THE INDIRECT MEASUREMENT OF LAKE/RESERVOIR EVAPORATION

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1. Introduction

In the design and management of bulk water storage in lakes and reservoirs the water gains are from catchment rainfall and from inflowing streams and the water losses are via outflowing streams, water extraction for public or private supply, outward seepage through banks and bottom, and evaporation. The last two appear as a combined change in water level.

The literature (eg CIMO (1966), Hounam (1978)) contains accounts of a variety of methods of estimating or of attempting to measure lake/reservoir evaporation. Floating pans are generally regarded as unreliable because of inward and outward splashing. There is also good reason to doubt their representativeness (as compared with lake evaporation) on the grounds of the reflective and absorptive characteristics of the pans and because the water "sample" in a floating pan is isolated from the vertical water circulation of the main water mass.

In the experiment described in this paper three important features are introduced. Firstly the "pan" (known as the "mini-tank") was made of transparent plastic. Secondly the evaporation from the "lake" was known, accurately, because the 20m^2 tank at Kew was used. Thirdly the occasions of assumed splashing were separated from the main body of the data in the analysis.

2. Observations

The observations used were from 10 May 1976 to 30 September 1977 at Kew Observatory using the standard Russian 20 square metre evaporimeter (diameter 5m, depth 2m), with a small tank, inside diameter 30.5 cm (12"), inside depth 26 cm (10"), constructed of 1.3 cm thick perspex, suspended into it. A clearance of approximately 50 mm was maintained between the lip of the mini-tank and the outer water surface, the inner water level being maintained as close as possible to this.

Readings of water level were taken every day with a downward facing micrometer screw gauge on the 20m^2 tank, and every three days on the mini tank by removing it to a nearby building and measuring the water loss or gain volumetrically.

Rainfall measurements from an adjacent ground level (flush) raingauge were used to adjust the water level readings in the 20m^2 and mini tanks to give evaporation totals.

3. Results

Three day evaporation totals from the tanks and the ratios thereof are tabulated in the Appendix.

Since it was important that any occasions of splashing, both in and out of the mini-tank should be eliminated from the analysis, negative (water gain) readings were ignored. The number of these negative readings related to the season of the year is important.

During the summer months, April-September the number of these occasions was low (4.1%), whilst from October-March the unacceptably high percentage of 50% was recorded.

For this reason only the summer period observations were considered to be of any value for obtaining a coefficient to relate mini-tank and $20m^2$ tank evaporation totals.

4. Analysis

The ratios of evaporation from the mini-tank and from the large tank $\frac{(mini)}{(20m^2)}$ were calculated for each set of readings, and then averaged over monthly intervals (Table 1) and also for various periods.

Table 1

	1976	1977
January		1.33
February		1.27
March		1.58
April		1.24
May	1.15	1.26
June	1.32	1.31
July	1.11	1.25
August	1.18	1.15
September	1.18	1.17
October	.88	
November	1.25	
December	3.4	

Average value of $\frac{mini}{20m^2}$ for period May - September 1976 = 1.19

Average value of $\frac{mini}{20m^2}$ for period October 1976-March 1977 = 1.61

Average value of $\frac{mini}{20m^2}$ for period April-September 1977 = 1.23

Average value of $\frac{mini}{20m^2}$ for both summer seasons = 1.21

Some seasonal variation is apparent, with a maximum in June, and minima in May and September, but two seasons' data were considered insufficient to establish the existence of a proven seasonal pattern, so a frequency diagram was constructed for both summer seasons together. (Fig 1)

The frequency diagram of the winter season, whilst showing the poor quality of the readings, does confirm that the winter half-year ratio was of the same order. (Fig 2) The summer half-year data are also plotted as scatter diagrams. (Figs 3 and 4)

5. Conclusion

It was thought reasonable to conclude that the evaporation from a small tank is greater than a larger mass of water surrounding it, probably due to thermal mixing in the main water mass, and that a ratio of 1.2 : 1.0 is suggested as a working rule for correction.

A mini-tank such as used in this experiment could be used, with a correcting factor, as a measure of evaporation in a reservoir under conditions of little wind. The factor obtained at Kew could be tried as a first approximation.

It is clearly desirable to be able to make such indirect measurements of lake/reservoir evaporation under all weather conditions. The authors suggest that a mini-tank fitted with exterior and interior splash guards, and interior (and perhaps exterior wave spoilers could be of use. Such a device would be supported by some arrangements of buoys and spars.

A device such as illustrated in Fig 5 would presumably lose less water by evaporation than the simple mini-tank, but a coefficient could be determined experimentally.

The mini-tank method could also be used on a lake/reservoir to provide check measurements with which to calibrate evaporation estimates obtained using direct eddy flux data from raft-mounted sensors.

