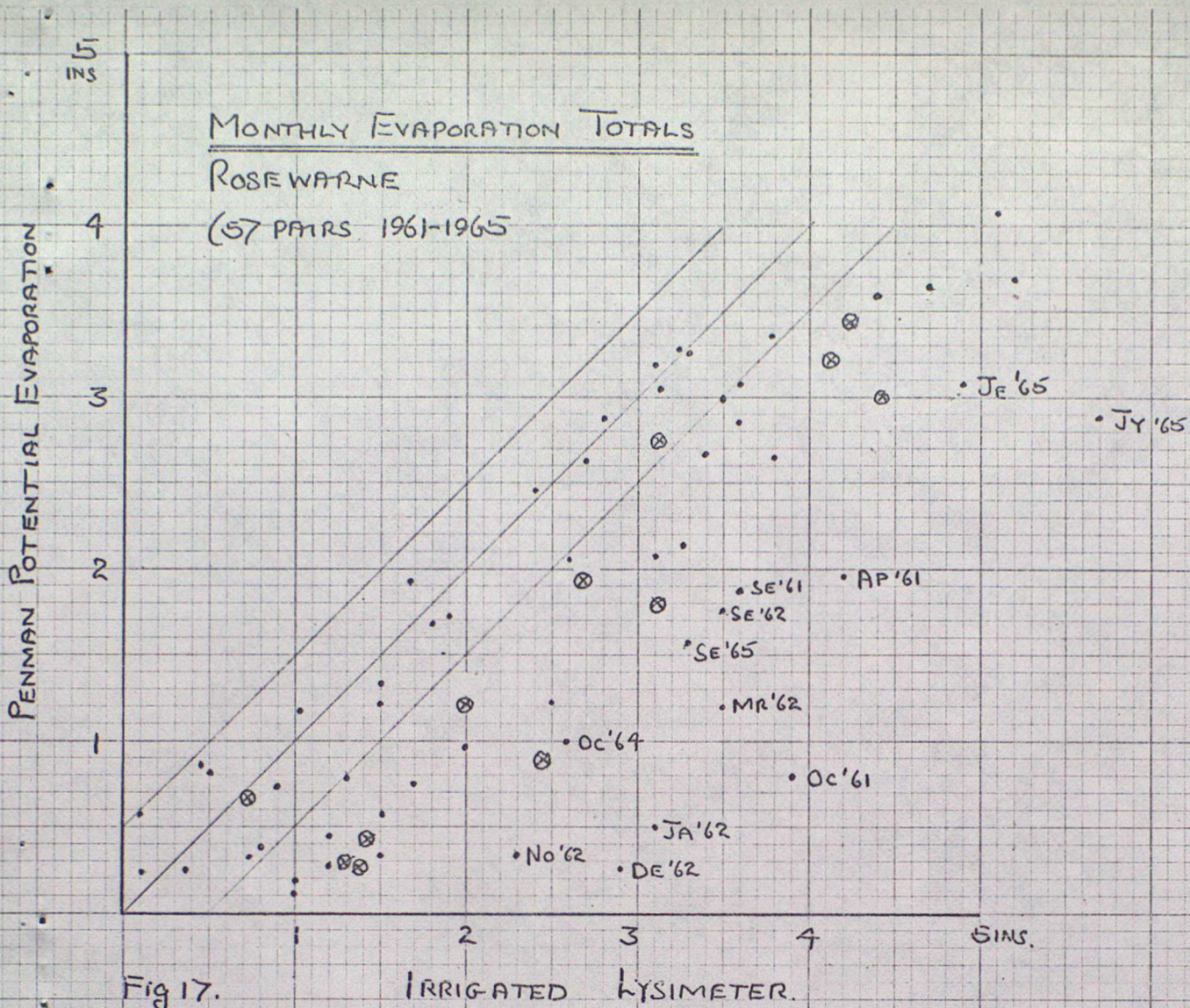




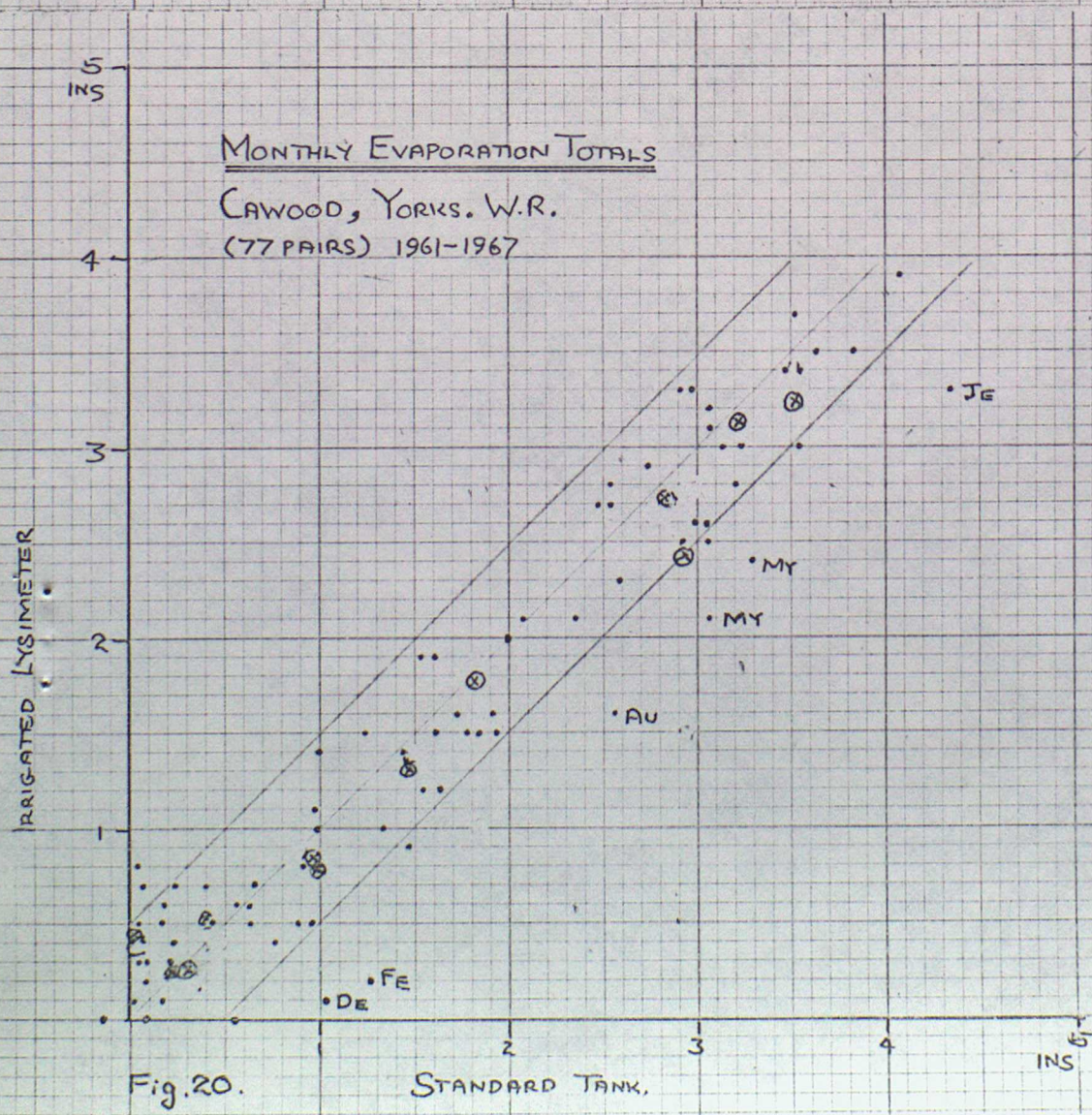
