REPORT ON COLLABORATIVE PROJECT
WITH THE BRITISH WATERWAYS BOARD
ON THE EFFECTS OF AFFORESTATION
ON THE RUNOFF FROM THE CATCHMENTS
SUPPLYING THE
CRINAN CANAL RESERVOIRS

CONTENTS

(2) FOREST INTERCEPTION MEASUREMENTS

Cumulative values of gross rainfall from the Loch An Add ground level gauge and net rainfall from the two plastic sheet gauges are shown in Figure 2.

For periods in which data were lost from one sheet only the data from the other were directly substituted (periods 1.4.79-20.4.79 and 1.7.79-31.7.79 see Figure 2).

However, for two months during the winter of 1978-1979 data were lost through icing of both net rainfall gauges and net rainfall had to be estimated by assuming an appropriate value of the interception ratio (where the interception ratio is defined by :
(Rainfall-Net rainfall)/Rainfall.

The value chosen was 33% and these estimates are shown as a dotted line for this period in Figure. 2.

The monthly and annual totals (excluding snow periods) of rainfall, and net rainfall recorded by the two sheets are shown in Table 1 together with the interception ratios.

(1) INTRODUCTION

Recent research has shown that in the high rainfall upland areas of the UK, evaporation losses from forest are higher than those from shorter vegetation. The primary cause of the increased evaporation is the much enhanced evaporation rates from forests during and following precipitation (an "interception" loss).

The objective of the present study is to determine the increase in evaporation loss that will result from the afforestation that is now taking place on the catchments of the Crinan Canal Reservoirs.
The study, initiated in November 1978 has so far been concerned with:

(1) Measuring and modelling the interception loss from mature forest at an experimental site located on the western bank of Loch An Add (see Fig. 1);

(2) measuring soil moisture deficits beneath forest and heath vegetation to determine the transpiration from these crops (The location of neutron probe access tubes are also shown in Fig. 1), and mor e recently, since June 1980, with:

(3) an experiment to measure the interception characteristics of intermediate height heath vegetation using a "wet-surface" lysimeter system.

Table 1

Period:November 1978 - November 1979

	Rainfall	Net Rainfall		Interception Ratio	
		Sheet 1	Sheet 2	Sheet 1	Sheet2
10.11.78-30.11.78	197.3	128.21	132.97	0.350	0.326
1.12.78-28.12.78	145.8	84.74	89.16	0.419	0.388
29.12.78-26. 1.79	Snow Period				
27. 1.79-22. 2.79	Snow Period				
23. 2.79-29. 3.79	197.6	126.55	124.25	0.359	0.371
30. 3.79-26. 4.79	88.8	46.79	49.41	0.473	0.444
27. 4.79-31. 5.79	107.6	57.87	60.34	0.462	0.439
1. 6.79-28. 6.79	63.3	32.14	34.37	0.492	0.457
29. 6.79-26. 7.79	129.5	82.87	90.74	0.360	0.299
27. 6.79-23. 8.79	158.5	99.53	105.74	0.372	0.333
24. 8.79-27. 9.79	195.9	113.6	118.01	0.420	0.398
28. 9.79-10.11.79	324.6	206.51	218.31	0.364	0.327
Annual	1631.4	978.81	1022.76	0.400	0.373

Period: November 1979 - November 1980

	Rainfall	Net Rainfall		Interception Ratio	
		Sheet 1	Sheet 2	Sheet 1	Sheet 2
11.11.79-29.11.79	179.3	111.01	118.43	0.38	0.34
30.11.79- 4. 1.80	256.5	135.74	157.37	0.47	0.38
5. 1.80-31. 1.80	65.0	26.11	29.18	0.59	0.55
1. 2.80-28. 2.80	126.0	60.97	73.20	0.51	0.41
29. 2.80-27. 3.80	83.4	53.72	57.51	0.35	0.31
28. 3.80-24. 4.80	27.5	9.13	8.59	0.66	0.68
25. 4.80-29. 5.80	33.9	23.32	24.92	0.31	0.26
30. 5.80-26. 6.80	164.3	89.46	106.30	0.45	0.35
27. 6.80-31. 7.80	180.7	98.01	103.31	0.46	0.43
1. 8.80-28. 8.80	120.5	67.06	71.78	0.44	0.40
29. 8.80-25. 9.80	283.5	177.87	190.06	0.37	0.33
26. 9.80-30.10.80	309.5	186.74	208.09	0.39	0.33
31.10.80-27.11.80	179.0	107.37	114.66	0.40	0.36
Annual	2009.1	1146.53	1263.40	0.43	0.37

(3) FOREST INTERCEPTION MODELLING

The present interception model is defined by the Penman-Monteith evaporation equation (Monteith 1965):

$$\text{Lambda}*E = \frac{\text{Delta}*Rn + (\text{Rho}*Cp*VPD)/Ra}{\text{Delta} + \text{Gamma}*(1+Rs/Ra)} \qquad (J\ m^{-1}\ s^{-1})$$

where Delta = slope of the saturation vapour pressure curve ($kPa\ ^{o}C^{-1}$)

E = vapour flux ($kg\ m^{-2}\ s^{-1}$)

Gamma = psychrometric constant ($kPa\ ^{o}C^{-1}$)

Lambda = latent heat of vapourisation ($J\ kg^{-1}$)

Ra = aerodynamic resistance ($s\ m^{-1}$)

Rho = density of air ($kg\ m^{-3}$)

Cp = specific heat of air ($J\ kg^{-1}$)

Rn = net radiation ($W\ m^{-2}$)

Rs = surface resistance (assumed zero when the canopy is wet) ($s\ m^{-1}$)

VPD = vapour pressure deficit (kPa)

and by the continuity equation:

$$dC/dT = k(1 - \exp(bC)) - [illegible] \qquad (mm\ min^{-1})$$

where [illegible] = $(1 - p)R - E$ (mm)

and b = drainage parameter (mm^{-1})

C = canopy storage (mm)

E = evaporation rate as estimated by the Penman-Monteith equation $(mm\ min^{-1})$

k = drainage parameter $(mm\ min^{-1})$

p = "free throughfall" fraction (dimensionless)

Q = the rate of precipitation plus evaporation $(mm\ min^{-1})$

= precipitation rate $(mm\ min^{-1})$

The canopy drainage parameters b, k, and p and the aerodynamic parameter Ra, are derived by optimisation techniques using a non-linear least squares algorithm. This algorithm minimises the sum of squares of the differences between the predicted and observed net rainfall profiles on a 5 minute basis. The optimal parameter values determined for the Spruce forest at Crinan during the period 16 August to 24 August 1979 are shown in Table 2. For comparison, the optimal parameter values determined for the Spruce forest at Plynlimon are also shown.

Table 2

Model parameter	(Threshold Plynlimon Model, Calder 1979)	Crinan
Ra	3.5	4.07
p	0.05	0.057
k		$9.56 * 10^{-5}$
b		2.24

(4) HEATH INTERCEPTION MEASUREMENTS

Measurements of the evaporation rates from wet heather and grass have been made using a recently developed wet-surface weighing lysimeter system and constitute the first serious field trial of it.

The system essentially comprises a Pet microcomputer and Sartorius electronic balance (0 to 30 kg) with an accuracy of one gramme. It is powered by a 1.5 kW Honda generator. Meteorological variables are also measured by an automatic weather station. Figure 3 shows the lysimeter and weather station and figure 4 shows the sample after installation of the lysimeter. A cross-sectional diagram of the lysimeter is shown in figure 5.

The Pet and its peripheral devices are housed in a caravan which can be parked up to 100 metres distant from the site of the experiment. Multicore cables connect the computer to the balance which is housed in a purpose built box which protects it from dirt and moisture while allowing it to function normally. When the lysimeter is in operation a pan containing the sample of vegetation together with the top few centimetres of soil rests on top of the box which resides in a lined hole (see Fig. 5). The hole is kept free of standing water by a small battery operated marine (totally immersible) pump and float-switch. The weight of the sample is monitored by the Pet approximately once a second and it also monitors the meteorological variables from the weather station at a frequency determined by the experimenter; a frequency of once a minute was used at Crinan. On-line calculations are performed and the raw data are stored on floppy disks for later analysis.

The experiment was set up at four sites on the catchment (see Fig. 1), each one chosen as being representative of the local area. Samples which were either predominantly heather or grass were used and evaporation rates were

determined while the canopy was wet (and therefore did not represent transpiration rates). Sprayers, both petrol driven and manual pump types, were used on occasions when there was either no rain or not enough to wet the canopy thoroughly. Care was taken when setting up the lysimeter and throughout the experiment to ensure that surrounding vegetation was disturbed as little as possible.

When the canopy is wet the evaporation rate is dependent only upon the net radiation, the temperature, the vapour pressure deficit and the aerodynamic resistance; the aerodynamic resistance is in turn governed by the wind speed, crop type and condition and site characteristics. The evaporation rates were measured at site 1 in June and at the other sites in September. Sites 1 and 4 were on exposed hills with wind speeds higher than the average for all the sites: site 3 was near Loch na Faoilinn. A variety of weather conditions were encountered.

Table 3 summarises the evaporation results. As expected the exposed sites gave higher evaporation rates than the other two and it is also believed that the values obtained from the spray runs may be unrepresentative of natural wet conditions due to high vapour pressure deficits caused by the dryness of the surrounding area. From the non-spray run measurements it is possible to give a mean summer daytime evaporation rate for wet heather of about 0.5 mm an hour for sunny conditions and 0.3 mm an hour for cloudy conditions. The mean rate for wet grass is about 0.11 mm an hour. Winter evaporation rates will be considerably less. Night time evaporation was also measured and found to be less than 0.01 mm an hour for both heather and grass.

Further analysis of the data will yield parameter values which can be used in interception modelling.