References

CIMO (1966) Measurement and estimation of evaporation and evapotranspiration. Tech. Note 83 WMO Geneva, 121 pp.

Hounam, C E (1973) Comparison between lake and pan evaporation. Tech. Note 126 WMO Geneva, 52 pp.

	20m²	mini	mini / 20m²	
MAY 10-2	10·7	10·5	·98	
13-15	9·9	11·8	1·19	
16-18	9·3	12·2	1·31	
19-21	8·2	6·3	·77	
22-24	7·8	11·2	1·44	
25-27	8·8	10·6	1·20	
28-30	8·3	9·8	1·18	Av. 1·15
MAY 31-Ju. 2	8·1	10·5	1·30	
JUNE 3-5	7·5	11·0	1·47	
6-8	11·2	14·1	1·26	
9-11	14·2	18·9	1·33	
12-14	11·8	13·7	1·16	
15-17	8·8	11·6	1·32	
18-20	10·4	11·2	1·08	
21-23	9·1	14·7	1·62	
24-26	14·8	18·5	1·25	
27-29	15·5	21·6	1·39	Av 1·32
JUNE 30-JUL 2	22·3	26·8	1·20	
JULY 3-5	16·2	20·5	1·26	
6-8	17·9	21·9	1·22	
9-11	15·5	18·5	1·19	
12-14	15·1	16·7	1·11	
15-17	8·0	6·2	·77	
18-20	12·9	13·5	1·05	
21-23	12·8	14·4	1·12	
24-26	9·5	11·0	1·16	
27-29	13·0	13·7	1·05	Av 1·11
JULY 30,31 – AUG 1	12·7	13·7	1·08	
AUG 2-4	10·4	12·1	1·16	
5-7	9·9	11·0	1·11	
8-10	10·0	12·8	1·28	
11-13	9·0	11·0	1·22	
14-16	12·3	15·4	1·25	
17-19	11·0	13·7	1·24	
20-22	14·2	18·3	1·29	
23-25	12·6	15·5	1·23	
26-28	9·7	8·1	·83	
29-31	4·1	5·3	1·29	Av 1·18

	20m²	mini	mini / 20m²	
SEPT 1-3	8·5	11·0	1·29	
4-6	7·0	8·2	1·17	
7-9	11·4	14·7	1·29	
10-12	4·6	−3·7?		
13-15	3·0	3·9	1·3	
16-18	4·0	5·6	1·4	
19-21	4·3	6·9	1·6	
22-24	1·0	−1·1?		
25-27	2·4	0·5	0·2	
28-30	2·2	2·6	1·18	Av. 1·18
OCT 1-3	2·0	−2·8		
4-6	3·2	3·0	·94	
7-9	4·2	5·0	1·19	
10-12	4·0	2·9	·73	
13-15	3·8	0·1	·03	
16-18	2·7	3·4	1·26	
19-21	1·6	0·6	·37	
22-24	1·0	1·5	1·5	
25-27	1·9	−1·5		
28-30	0·3	0·3	1	Av ·88
OCT 31- NOV 2	2·1	2·4	1·14	
NOV 3-5	1·5	3·0	2	
6-8	0·5	−0·1		
9-11	0·3	−0·8		
12-14	1·1	1·2	1·09	
15-17	0·3	−0·5		
18-20	1·7	1·2	·71	
21-23	2·1	2·8	1·33	
24-26	−0·1	−0·1		
27-29	1·3	−5·1?		Av 1·25
NOV 30-DEC 2	1·8	−2		
3-5	0·4	−0·7		
6-8	0·3	−3·3		
9-11	0·4	−0·1		
12-14	−0·4	0·1		
15-17	0·1	−1·8		
18-20	−0·5	−1·4		
21-23	0·5	1·7	3·4	
24-26	0·6	0·0		
27-29	0·8	−1·5		Av 3·4

EVAPORATION AT KEW - $20m^2$ and Mini-Tank

MAY – DEC 1976.