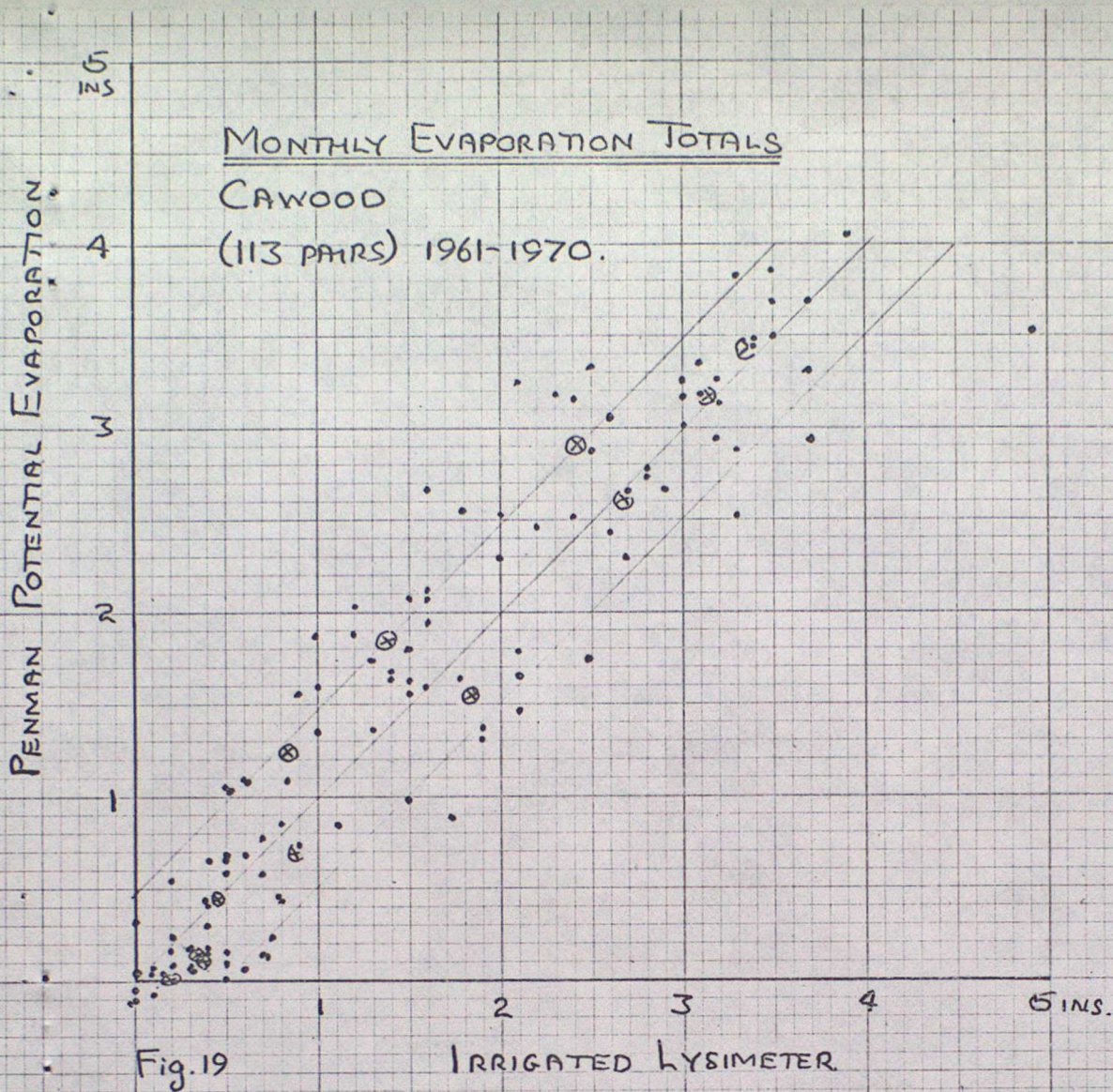