Table 3

Crop	Site	Date	Time g.m.t.	Weather	Spray	Mean Windspeed m/s	Evaporation rate mm/hr
Heather	1	21-6	1700	overcast	no	5.7	0.325 +/- .005
	1	22-6	1015	sunny	no	6.3	0.44 +/- .005
	2	23-9	1715	cloudy	no	4.9	0.08 +/- .01
	2	23-9	2200		no	2.1	0.006 +/- .001
	2	24-9	0630		no	2.0	0.36 +/- .001
	2	24-9	0740		no	3.4	0.23 +/- .002
	2	24-9	0905	sunny	no	3.7	0.56 +/- .002
	2	24-9	1050	cloudy	no	4.1	0.39 +/- .003
	2	24-9	1156	bright sun	no	4.3	0.71 +/- .001
	3	25-9	1624	cloudy	yes	3.0	0.38 +/- .001
	3	25-9	1730	cloudy	yes	3.9	0.15 +/- .001
	4	27-9	1320	sunny	yes	6.6	0.85 +/- .005
	4	27-9	1425	sunny	yes	6.5	0.65 +/- .001
	4	27-9	1530	sun/cloud	yes	5.5	0.57 +/- .001
	4	27-9	1630	sun/cloud	yes	4.0	0.19 +/- .001
	4	27-9	1740	sun/cloud	yes	4.2	0.13 +/- .004
	4	28-9	0715	cloudy	no	3.6	0.03 +/- .005
	4	28-9	0855	cloudy	yes	4.4	0.11 +/- .0005
	4	28-9	1100	cloudy	no	3.5	0.47 +/- .001
	4	28-9	1330	sunny	yes	5.3	2.5 +/- .003
Grass	2	24-9	1405	cloud/sun	yes	3.4	0.17 +/- .001
	3	24-9	1700		yes	2.5	0.006 +/- .002
	3	25-9	0800	sun/cloud	no	1.9	0.04 +/- .0001
	3	25-9	0949	sun/cloud	no	2.5	0.19 +/- .0003
	3	25-9	1140	sunny	yes	3.1	0.33 +/- .001
	4	28-9	1730		yes	2.0	0.005 +/- .002

(5) SOIL MOISTURE MEASUREMENTS

The object of the soil moisture observations on the Crinan catchments was to estimate the losses due to transpiration by monitoring the development of soil moisture deficits (SMD) under different vegetation types. This method has the disadvantage that when the soil is beneath field capacity the residual drainage (both vertical and lateral) is ignored. This residual drainage has been found to be appreciable in situations with deep water tables but is expected to be small in the soils found at Crinan which overlie impermeable bedrock and generally have shallow water tables.

The soil moisture observations were made using a neutron probe developed at the Institute of Hydrology. The details of the sites of the access tubes are shown in table 4. The first group of sites were set up in July/August 1979 and the second in May 1980 when it became evident that large SMDs were developing.

Table 4

Date installed	Grid ref.	Tube depths	Vegetation	Soil type	Tube no.
31 - 7 - 79	NR 796879	1.20m - 2.25m	sitka spruce	brown earth	04-07
31 - 7 - 79	NR 801878	all 2.50m	myrtle	peat	01-03
1 - 8 - 79	NR 802878	1.00m - 1.35m	myrtle/ heather	brown earth	11-13
1 - 8 - 79	NR 818901	1.60m - 2.25m	bracken	brown earth	
20 - 5 - 80	NR 817885	1.0m - 1.2m	heather	peat	26-31
20 - 5 - 80	NR 819887	1.75m - 2.25m	heather	peat	20-25

The analysis used below follows broadly the methods outlined in detail in Calder et al (1981). Model estimates of the SMD are made using a daily soil moisture balance:

for day i

$$SMD_i = SMD_{i-1} + \text{evaporation estimate} - \text{rainfall}$$

$$SMD_i < 0, \; SMD_i = 0.$$

The evaporation estimate is generally a potential evaporation, sometimes reduced using a soil moisture depletion model.

To calculate the observed SMD a field capacity value at each tube is required, this was found by optimisation using a simple SMD model (the optimisation uses only periods when the SMD is small (< 30 mm)). This procedure provides an objective method of determining the field capacities. For this optimisation it was assumed that the evaporation is always equal to the Penman potential. It has

been shown that the optimised values are essentially independent of the evaporation sub-model used. For these field capacity optimisations and for the subsequent model runs it was necessary to construct estimates of the daily potential evaporation from daily meteorological observations of temperature, humidity, sunshine, rainfall and wind speed. These quantities were estimated from the local climatological stations: Knapdale, Machrihanish, Dunstaffnage and Kildonan. The data from the automatic weather stations were used to check that these values were representative of the Crinan catchments. The various estimates the potential evaporation used in Calder et al (1981) were calculated for Crinan (Fig. 10), of these most use was made of Penman Et, this is the standard 1948 form using an albedo of 0.25.

Figures 6 to 9 show the predictions of one of the simpler models, using the Penman Et as the evaporation estimate. It is evident that the only appreciable SMDs (observed or predicted) occured in the dry period in April and May 1980. It is these data that provide the most useful information. In the rainless period (days 100-140) the development of the SMD beneath the forest is predicted to within 5 mm by the use of the Penman potential evaporation and no soil moisture depletion model, a maximum SMD of 100 mm is reached. In the subsequent wetting up period (days 140-200) the soil did not wet up as fast as the model predicted; this suggests a loss of rainfall which could be accounted for by the interception losses from the forest. Figure 11 shows how the model fit is improved by including a simple interception ratio (the model used is similar to Calder and Newson, 1979); considering the limited data and the uncertainties within the model the agreement is very good.

The SMDs observed at the myrtle and heather sites, unlike the forest, did not develop at the potential rate, possible explanations for this anomally are that:

1/ heather and myrtl. exert a strong stomatal control,

2/ the new season leaves may not have fully developed at this time of year,

3/ there is a significant lateral inflow of soil moisture.

Explanation 3 is possible for the heather and myrtle site, which is a peat site at the bottom of a local valley, but is unlikely at the other heather sites. It must be concluded that at this time of year the transpiration from heather is much less than from spruce.

The results described above are based on only one dry period, and the observations at two of the sites were only started halfway through this period. It is suggested that the soil moisture observations are continued for the summer and autumn of 1981 at least. The access to the upper heather site is now considerably more difficult and it is proposed that this be dismantled and a new site established within bracken. The heather and myrtle site was ploughed and planted with spruce a few years before the installation of the tubes; in 1979 these trees were small relative to the myrtle but they are now of similar size; it would be of interest to monitor the changes of SMD as the trees develop further.

(6) CLIMATOLOGY

The monthly averages of the meteorological variables from one of the automatic weather stations above the forest canopy (Mull 1) are presented in table 5 for 1980. The figures confirm the picture of the climate described in the earlier report (a very low vapour pressure deficit, a relatively low summer temperature and moderate wind speeds). A comparison was made with the observations from the nearest standard climatological station, Knapdale, a station by the canal at Cairnbarn, this comparison showed:

1/ the estimate of wind speed and vapour pressure deficit are very similar to those measured on the catchments,

2/ the monthly rainfall totals are within a few mms of those measured at Loch An Add, the only major deviation occuring in Febuary 1979 when there was appreciable snowfall, the Loch An Add measurement in this period is probably an underestimate,

3/ the solar and net radiations are badly estimated from the Machrihanish sunshine observations (there are no such observations from Knapdale), this is not surprising considering the separation of the stations and the uncertainties in the equations used.

Figure 12 shows the year by year changes in the maximum soil moisture deficit reached in each year, as calculated by the Meteorological Office grassland SMD model. It shows that in the middle to late 70s there has been a run of years in which large SMDs have developed. These are a result of dry periods of one or two months in the summer or autumn; clearly this slightly anomalous climatic fluctuation has put additional strains on the water resources of the region. It is interesting to note that this climatic change is not evident in the annual rainfall figures, it being the seasonal distribution of rainfall which has been

affected.

Table 5

1980	Jan	Feb	March	April	May	June	July	Aug
solar radiation (MJ m^{-2} day^{-1})	1.8	2.7	6.1	11.4*	19.1	13.6	14.3	
net radiation (MJ m^{-2} day^{-1})	-0.1	1.4	3.2	6.3*	12.6	8.3	8.8	
VPD (mb)	0.68	0.82*	0.75		3.75	1.55	1.69	1.34
temperature	3.4	3.1*	3.0		11.5	12.1	13.1	13.0
wind speed (m sec^{-1})	2.7	3.1*	3.0		2.8	2.6	2.5	2.9
Penman P E (mm day^{-1})	0.3	0.6*	0.9	2.0	4.2	2.5	2.7	2.4

(* = less than 25 days of observations)

(7) EXTRA EVAPORATION LOSS RESULTING FROM AFFORESTATION

An estimate of the extra evaporation loss resulting from afforestation of the Crinan Canal reservoirs may be calculated using the evaporation model proposed by Calder and Newson 1979.

The model is defined by the equation:

$$\text{extra loss} = f(P * \text{alpha} - w * Et)$$

where,

f = fraction of catchment with complete canopy coverage;
P = annual precipitation (mm);
alpha = interception fraction, i.e., the fraction of annual precipitation lost to interception;
w = fraction of year when the canopy is wet: and
Et = Penman's Et estimate.

Estimates of these parameter values for the Crinan Canal catchments are given below:

Total area of catchment = 527 ha (100%)

Area of catchments excluding reservoirs (see Fig. 1) = 428 ha or 81%

Area of land proposed for forestry = 70% of land area (information supplied by F.C.) = 300 ha or 57%

Projected area of land under complete canopy coverage, i.e., area under forestry minus area of roads and rides

= 264 hectares or 50% of catchment area.

Therefore $f = 0.5$

and also $P = 1660$ mm

Alpha = 0.4

$w = 0.2$

$Et = 410$ mm

Therefore projected extra evaporation loss per annum $= 0.5 * (1660 * 0.4 - 0.2 * 410)$

= 291 mm

= 340 million gallons

(8) CONCLUSIONS

(1) The results have confirmed the importance of the role of interception in the annual evaporation from forest at Crinan; 715 mm interception in 1989 mm rainfall during 1979 and 804 mm interception in 2009 mm rainfall during 1980.

(2) The forest interception results are in good agreement with other results obtained in the UK (Fig. 13).

(3) Preliminary results suggest that interception losses from heather are significantly higher than those from grass and may even approach those from forests; typical summer daytime evaporation rates from wet forest, heather and grass are 1.25, 0.4, and 0.1 mm an hour respectively. Annual losses from heather may not, however, be dissimilar as there is also evidence to suggest that transpiration rates from heather may be lower than from grass.

(4) Further research is required to determine in greater detail the evaporation characteristics of this medium height upland vegetation.

(5) Until further results on this research topic are available we believe the most reasonable estimate of evaporation loss from upland heath vegetation is provided by Penmans' Et. With this assumption, and by making use of the Calder and Newson model, the projected extra annual loss from the Crinan Canal catchments as a result of afforestation is 291mm which is equivalent to 340 million gallons.

(9) REFERENCES

Calder I. R., Harding R. J. and P. T. W. Rosier, 1981: The prediction of soil moisture deficit: what are the controlling factors? Submitted to J. of Hydro.

Calder I. R. and Newson M.D., 1979: Land-use and upland water resources in Britain. Water Res. Bull., 15, 1628-1639.

Monteith J. L., 1965: Evaporation and environment. In: The state and movement of water in living organisms. Symp. Soc. Exptl. Biol., 19, 205-234.

CAPTIONS

Fig. 1 Map of the Crinan catchment area, showing experimental sites.