	$20m^2$	mini	$\frac{mini}{20m^2}$	
MAY 10-2	10·7	10·5	·98	
13-15	9·9	11·8	1·19	
16-18	9·3	12·2	1·31	
19-21	8·2	6·3	·77	
22-24	7·8	11·2	1·44	
25-27	8·8	10·6	1·20	
28-30	8·3	9·8	1·18	Av. 1·15
MAY 31-JU. 2	8·1	10·5	1·30	
JUNE 3-5	7·5	11·0	1·47	
6-8	11·2	14·1	1·26	
9-11	14·2	18·9	1·33	
12-14	11·8	13·7	1·16	
15-17	8·8	11·6	1·32	
18-20	10·4	11·2	1·08	
21-23	9·1	14·7	1·62	
24-26	14·8	18·5	1·25	
27-29	15·5	21·6	1·39	Av 1·32
JUNE 30-JUL 2	22·3	26·8	1·20	
JULY 3-5	16·2	20·5	1·26	
6-8	17·9	21·9	1·22	
9-11	15·5	18·5	1·19	
12-14	15·1	16·7	1·11	
15-17	8·0	6·2	·77	
18-20	12·9	13·5	1·05	
21-23	12·8	14·4	1·12	
24-26	9·5	11·0	1·16	
27-29	13·0	13·7	1·05	Av 1·11
JULY 30, 31 - AUG 1	12·7	13·7	1·08	
AUG 2-4	10·4	12·1	1·16	
5-7	9·9	11·0	1·11	
8-10	10·0	12·8	1·28	
11-13	9·0	11·0	1·22	
14-16	12·3	15·4	1·25	
17-19	11·0	13·7	1·24	
20-22	14·2	18·3	1·29	
23-25	12·6	15·5	1·23	
26-28	9·7	8·1	·83	
29-31	4·1	5·3	1·29	Av 1·18

	$20m^2$	mini	$\frac{mini}{20m^2}$	
SEPT 1-3	8·5	11·0	1·29	
4-6	7·0	8·2	1·17	
7-9	11·4	14·7	1·29	
10-12	4·6	−3·7?		
13-15	3·0	3·9	1·3	
16-18	4·0	5·6	1·4	
19-21	4·3	6·9	1·6	
22-24	1·0	−1·1?		
25-27	2·4	0·5	0·2	
28-30	2·2	2·6	1·18	Av. 1·18
OCT 1-3	2·0	−2·8		
4-6	3·2	3·0	·94	
7-9	4·2	5·0	1·19	
10-12	4·0	2·9	·73	
13-15	3·8	0·1	·03	
16-18	2·7	3·4	1·26	
19-21	1·6	0·6	·37	
22-24	1·0	1·5	1·5	
25-27	1·9	−1·5		
28-30	0·3	0·3	1	Av ·88
OCT 31-NOV 2	2·1	2·4	1·14	
NOV 3-5	1·5	3·0	2	
6-8	0·5	−0·1		
9-11	0·3	−0·8		
12-14	1·1	1·2	1·09	
15-17	0·3	−0·5		
18-20	1·7	1·2	·71	
21-23	2·1	2·8	1·33	
24-26	−0·1	−0·1		
27-29	1·3	−5·1?		Av 1·25
NOV 30-DEC 2	1·8	−2		
3-5	0·4	−0·7		
6-8	0·3	−3·3		
9-11	0·4	−0·1		
12-14	−0·4	0·1		
15-17	0·1	−1·8		
18-20	−0·5	−1·4		
21-23	0·5	1·7	3·4	
24-26	0·6	0·0		
27-29	0·8	−1·5		Av 3·4

EVAPORATION AT KEW - 20m² and Mini-Tank.

JAN - SEPT 1977

	20m²	mini	mini/20m²	
DEC 30-JAN 1	-0.9			
JAN 2-4	0.7	-1.0		
5-7	-0.2	0.8		
8-10	-0.3	-0.3		
11-13	-0.4	-9.8		
14-17	0.3	0.4	1.33	
18-20	-0.1	-0.3		
21-23	-0.2	-1.2		
24-26	-0.1	-6.1		
27-29	1.8	2.4	1.33	Av 1.33
JAN 30-FEB 1	0.7	0.9	1.29	
FEB 2-4	-0.4	-2.3		
5-7	-0.5	0.1		
8-10	1.6	—		
11-13	1.3	2.1	1.61	
14-16	1.7	1.3	·76	
17-19	0.5	—		
20-22	-0.1	-0.4		
23-25	2.0	3.2	1.6	
26-28	3.6	4.0	1.11	Av 1.27
MAR 1-3	0.7	2.4	3.42	
4-6	3.1	4.3	1.39	
7-9	2.5	3.1	1.24	
10-12	2.1	3.1	1.47	
13-15	2.4	-2.4		
16-18	1.1	2.2	2.0	
19-21	2.6	1.4	·54	
22-24	1.5	2.4	1.6	
25-27	1.9	2.7	1.42	
28-30	4.8	5.5	1.15	Av 1.58
MAR 30-AP 2	2.8	1.8	·64	
APR. 3-5	4.5	7.5	1.67	
6-8	4.2	14.4	1.05	
9-11	3.5	6.0	1.71	
12-14	5.7	6.7	1.17	
15-17	5.1	6.9	1.35	
18-20	2.6	5.3	2.03	
21-23	6.3	7.4	1.17	
24-26	4.5	3.0	·57	
27-29	6.4	6.0	·94	Av 1.24
AP 30-MY 2	6.3	5.1	·81	
MAY 3-5	3.2	4.3	1.34	
6-8	5.3	4.7	·89	
9-11	2.5	3.7	1.48	
12-14	5.8	6.2	1.06	