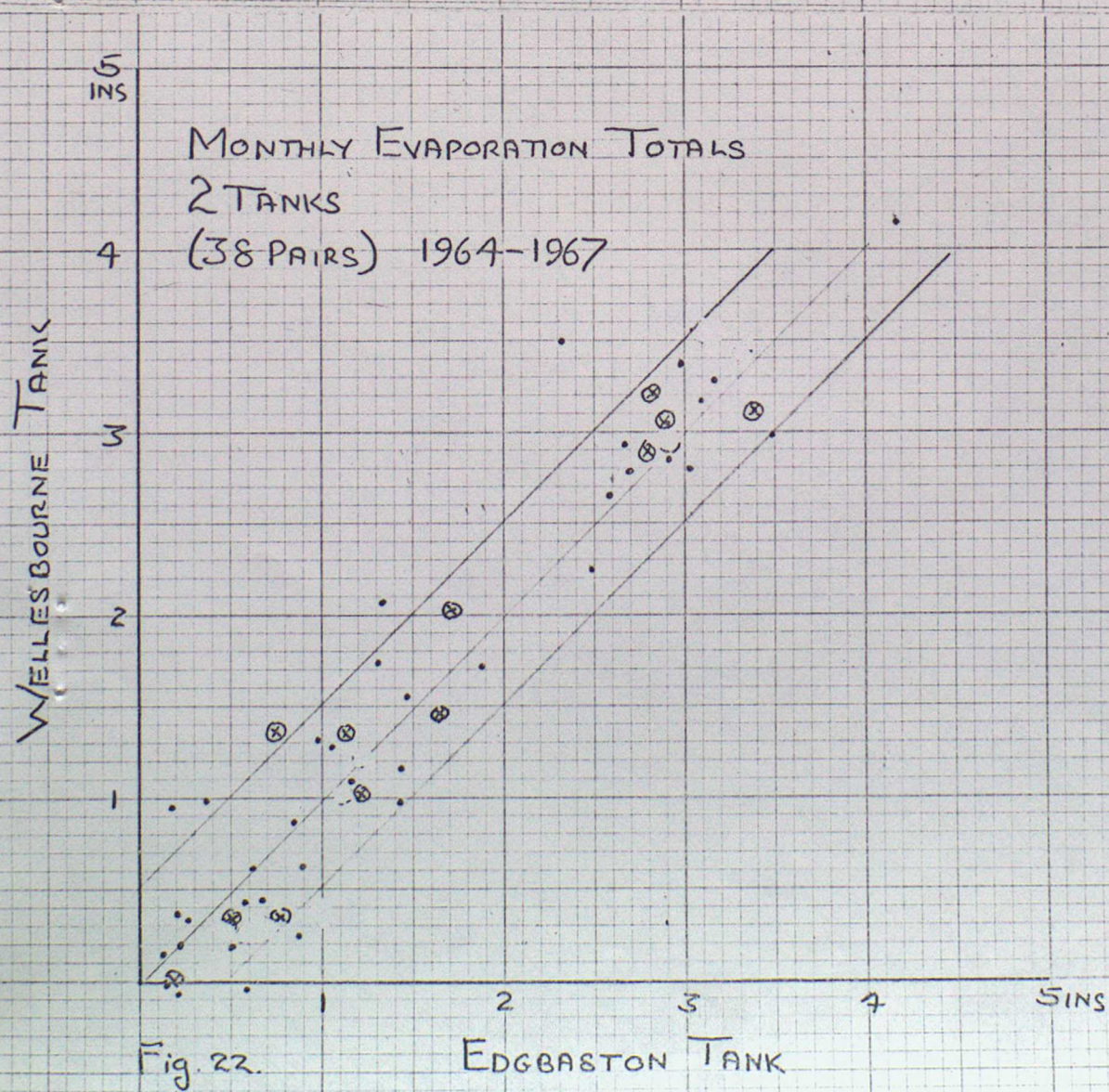