Fig. 2 Cumulative values of rainfall and net rainfall measured beneath the forest canopy, for 1979 and 1980.

Fig. 3 Photographs of wet-surface weighing lysimeter and automatic weather station.

Fig. 4 Photograph of vegetation sample in place on lysimeter.

Fig. 5 Schematic diagram of wet-surface weighing lysimeter.

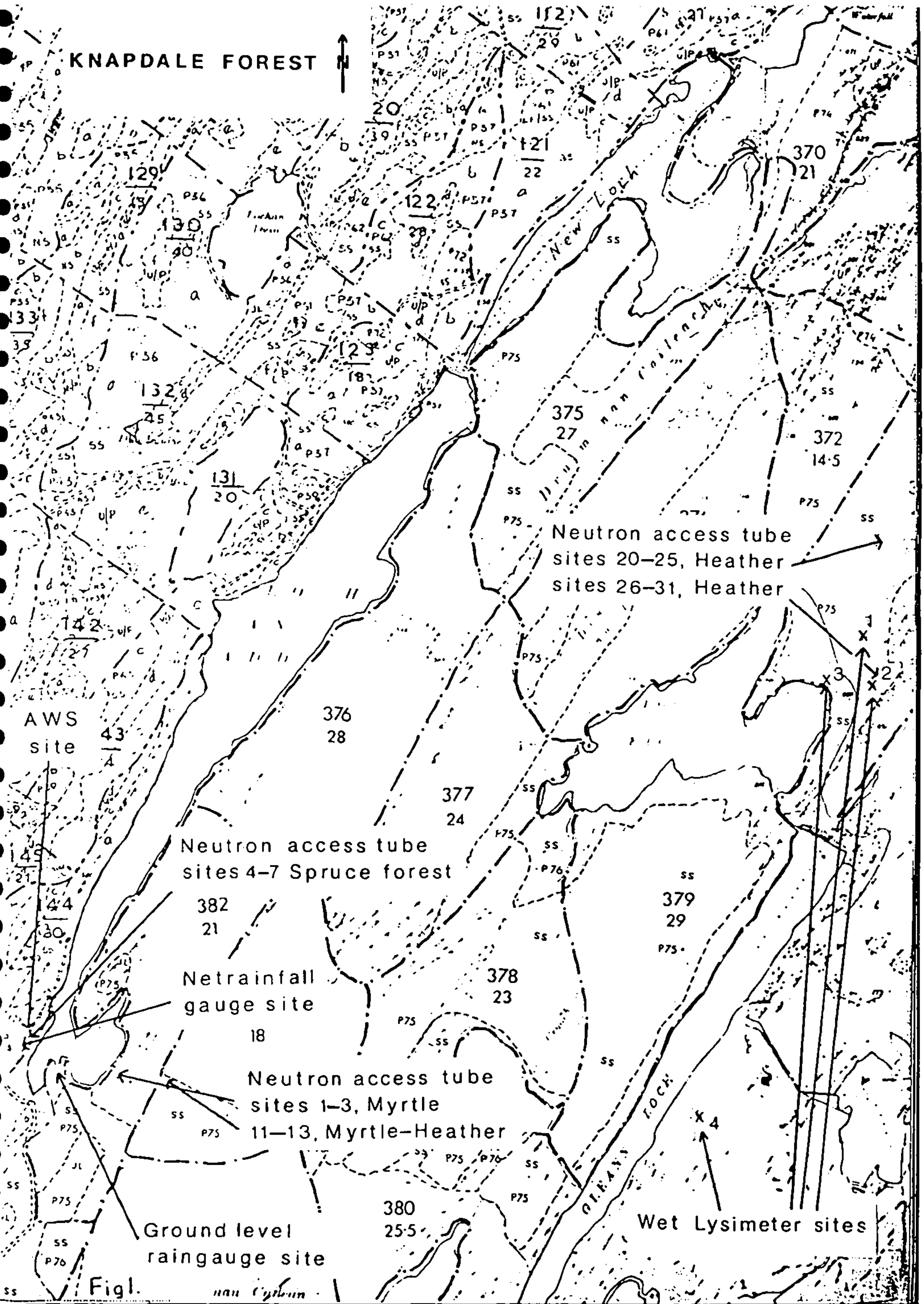
Figs. 6 - 9 Soil moisture observations and simple model predictions for four of the sites.

Fig. 10 Daily estimates of potential evaporation for the Crinan catchments.

Fig. 11 Observed and predicted SMDs with simple interception model.

Fig. 12 Historical rainfall and maximum SMD reached in each year.

Fig. 13 Cumulative interception ratios as a function of annual precipitation measured for forests in the UK.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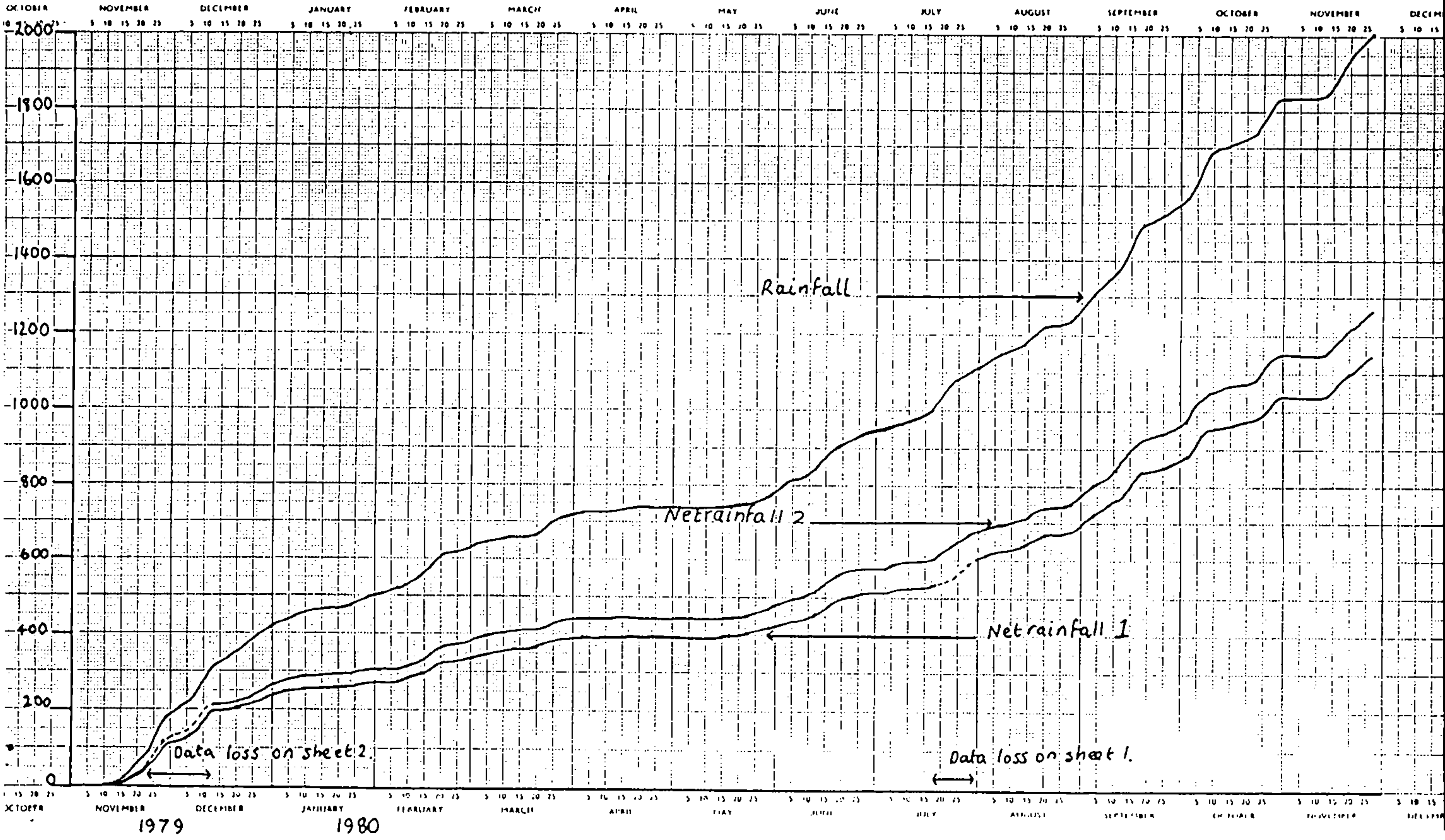
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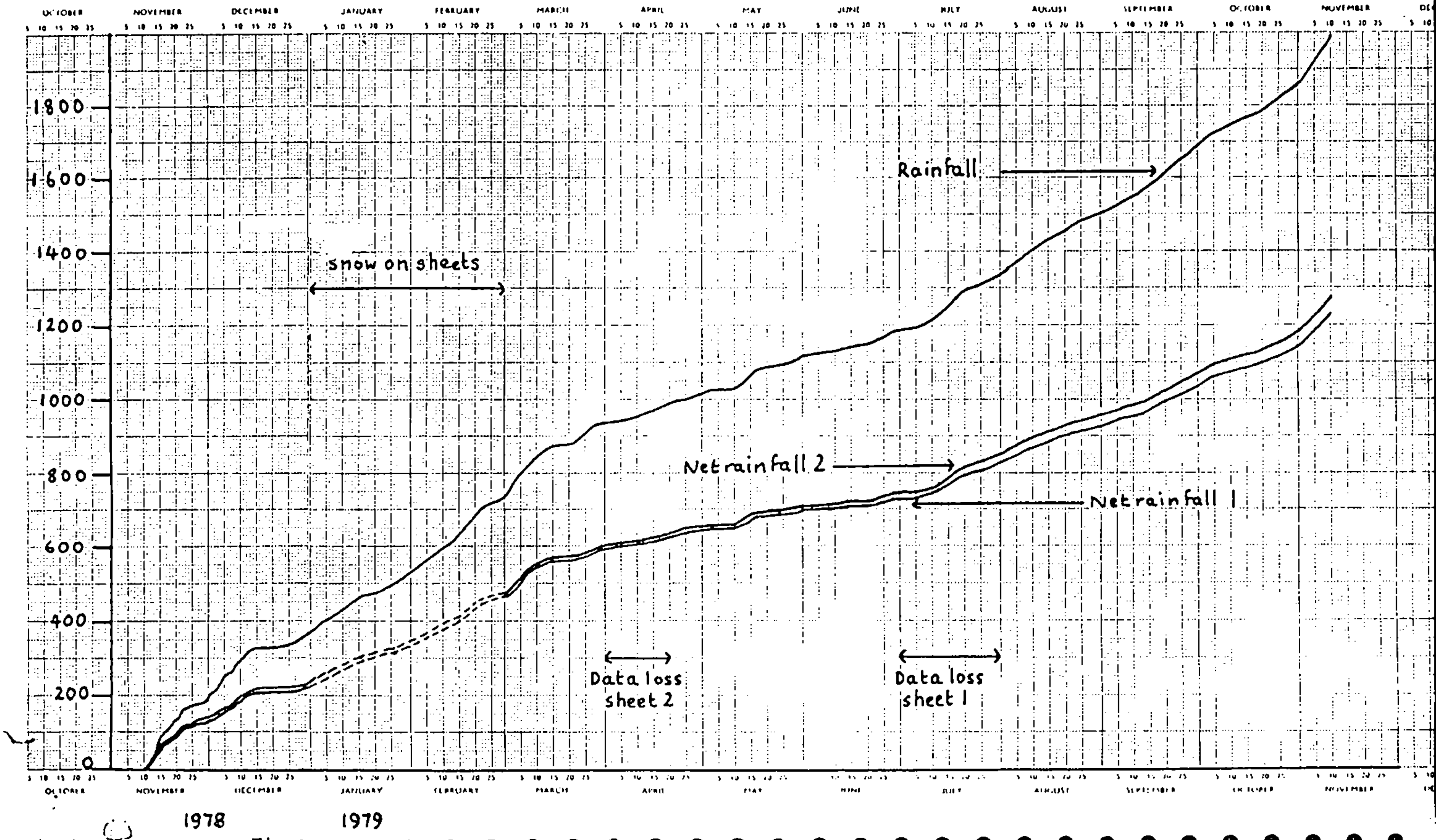
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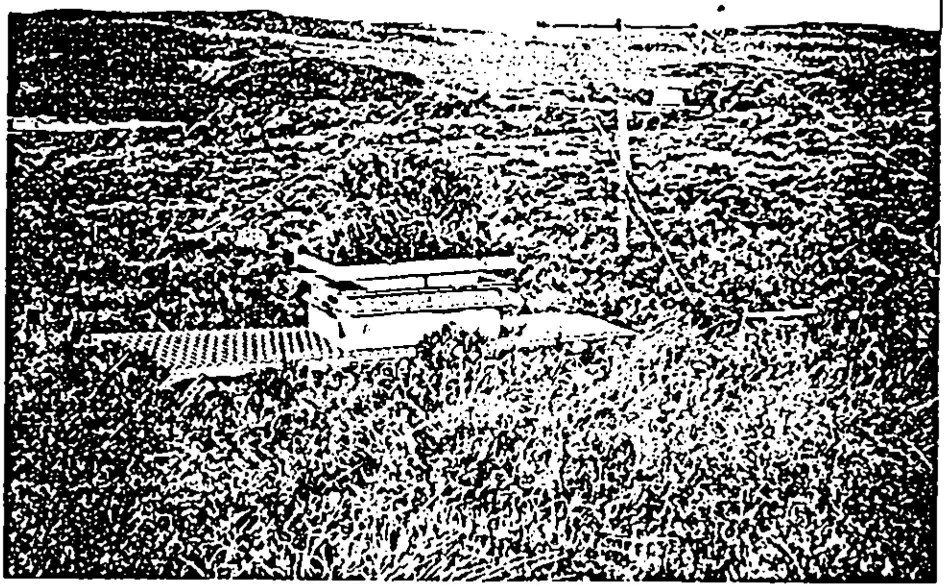