	20m²	mini	mini/20m²	
MAY 15-17	8.4	11.6	1.38	
18-20	9.7	13.9	1.43	
21-23	13.2	17.8	1.35	
24-26	11.9	18.2	1.53	
27-29	12.0	16.4	1.37	Av 1.26
MAY 30-JU 1	10.5	12.6	1.2	
JUNE 2-5	10.0	12.3	1.23	
6-8	7.4	8.1	1.09	
9-11	3.1	3.0	·97	
12-13	2.9	-2.2		
14-16	4.5	8.5	1.89	
17-19	5.4	5.3	·98	
20-22	4.2	8.0	1.9	
23-25	6.6	8.8	1.33	
26-28	8.0	9.7	1.21	Av 1.31
JUN 29-JUL 1	8.8	12.1	1.37	
JULY 2-4	9.9	16.4	1.65	
5-7	13.3	15.1	1.13	
8-10	12.3	16.6	1.35	
11-13	10.5	11.0	1.05	
14-16	9.4	12.3	1.3	
17-19	10.8	12.2	1.13	
20-22	5.5	6.8	1.24	
23-25	9.6	9.6	1.0	
26-28	7.7	11.1	1.44	
29-31	8.4	8.9	1.06	Av 1.25
AUG 1-3	6.0	7.6	1.27	
4-6	7.1	5.5	·77	
7-9	5.4	8.9	1.65	
10-12	7.9	10.4	1.32	
13-15	2.5	3.1	1.24	
18-20	3.3	2.5	·76	
21-23	5.7	4.2	·74	
24-26	3.4	-1.8		
27-29	6.0	8.8	1.47	Av 1.15
AUG 31-SEP 1.	4.1	1.7	·41	
SEPT 2-4	6.3	6.0	·95	
5-7	4.1	7.4	1.8	
8-10	6.8	8.3	1.22	
11-13	6.0	6.0	1.0	
14-16	7.1	8.9	1.25	
17-19	5.9	5.5	·93	
20-22	2.6	3.0	1.15	
23-25	2.3	4.1	1.78	
26-28	4.2	5.2	1.24	Av 1.17