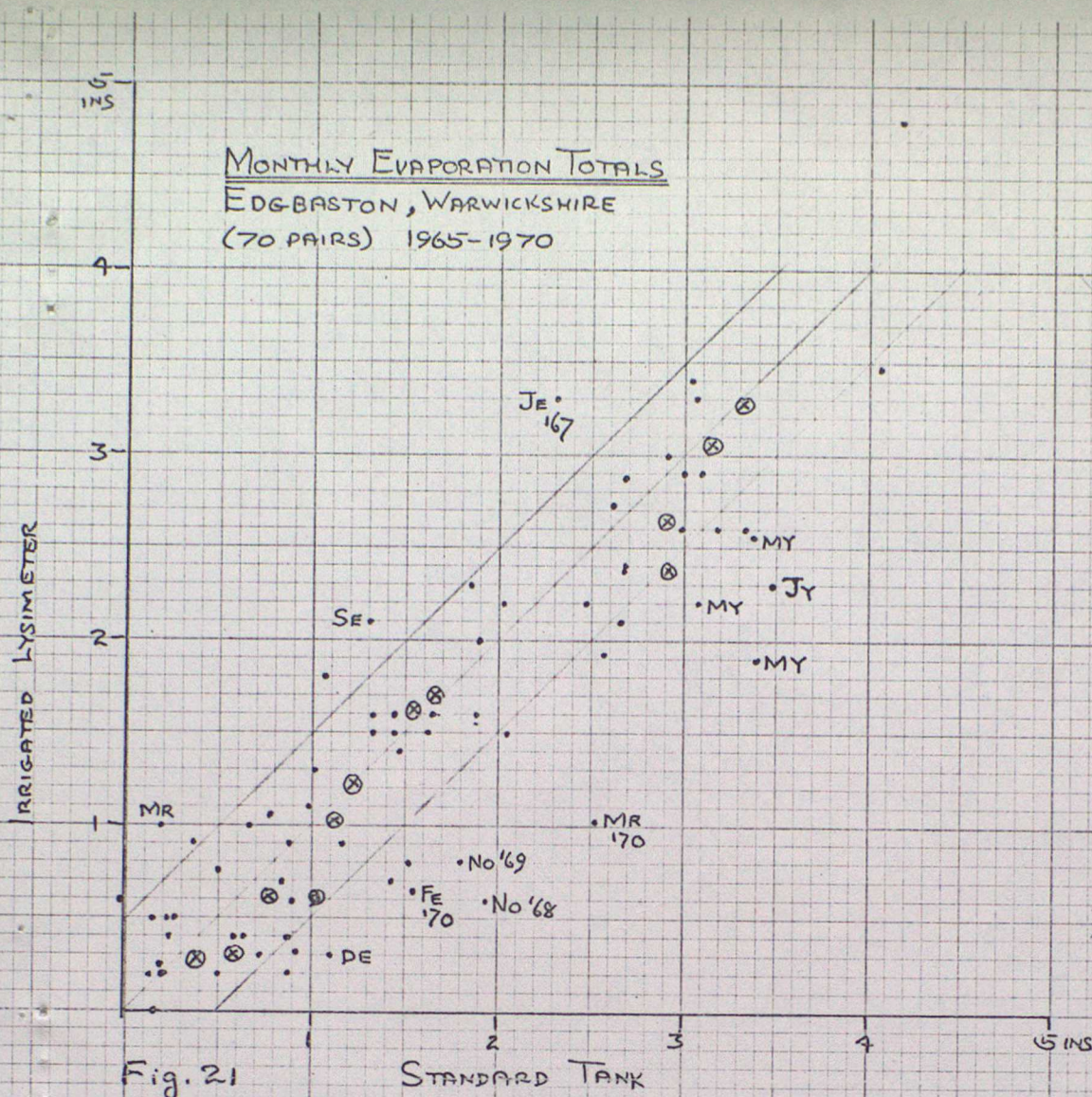