Fig 3

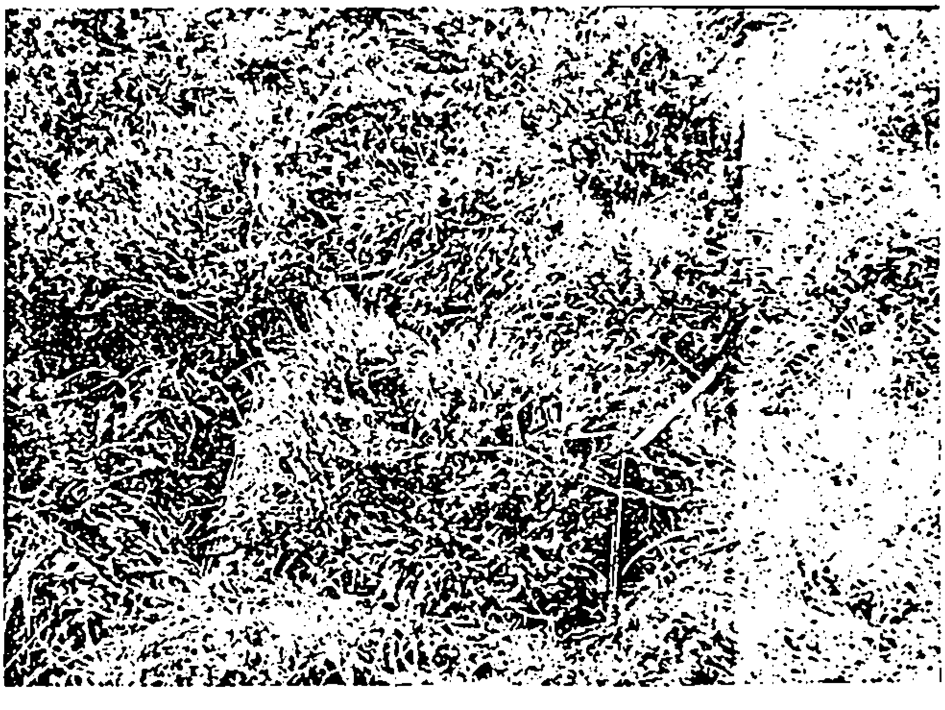
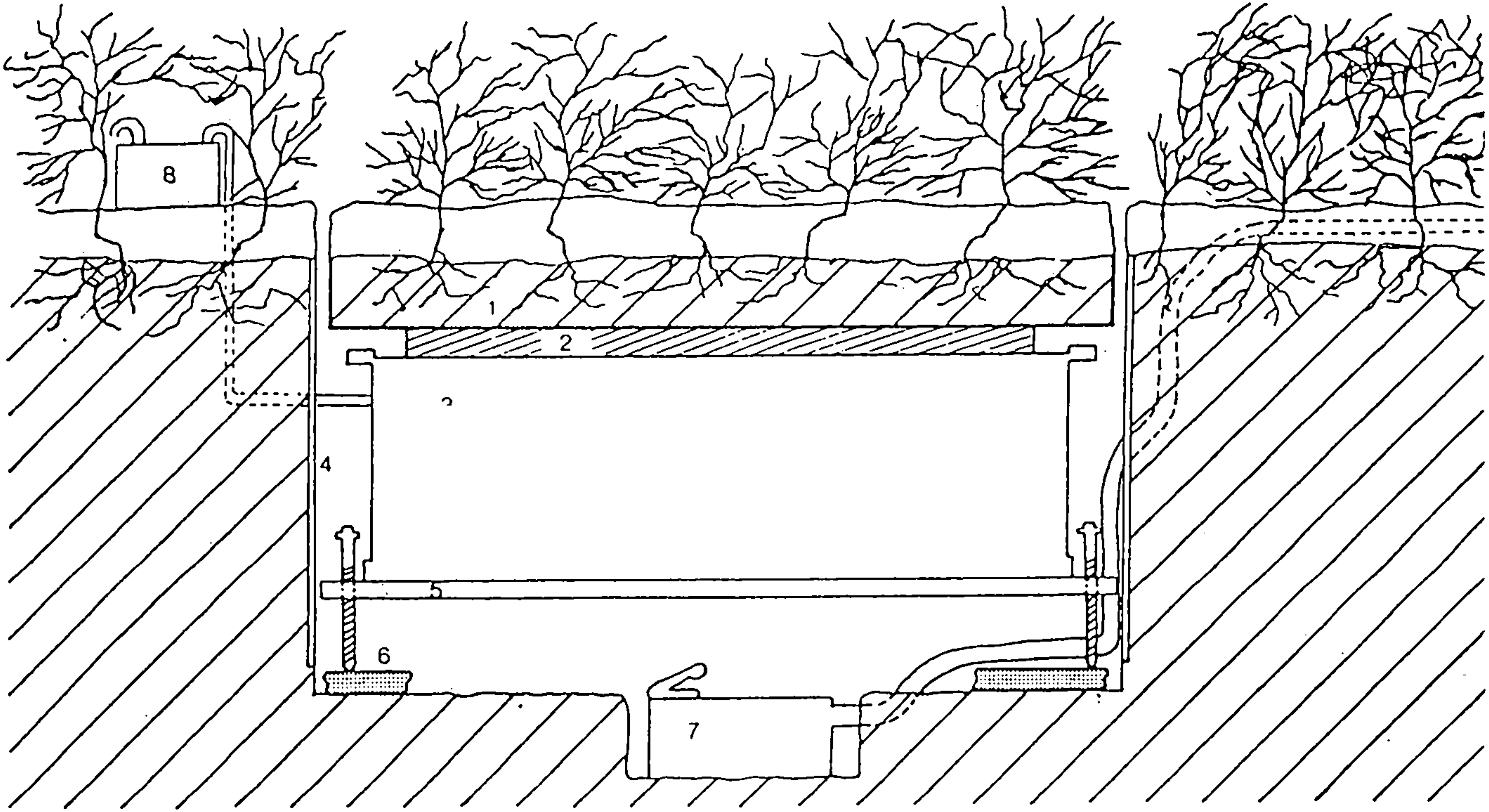
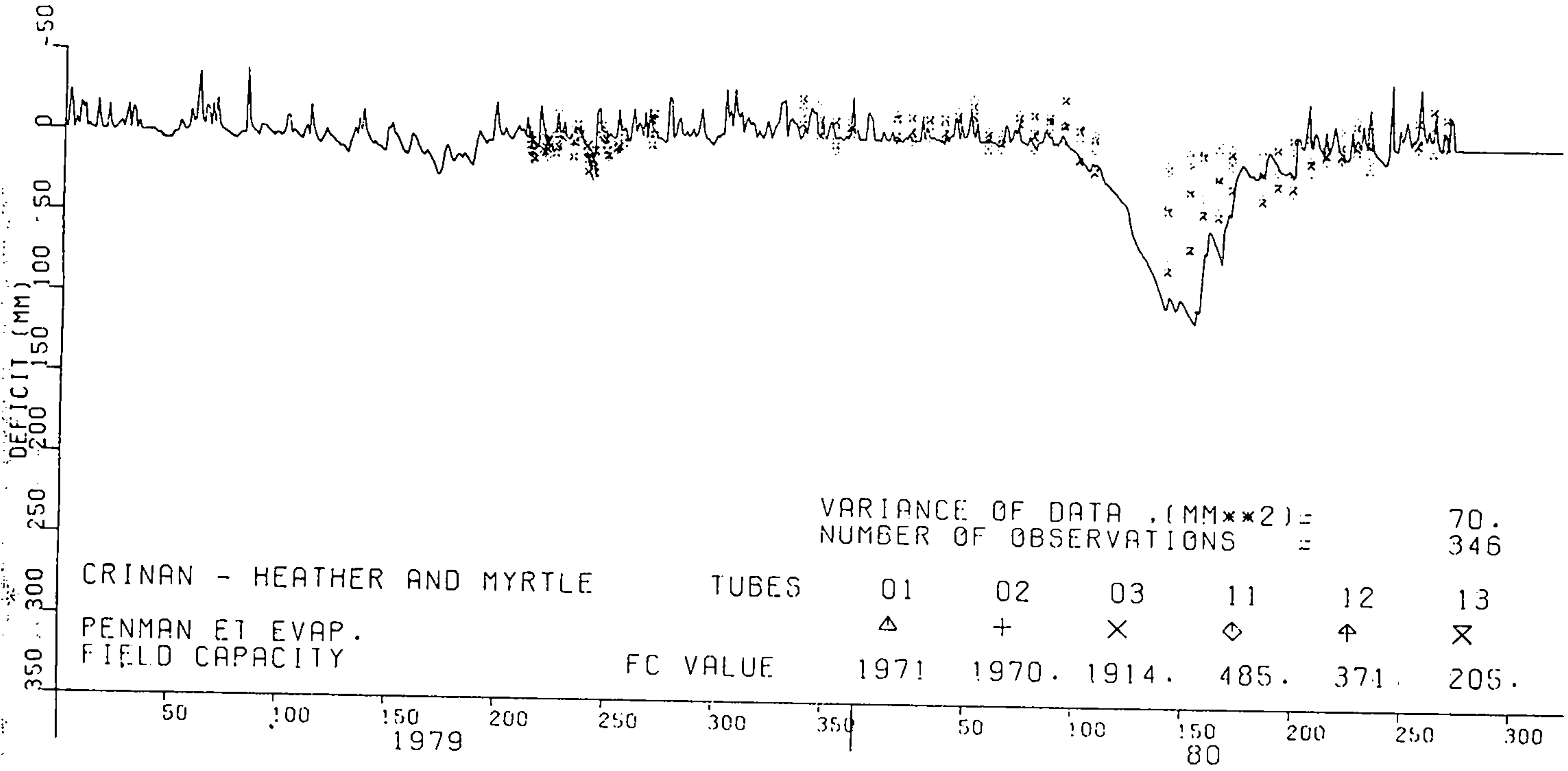