Average mini/20m² April - Sept 1977 = 1.23

Average mini/20m² Oct 1976 - March 1977 = 1.61

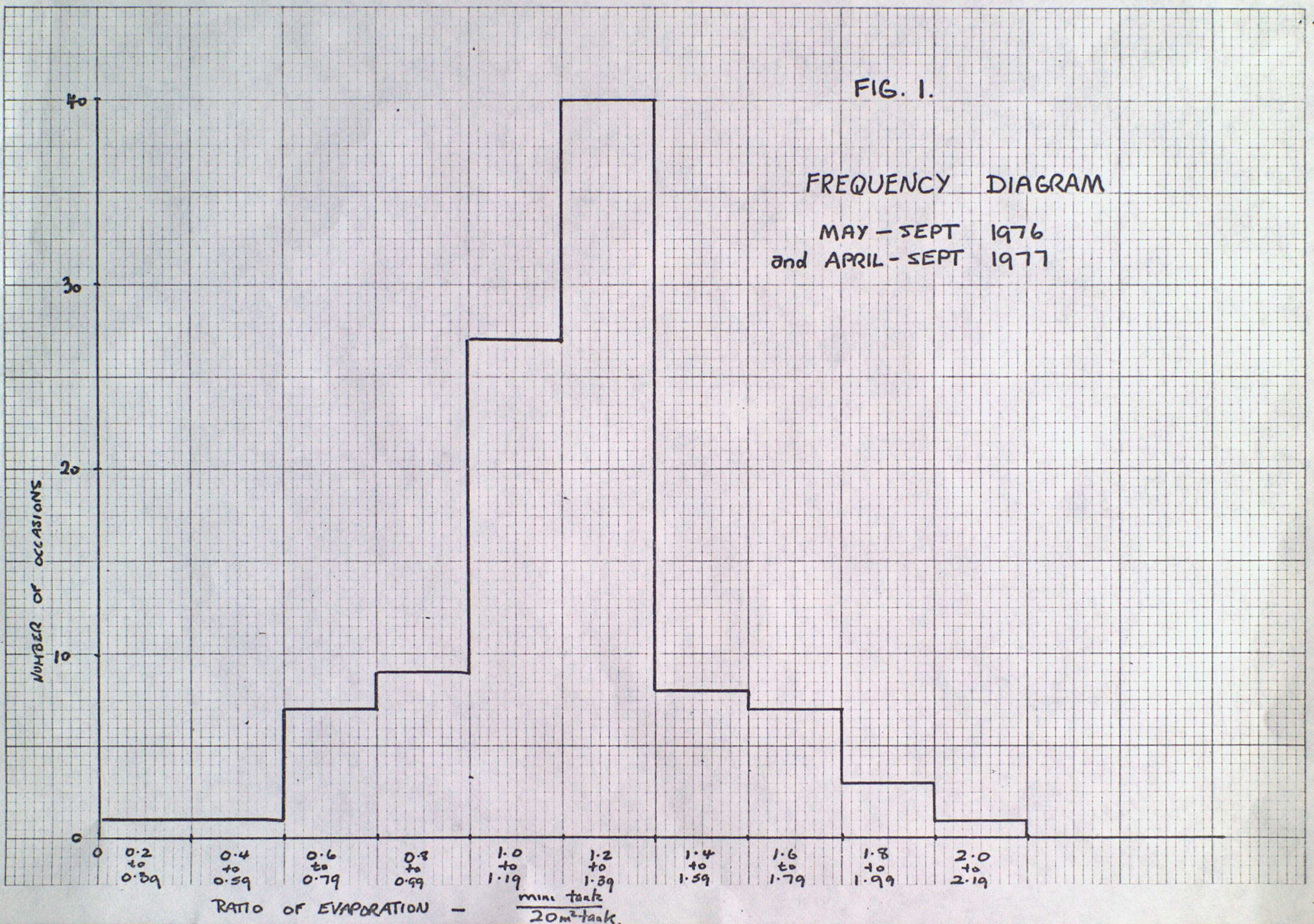
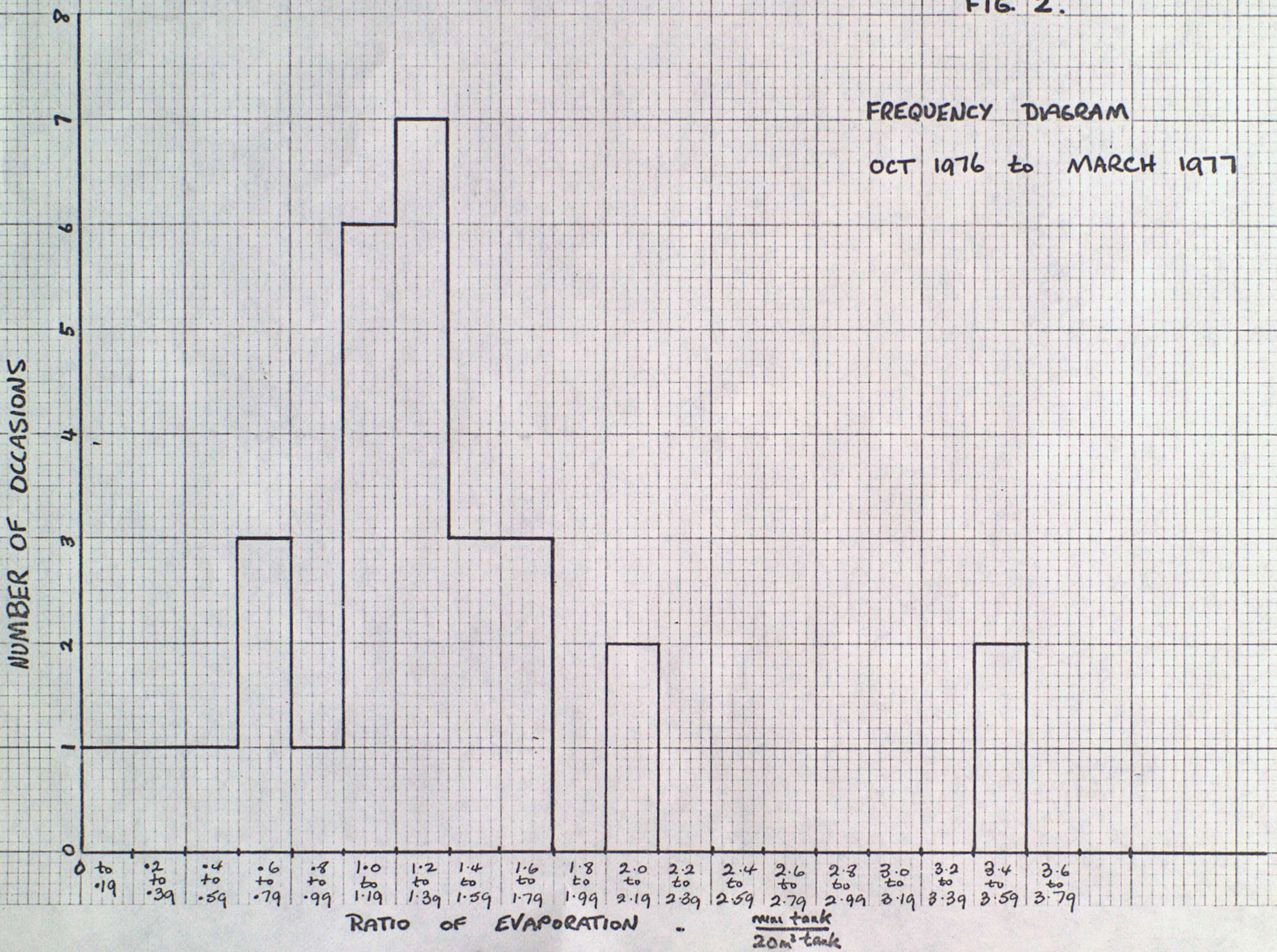