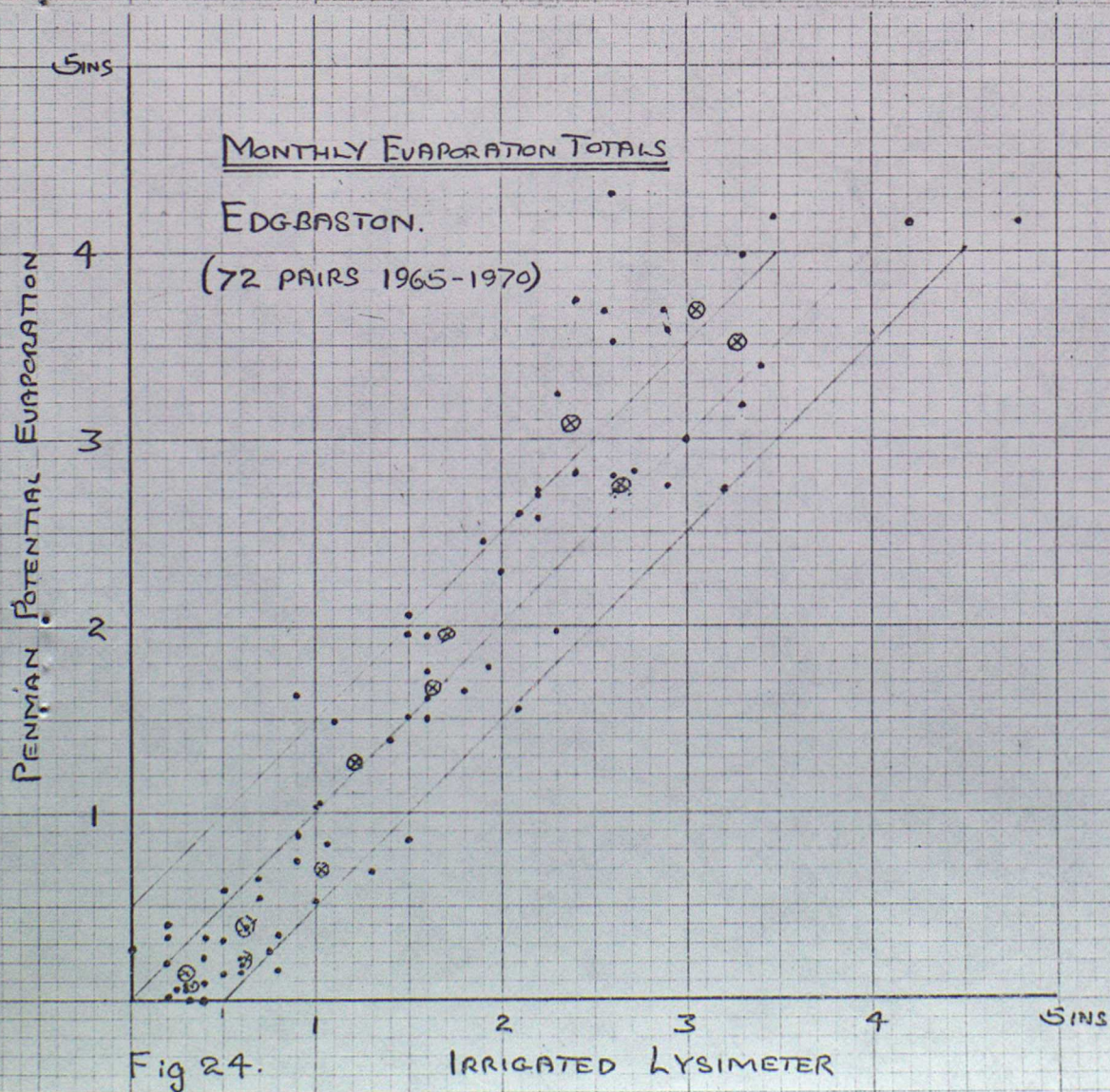