Fig 4

1. Tray containing specimen
2. Polystyrene spacer block
3. Box containing electronic balance
4. Aluminium hole liner
5. Levelling tray
6. Concrete blocks
7. Pump and switch
8. Breather

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NUMBER OF OBSERVATIONS = 346
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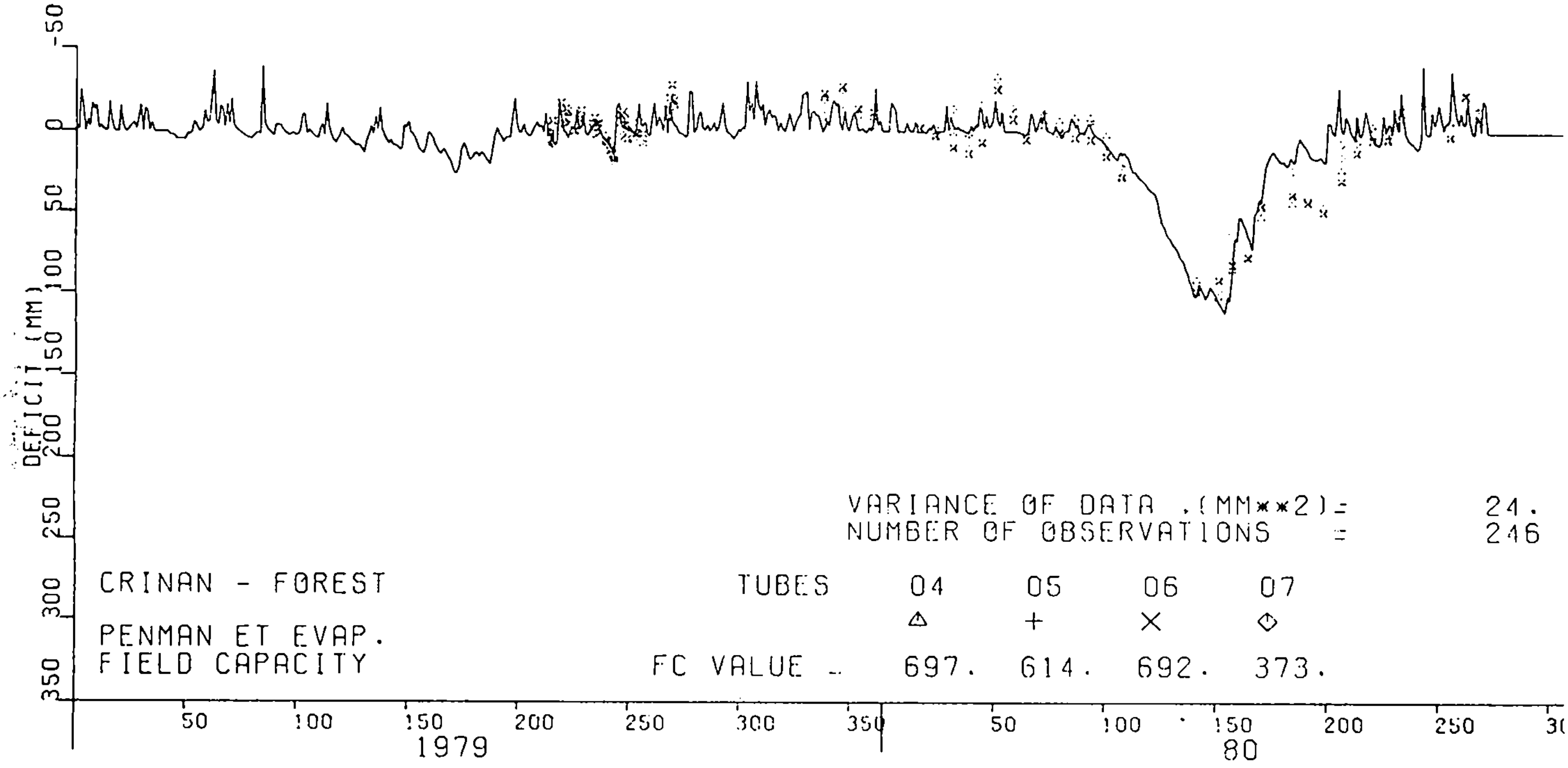
Fig 6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200
250
300
350
VARIANCE OF DATA .(MM**2)= 24.
NUMBER OF OBSERVATIONS = 246
CRINAN - FOREST
TUBES 04 05 06 07
△ + × ◇
PENMAN ET EVAP.
FIELD CAPACITY
FC VALUE - 697. 614. 692. 373.
50
100
150
200
250
300
350
1979
50
100
150
200
250
80

Fig 7

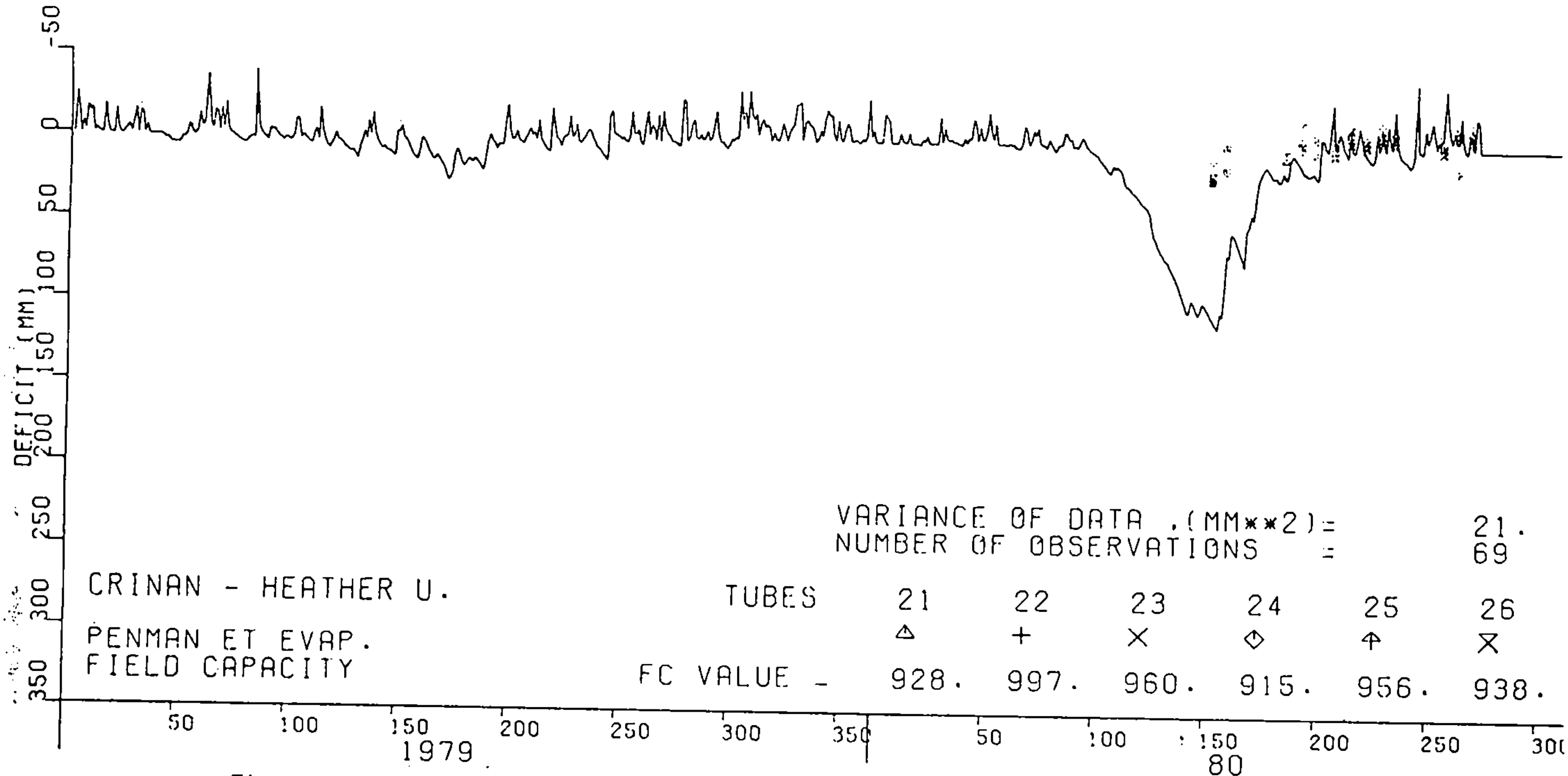

-50
0
50
100
150
200
250
300
350
DEFICIT (MM)
50
100
150
200
250
300
350
1979
50
100
150
200
250
30(
80
CRINAN - HEATHER U.
PENMAN ET EVAP.
FIELD CAPACITY
VARIANCE OF DATA .(MM**2)= 21.
NUMBER OF OBSERVATIONS = 69
TUBES 21 22 23 24 25 26
△ + × ◇ ↑ ⧖
FC VALUE - 928. 997. 960. 915. 956. 938.