FIG. 1.
FREQUENCY DIAGRAM
MAY – SEPT 1976
and APRIL – SEPT 1977
NUMBER OF OCCASIONS
0
10
20
30
40
0
0.2 to 0.39
0.4 to 0.59
0.6 to 0.79
0.8 to 0.99
1.0 to 1.19
1.2 to 1.39
1.4 to 1.59
1.6 to 1.79
1.8 to 1.99
2.0 to 2.19
RATIO OF EVAPORATION – mini tank / 20m² tank

FIG. 2.

FREQUENCY DIAGRAM

OCT 1976 to MARCH 1977



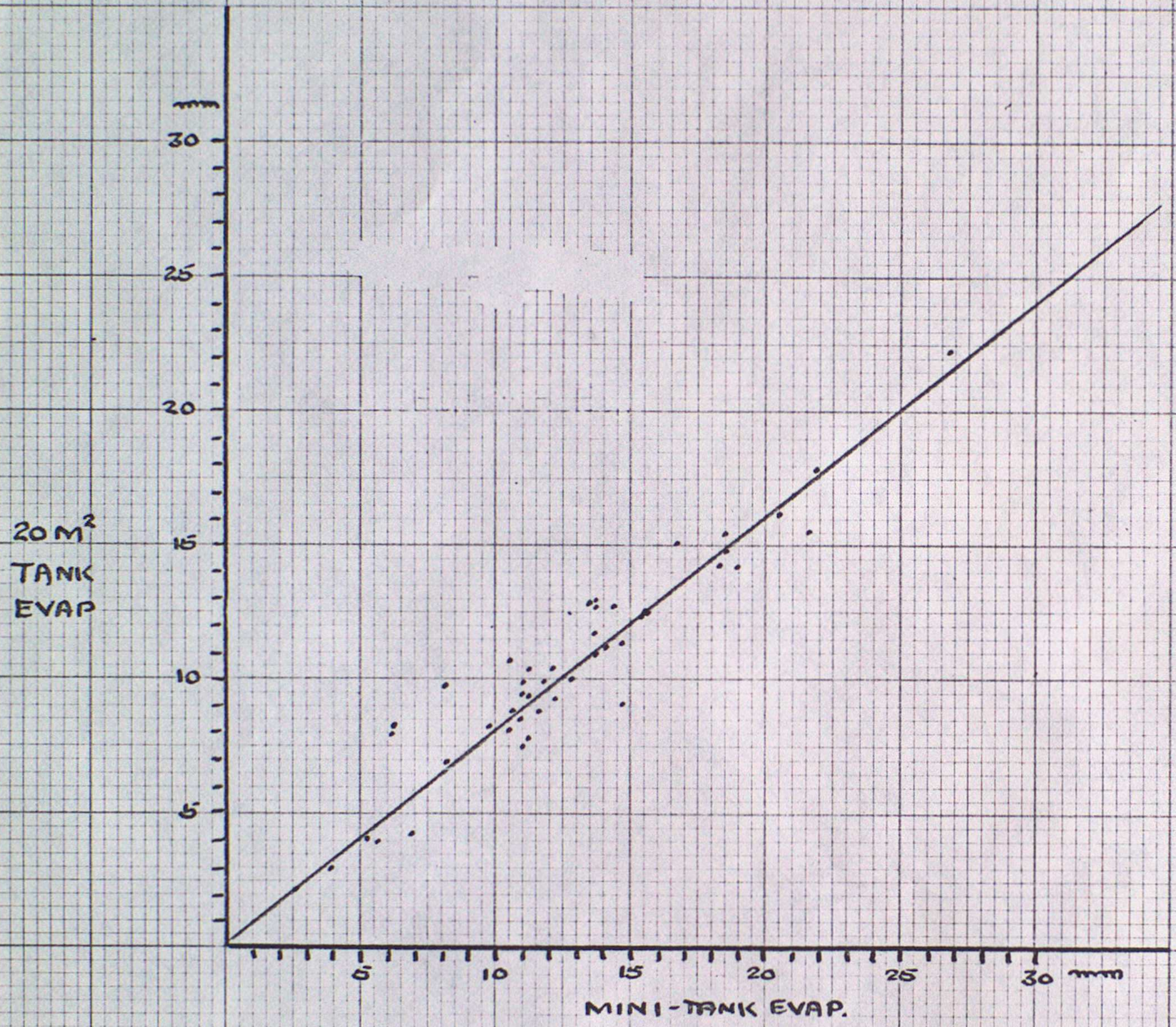


Fig. 3. 20 M^2 vs MINI TANK EVAPORATION 10 May - 30 Sep 1976
3-day totals - KEW OBSERVATORY