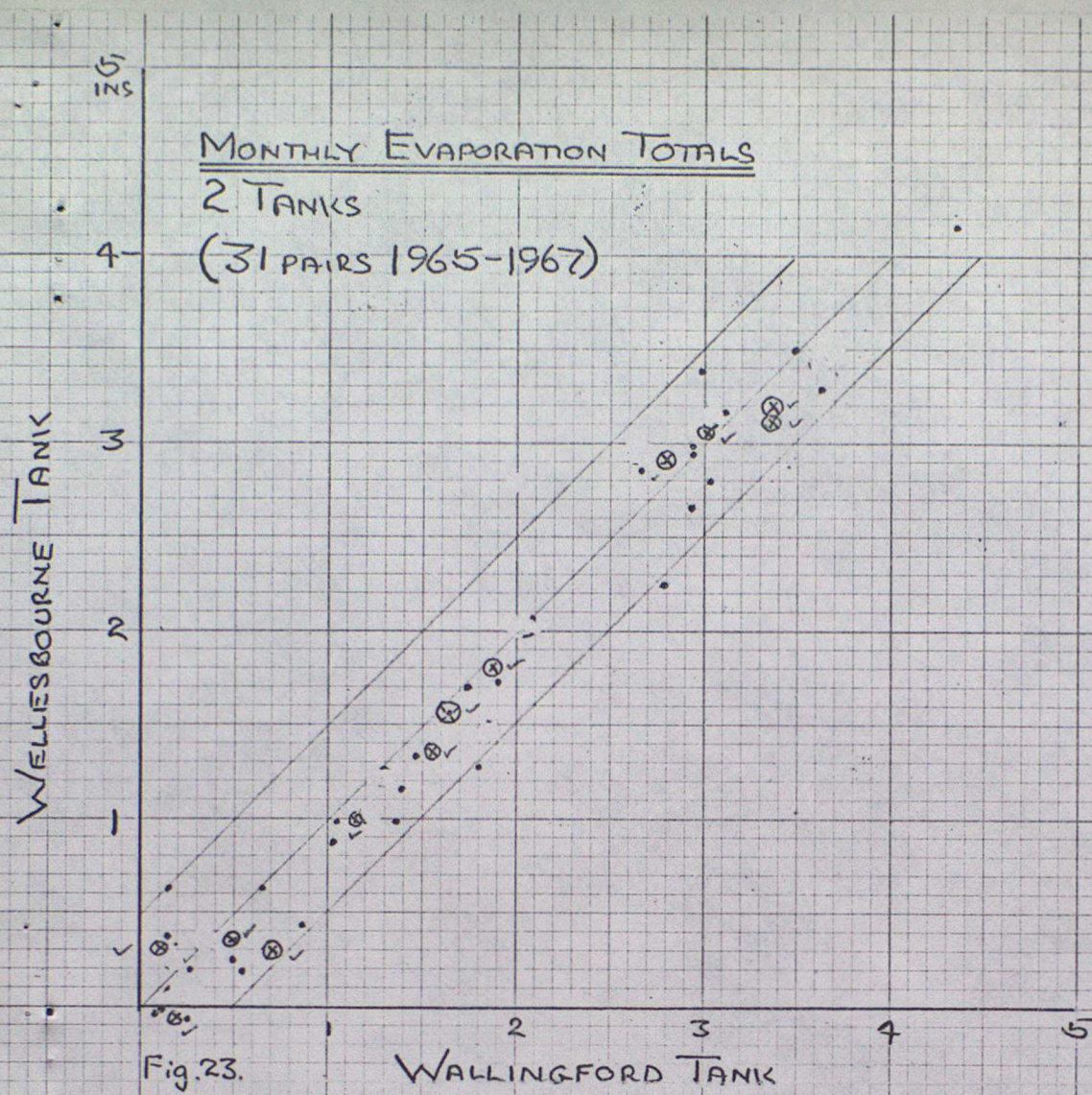


