Fig 8

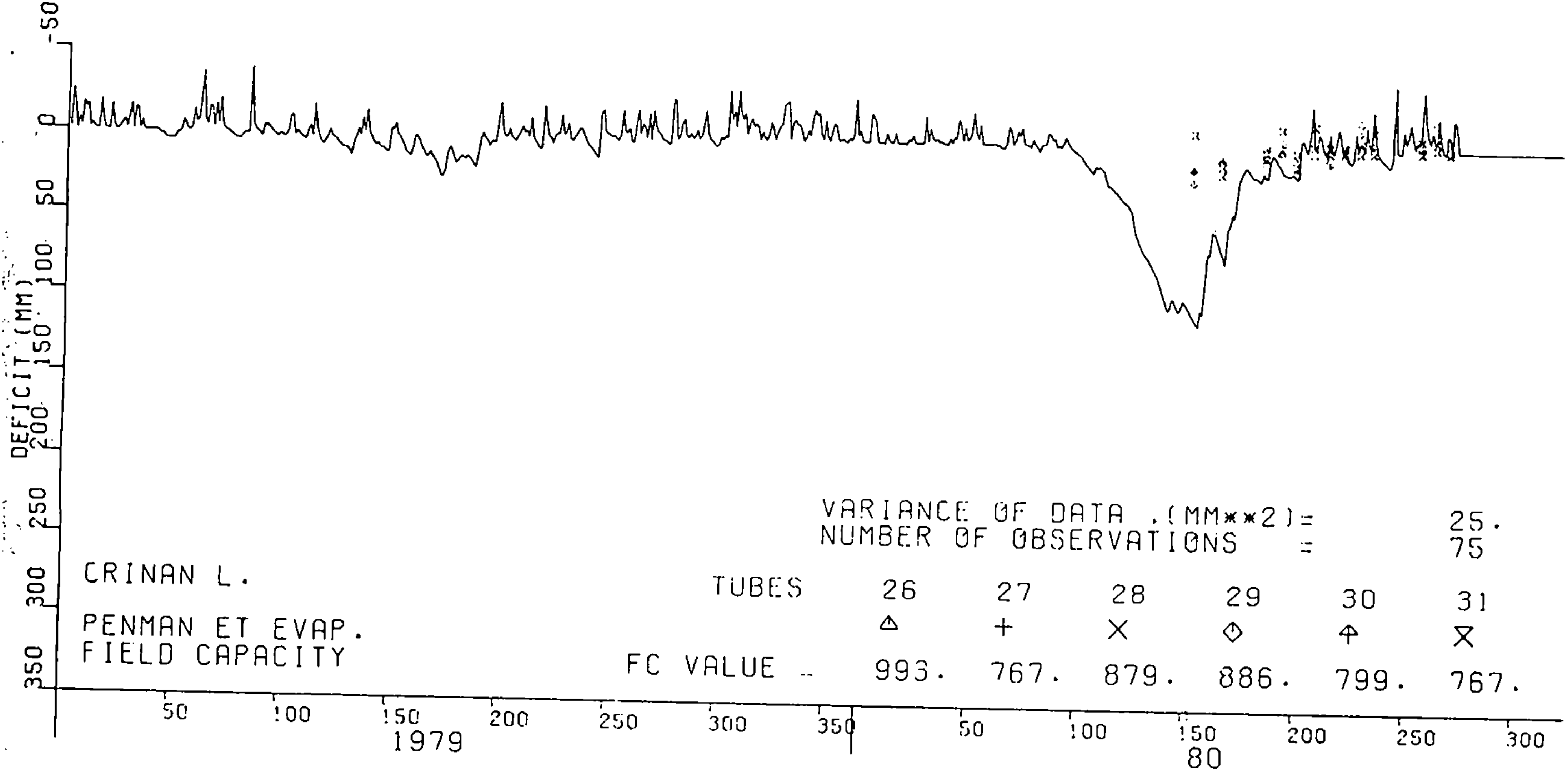
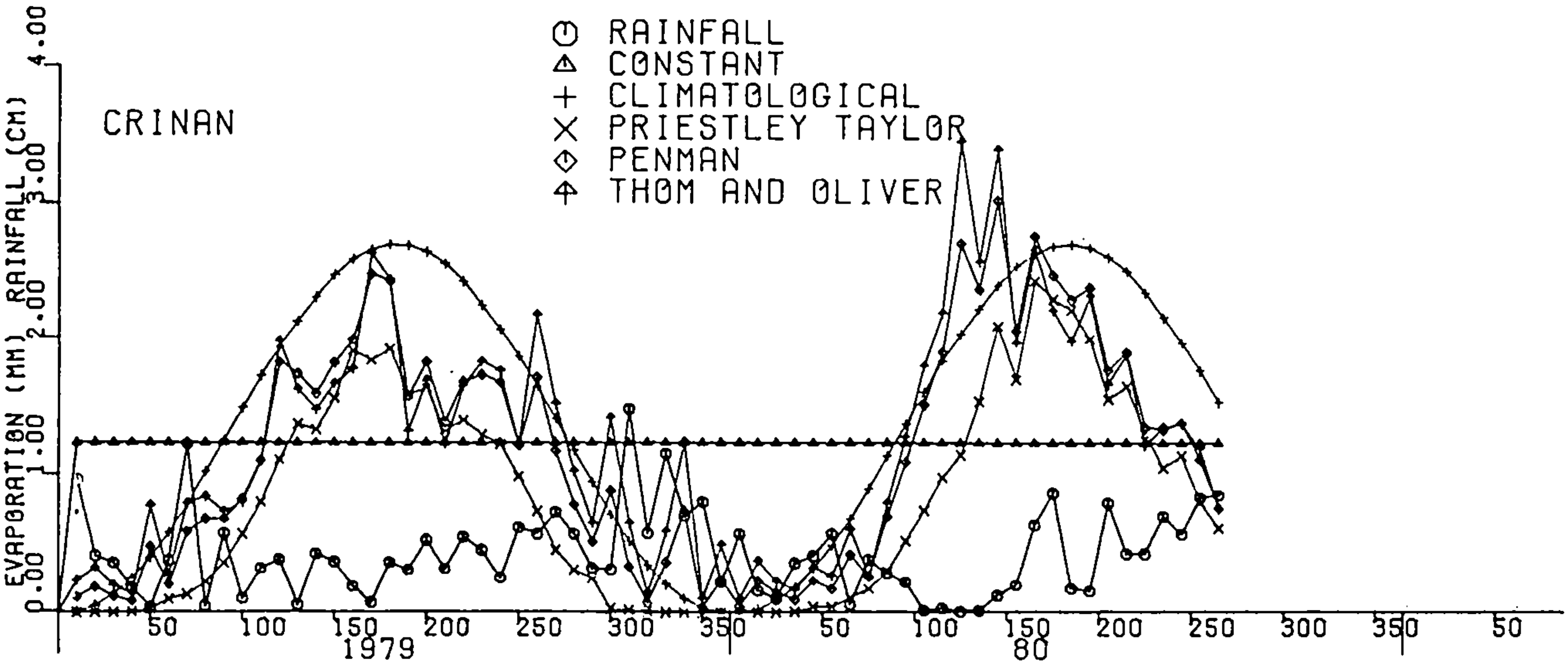
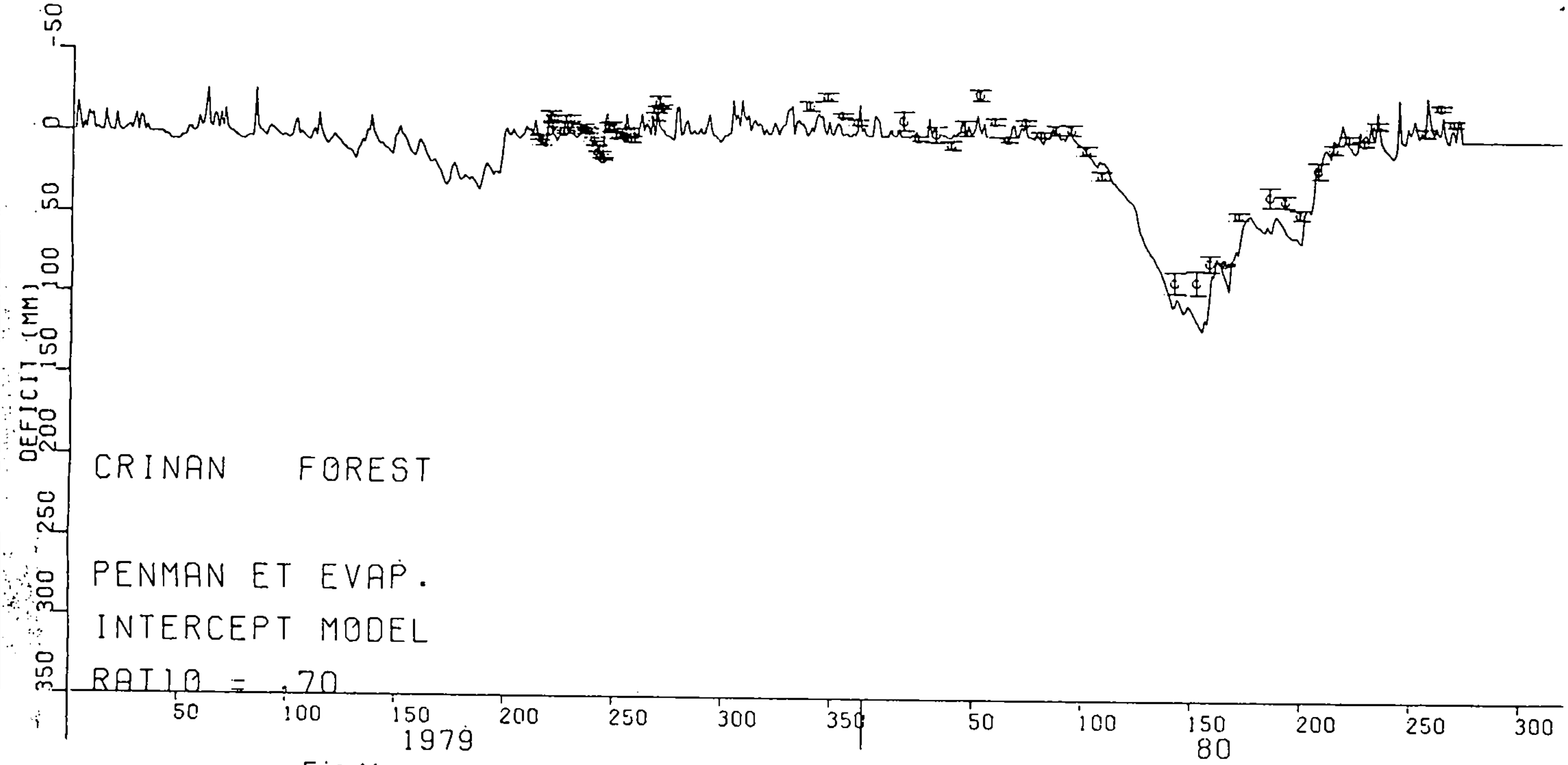