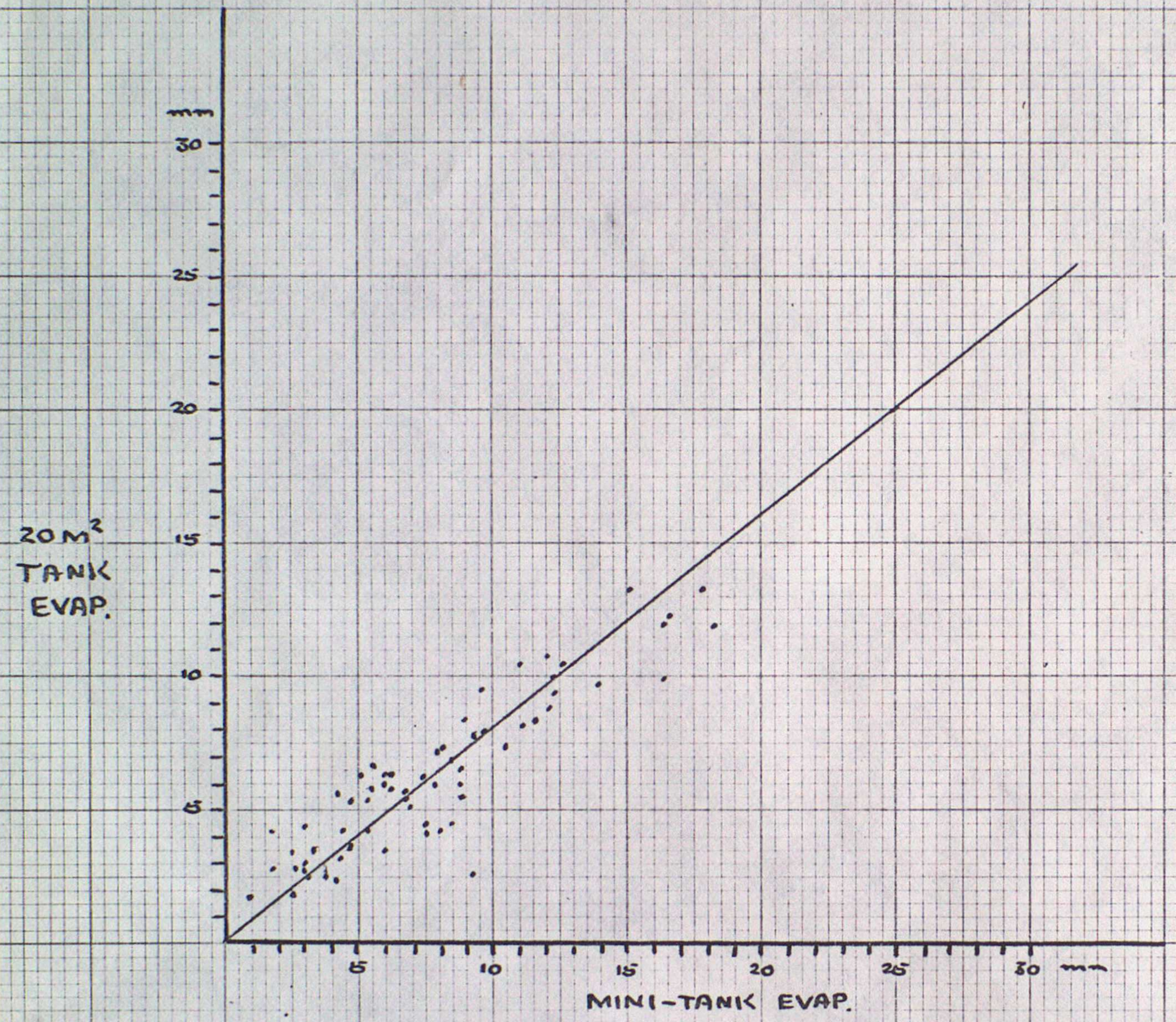
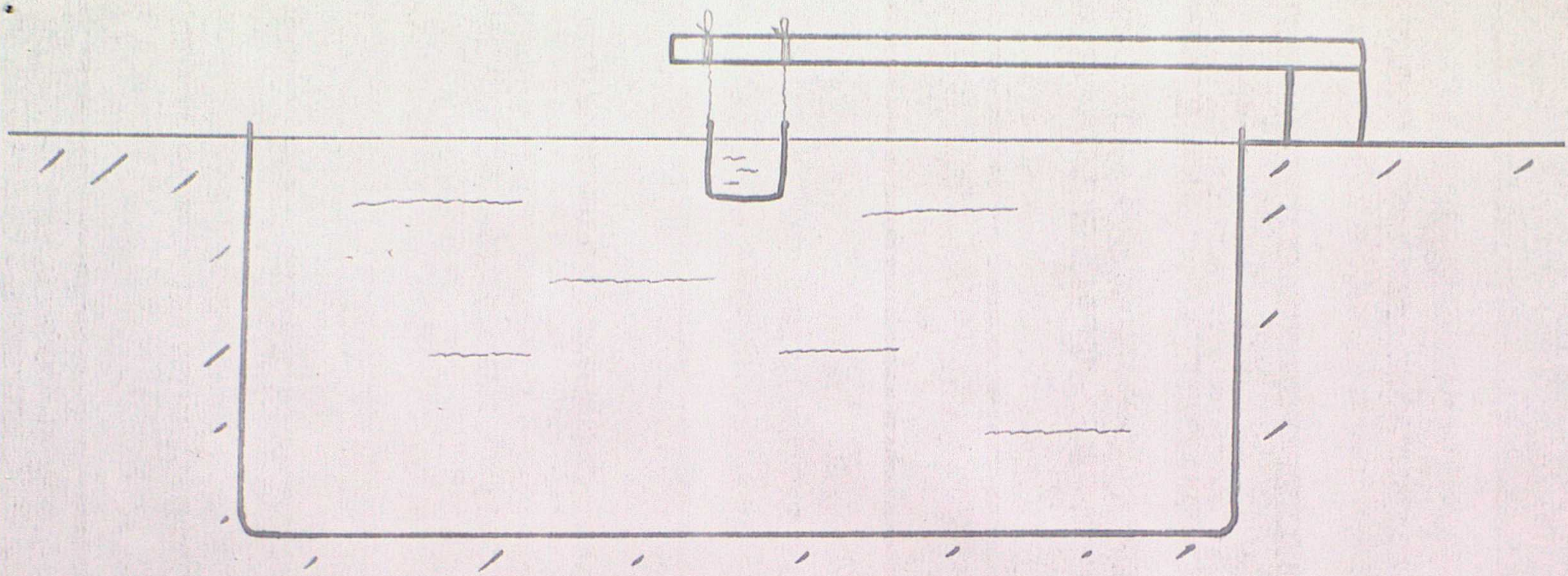