MONTHLY EVAPORATION TOTALS  
HOLLINSCLOUGH, STAFFORDSHIRE.  
 (22 PAIRS) 1964-1966

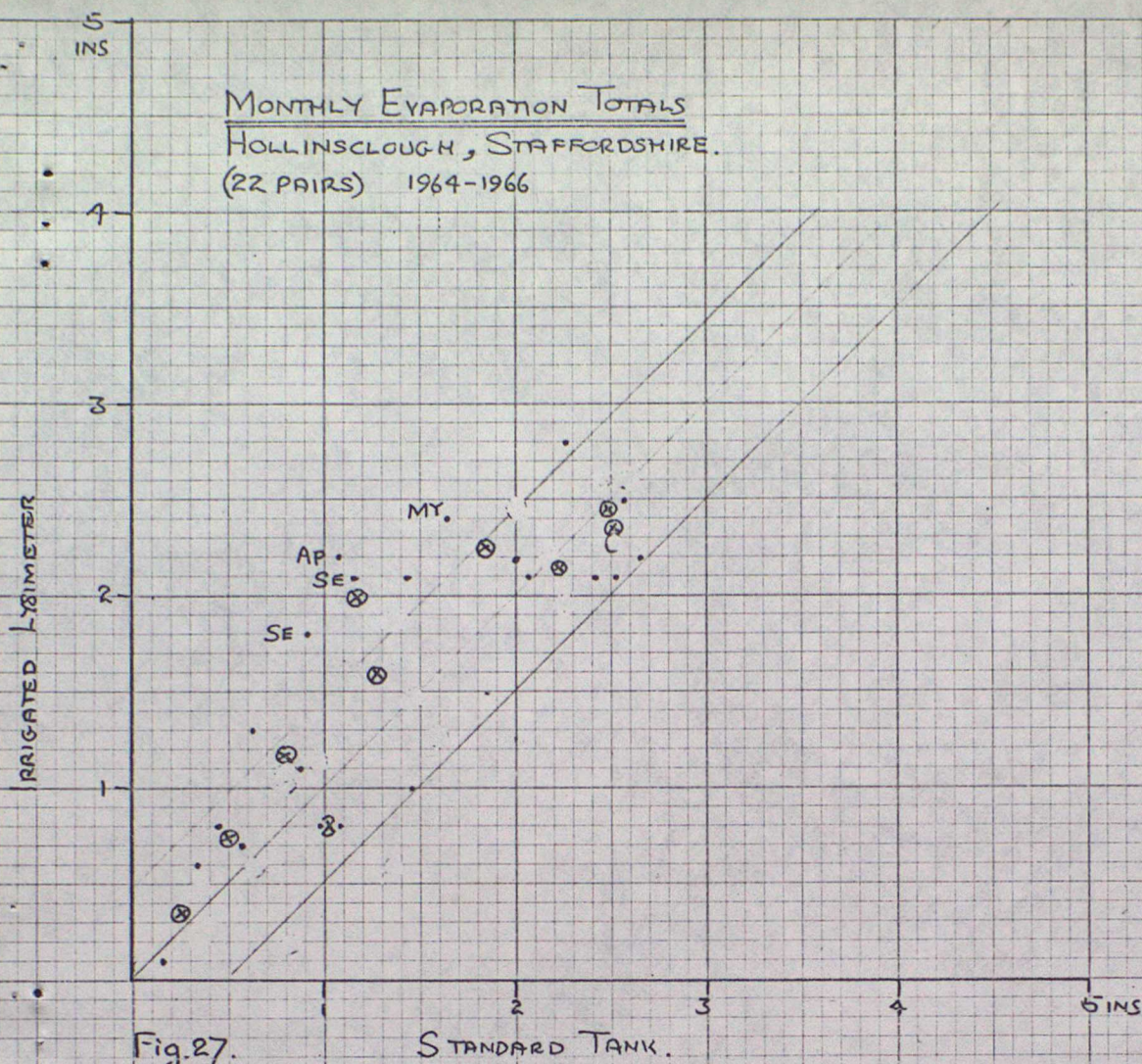


Fig.27.