-50
0
50
100
150
200
250
300
350
DEFICIT (MM)
CRINAN L.
PENMAN ET EVAP.
FIELD CAPACITY
VARIANCE OF DATA .(MM**2) = 25.
NUMBER OF OBSERVATIONS = 75
TUBES 26 27 28 29 30 31
△ + × ◇ ↑ ⊠
FC VALUE – 993. 767. 879. 886. 799. 767.
50
100
150
200
250
300
350
1979
50
100
150
200
250
300
80

Fig 9


CRINAN
RAINFALL
CONSTANT
CLIMATOLOGICAL
PRIESTLEY TAYLOR
PENMAN
THOM AND OLIVER
EVAPORATION (MM) RAINFALL (CM)
0.00
1.00
2.00
3.00
4.00
50
100
150
200
250
300
350
50
100
150
200
250
300
350
50
1979
80



-50
0
50
100
150
200
250
300
350
DEFICIT (MM)
CRINAN FOREST
PENMAN ET EVAP.
INTERCEPT MODEL
RATIO = .70
50
100
150
1979
200
250
300
350
50
100
150
80
200
250
300

Fig 11

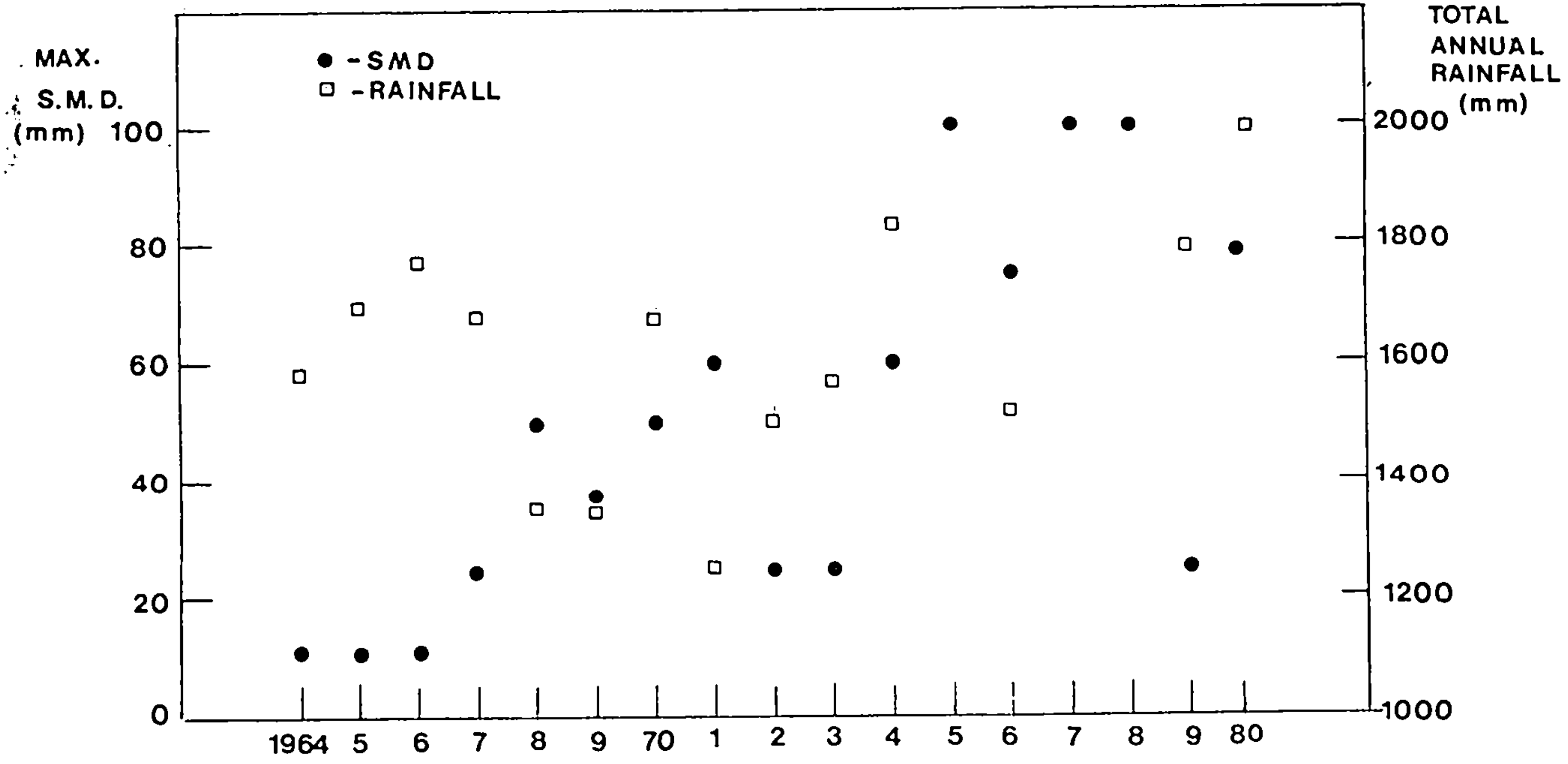

MAX. S.M.D. (mm)
0
20
40
60
80
100
TOTAL ANNUAL RAINFALL (mm)
1000
1200
1400
1600
1800
2000
● -SMD
□ -RAINFALL
1964
5
6
7
8
9
70
1
2
3
4
5
6
7
8
9
80

Fig 12

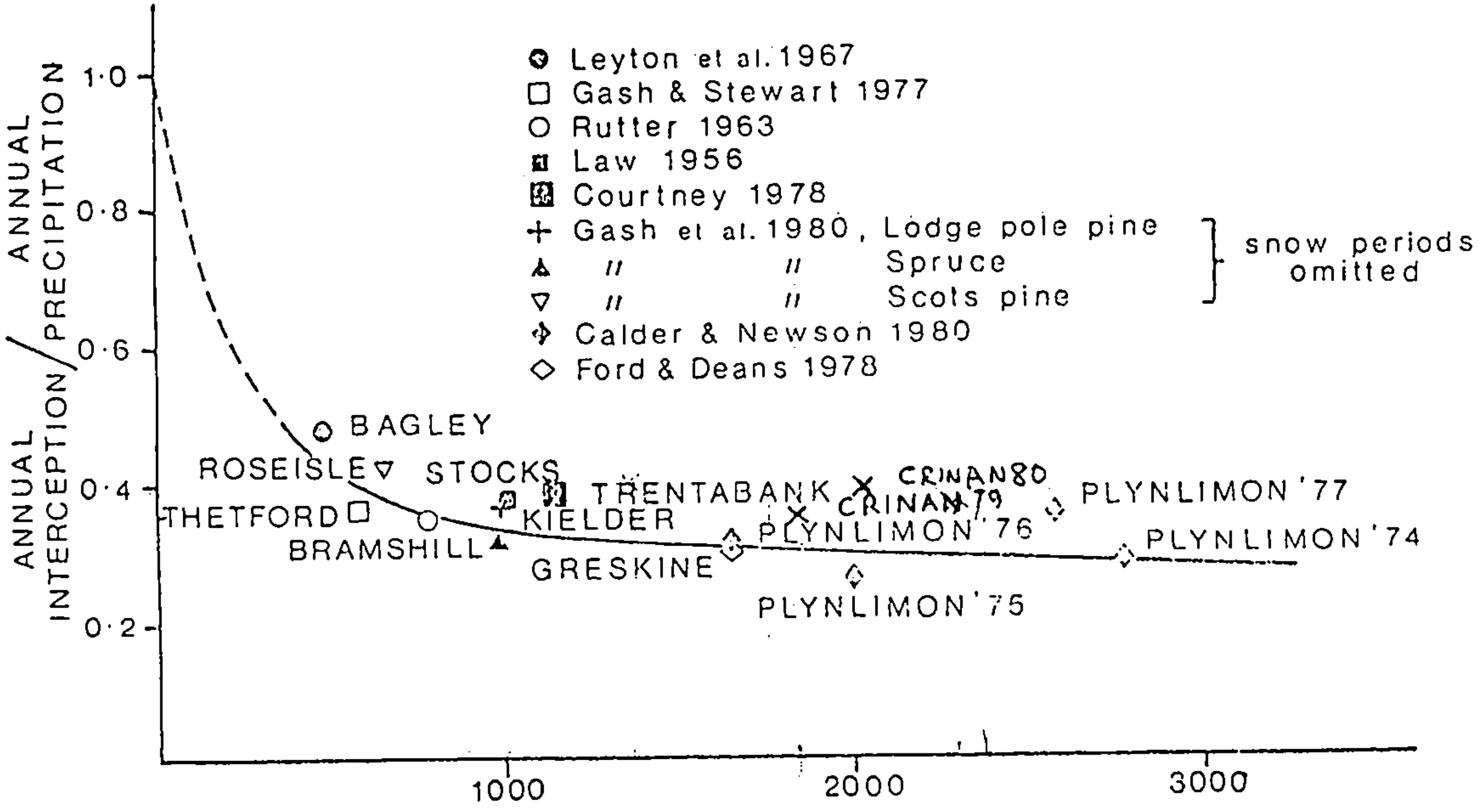

ANNUAL INTERCEPTION / ANNUAL PRECIPITATION
1·0
0·8
0·6
0·4
0·2
ANNUAL PRECIPITATION (mm)
1000
2000
3000
Leyton et al. 1967
Gash & Stewart 1977
Rutter 1963
Law 1956
Courtney 1978
Gash et al. 1980, Lodge pole pine
" " Spruce
" " Scots pine
snow periods omitted
Calder & Newson 1980
Ford & Deans 1978
BAGLEY
ROSEISLE
STOCKS
THETFORD
BRAMSHILL
KIELDER
TRENTABANK
GRESKINE
CRINAN 80
CRINAN 79
PLYNLIMON '76
PLYNLIMON '77
PLYNLIMON '74
PLYNLIMON '75