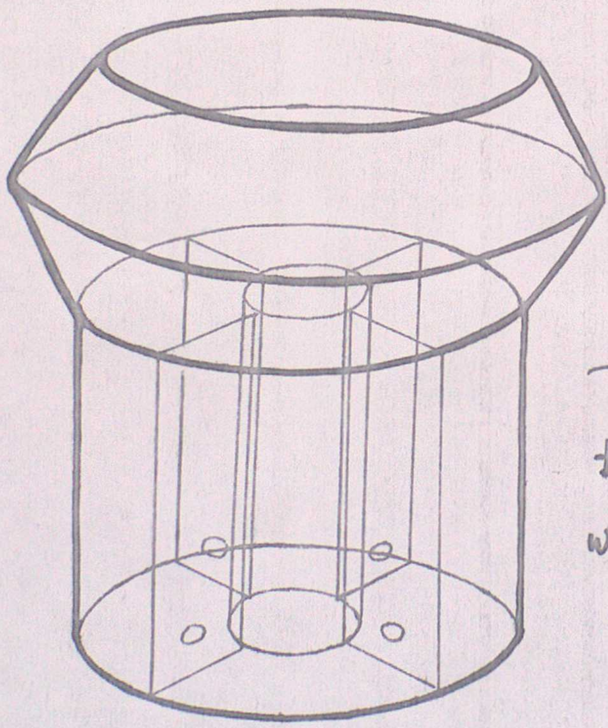
Fig. 4. 20 M² vs MINI TANK EVAPORATION 1 APR – 30 SEP 1977
3-day totals – KEW OBSERVATORY

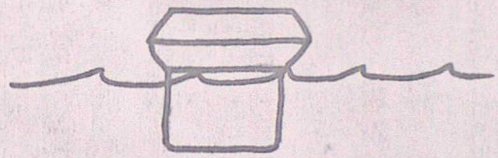
FIG. 5

MINI TANK AND $20 m^2$ TANK AS USED IN THE EXPERIMENT



Suggested Improved Mini Tank with interior spoilers and splash guard.





Preferably supported by floating buoys and with exterior wave spoilers.