MONTHLY EVAPORATION TOTALS  
ALICE HOLT LODGE  
 (113 PAIRS 1961-70)

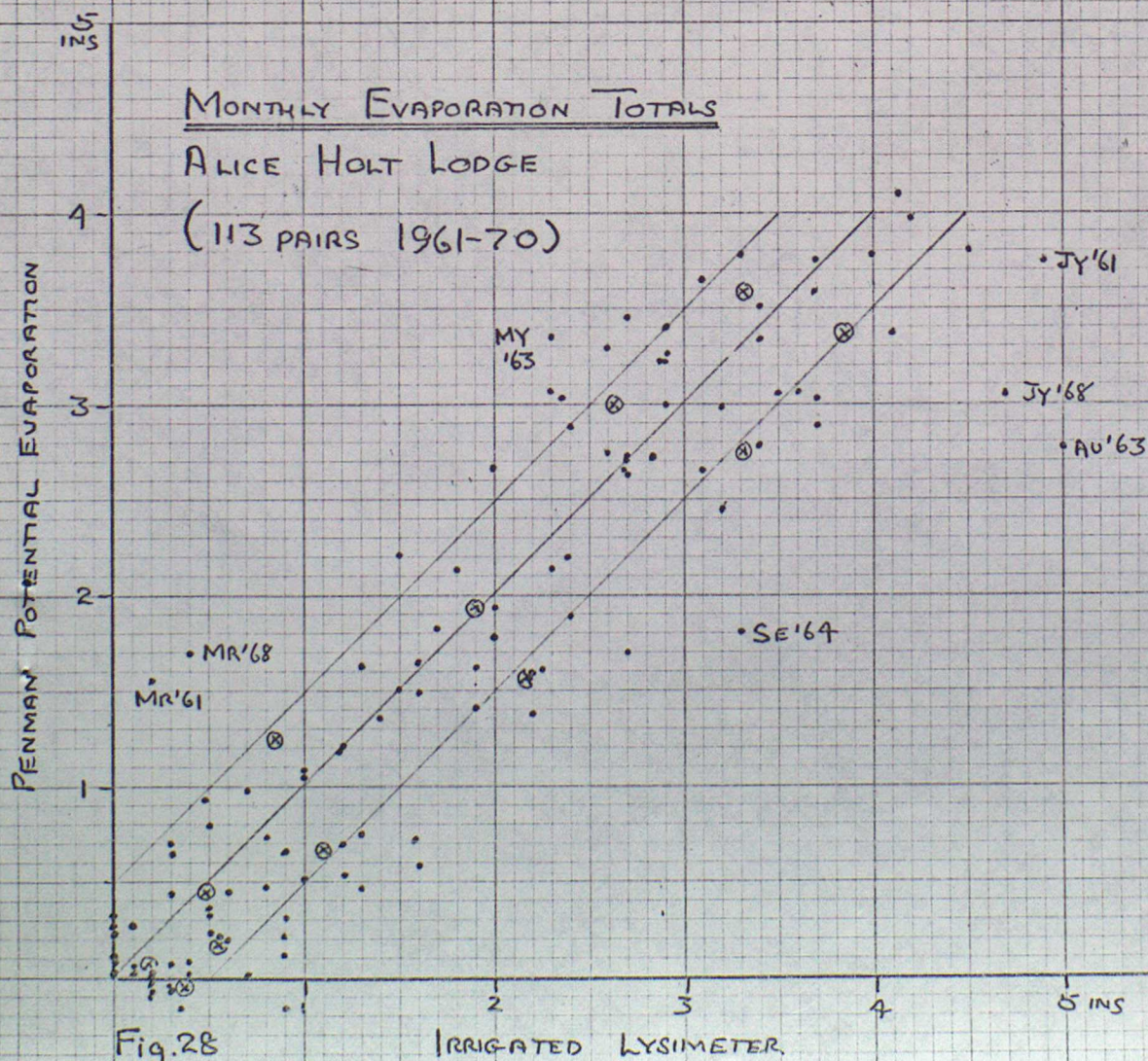


Fig.28



MONTHLY EVAPORATION TOTALS

HIGH MOWTHORPE

(63 PAIRS 1961-1969)

PENMAN POTENTIAL EVAPORATION

Fig. 29.

IRRIGATED LYSIMETER

MONTHLY EVAPORATION TOTALS.

SUTTON BONINGTON

(98 PAIRS 1963-1970)

PENMAN POTENTIAL EVAPORATION

Fig. 30.

IRRIGATED LYSIMETER