Fig 13

East = 1 West = 2

	RAIN	NO. OF TIPS 1	NO. OF TIPS 2	NET RAIN 1	NET RAIN 2	INT LOSS 1	INT LOSS 2	1/2	CUM RAIN	CUM NET RAIN1	CUM NET RAIN2	CUM INT LOSS 1	CUM INT LOSS 2
0.11.78	2.3	17	15	1.10	1.06	1.2	1.24	1.04	2.3	1.10	1.06	1.20	1.24
1.11.78	6.1	65	63	4.21	4.47	1.89	1.63	0.94	8.4	5.31	5.53	3.09	2.87
2.11.78	8.3	66	62	4.27	4.40	4.03	3.90	0.97	16.7	9.58	9.93	7.12	6.77
3.11.78	11.7	142	133	9.20	9.44	2.50	2.26	0.97	28.4	18.78	19.37	9.62	9.03
4.11.78	19.5	232	221	15.03	15.69	4.47	3.81	0.96	47.9	33.81	35.06	14.09	12.84
5.11.78	35.7	366	350	23.72	2485	11.98	10.85	0.95	83.6	57.53	59.91	26.07	23.69
6.11.78	5.5	42	36	2.72	2.56	2.78	2.94	1.06	89.1	60.25	62.47	28.85	26.63
7.[illegible]8	9.2	88	79	5.70	5.61	3.50	3.59	1.02	98.3	65.95	68.08	32.35	30.22
8.11.78	12.4	128	122	8.29	8.66	4.11	3.74	0.96	110.7	74.24	76.74	36.46	33.96
9.11.78	7.2	80	84	5.18	5.75	2.02	1.45	0.90	117.9	7942	8249	38.48	35.41
20.11.78	5.7	38	33	246	2.34	3.24	3.36	1.05	123.6	81.88	84.83	41.72	38.77
1.11.78	10.3	104	95	6.74	6.75	3.56	3.55	0.99	133.9	88.62	91.58	45.28	42.32
2.11.78	30.2	363	351	2352	2492	6.68	5.28	0.94	164.1	112.14	116.50	51.96	47.60
3.11.78	2.3	25	22	1.62	1.56	0.68	0.74	1.04	166.4	113.76	118.06	52.64	48.34
4.11.78	1.7	0	0	0.0	0.0	1.7	1.7	0.0	168.1	113.76	118.06	5434	5004
5.11.78	8.2	66	62	428	4.40	3.92	3.80	0.97	176.3	118.04	12246	58.26	53.84
6.11.78	0.9	11	10	0.71	0.71	0.19	0.19	1.00	177.2	118.75	123.17	58.45	5403
7.[illegible]8	3.5	2	1	0.13	0.07	3.37	3.43	1.86	180.7	118.88	123.24	61.82	57.46
[illegible]78	1.	0	0	0.0	0.0	1.0	1.0	0.0	181.7	118.88	123.24	62.82	58.46
9.11.78	0.2	0	0	0.0	0.0	0.2	0.2	0.0	181.9	118.88	123.24	63.02	58.66
0.11.78	15.4	144	137	9.33	9.73	6.07	5.67	0.96	197.3	128.21	132.97	69.09	6433
[illegible].12.78	5.6	76	73	4.92	5.18	0.68	0.42	0.95	202.9	133.13	138.15	69.77	64.75
2.12.78	0.1	0	0	0.0	0.0	0.1	0.1	0.0	203.0	133.13	138.15	69.87	6485
3.12.78	17.9	77	73	4.99	5.18	12.91	12.72	0.96	220.9	138.12	143.33	82.78	77.57
4.12.78	18.2	163	156	10.56	11.07	7.64	7.13	0.95	239.1	14868	154.40	90.42	84.70
5.12.78	15.4	173	171	11.21	12.14	4.19	3.26	0.92	254.5	159.89	166.54	94.61	87.96
[illegible].12.78	1.1	7	7	0.45	0.50	0.65	0.60	0.90	255.6	160.34	167.04	95.26	8856
[illegible].12.78	0.0	0	0	0.0	0.0	0.0	0.0	0.0	255.6	160.34	167.04	95.26	88.56
[illegible].12.78	13.3	101	118	6.55	8.38	6.75	4.92	0.78	268.9	166.89	17542	102.01	93.48
[illegible].12.78	16.7	242	205	15.68	14.56	1.02	2.14	1.07	285.9	182.57	189.98	103.03	95.62
0.12.78	5.7	43	45	2.78	3.19	2.92	2.51	0.87	291.3	185.35	19317	105.95	98.13

DATE	RAIN	NO. OF TIPS		NET RAIN		INT LOSS		1/2	CUM RAIN	CUM NET RAIN		CUM INT LOSS	
		1	2	1	2	1	2			1	2	1	2
14.12.78	35.6	354	344	22.94	24.42	12.66	11.18	1.13	326.9	208.29	217.59	118.61	109.31
21.12.78	1.5	1	2	0.06	0.14	1.44	1.36	1.06	328.4	208.35	217.73	120.05	110.67
28.12.78	14.5	71	62	4.60	4.40	9.90	10.10	0.98	342.9	212.95	222.13	129.95	120.77
16.1.79	124.0	SNOW ON		81.84	81.84	42.16	42.16	1.00	466.9	294.79	303.97	172.11	162.93
26.1.79	31.9	SHEETS NO		21.05	21.05	10.85	10.85	1.00	498.8	315.84	325.02	182.96	173.78
15.2.79	128.0	TIPS		84.48	84.48	43.52	43.52	1.00	626.8	400.32	409.50	226.48	217.30
22.2.79	74.0	2/3 GROSS RAIN		48.84	48.84	25.16	25.16	1.00	700.8	449.16	458.34	251.64	242.40
1.3.79	22.5	= NET RAIN		14.85	14.85	7.65	7.65	1.00	723.3	464.01	473.19	259.29	250.11
8.3.79	100.2	1050	945	68.04	67.09	32.16	33.11	0.97	823.5	532.05	540.28	291.65	283.22
15.3.79	48.0	440	399	28.51	28.33	19.49	19.67	0.99	871.5	560.56	568.61	310.94	302.89
22.3.79	5.3	16	11	1.04	0.78	4.26	4.52	0.94	876.8	561.60	569.39	315.20	307.41
29.3.79	44.1	447	395	28.96	28.05	15.14	16.05	0.94	920.9	590.56	597.44	330.34	323.46
5.4.79	16.8	125	125	8.10	8.87	8.70	7.93	1.09	937.7	598.66	606.31	339.04	331.39
12.4.79	18.5	135	135	8.75	9.58	9.75	8.92	1.09	956.2	607.41	616.06	348.79	340.31
19.4.79	25.0	208	208	13.48	14.77	11.52	10.23	1.13	981.2	620.89	630.83	360.31	350.54
26.4.79	28.5	254	228	16.46	16.19	12.04	12.31	0.98	1009.7	637.35	647.02	372.35	362.85
3.5.79	14.0	110	122	7.13	8.66	6.87	5.34	1.28	1023.7	644.48	655.68	379.22	368.19
10.5.79	3.1	5	4	0.32	0.28	2.78	2.82	0.98	1026.8	644.80	655.96	382.00	371.01
17.5.79	50.1	516	493	33.44	35.00	16.66	15.10	1.10	1076.9	678.24	690.96	398.66	386.11
24.5.79	15.4	89	80	5.77	5.68	9.63	9.72	0.99	1092.3	684.01	696.64	408.29	395.83
31.5.79	25.0	173	151	11.21	10.72	13.79	14.28	0.96	1117.3	695.22	707.36	422.08	410.11
8.6.79	10.2	81	75	5.25	5.33	4.95	4.87	1.02	1127.5	700.47	712.69	427.03	414.98
14.6.79	12.1	94	90	6.09	6.39	6.01	5.71	1.05	1139.6	706.56	719.08	433.04	420.69
21.6.79	10.2	41	39	2.66	2.77	7.54	7.43	1.01	1149.8	709.22	721.85	440.58	428.12
28.6.79	30.8	280	280	18.14	19.88	12.66	10.92	1.16	1180.6	727.36	741.73	453.24	439.04
5.7.79	7.7	28	27	1.81	1.92	5.89	5.78	1.02	1188.3	729.17	743.65	459.83	444.82
12.7.79	34.8	362	362	23.46	25.70	11.34	9.10	3.52	1223.1	752.63	769.35	470.47	[illegible]
20.7.79	64.0	662	662	42.89	47.00	21.11	17.00	3.52	1287.1	795.52	816.35	491.58	470.92
26.7.79	23.0	227	227	14.71	16.12	8.29	6.88	2.97	1310.1	810.23	832.47	479.87	477.80
2.8.79	34.0	375	307	24.30	27.79	9.70	6.21	1.56	1344.1	834.53	860.26	529.57	484.01

DATE	RAIN	NO. OF TIPS		NETRAIN		INTLOSS		1/2	CUM RAIN	CUM NET RAIN		CUM INT LOSS	
		1	2	1	2	1	2			1	2	1	2
.8.79	51.5	489	466	31.68	33.08	19.82	18.42	1.07	1395.8	866.21	1395.6	529.39	502.43
6.8.79	36.0	345	324	22.36	23.00	13.64	13.00	1.05	1431.8	888.57	1431.6	543.03	515.43
3.8.79	37.0	327	308	21.19	21.87	15.81	15.13	1.04	1468.8	909.76	1468.6	559.04	530.56
6.9.79	57.4	554	503	35.90	35.71	21.50	21.69	0.99	1526.2	945.66	1526.0	580.34	552.25
.9.79	33.0	258	246	16.72	17.47	16.28	15.53	1.05	1559.2	962.38	1559.0	596.62	567.78
0.9.79	56.0	473	455	30.65	32.31	25.35	23.69	1.07	1615.2	993.03	1615.0	621.97	591.47
7.9.79	49.5	468	458	30.33	32.52	19.17	16.98	1.13	1664.7	1023.36	1664.5	641.14	608.45
.10.79	49.0	567	545	36.74	38.69	12.26	10.31	1.19	1713.7	1060.1	1713.5	653.40	618.76
.10.79	56.4	466	443	30.19	31.45	26.21	24.95	1.05	1770.1	1090.29	1769.9	679.61	643.71
1.10.79	81.2	804	771	52.10	54.74	29.1	26.46	1.10	1851.3	1142.39	1851.1	708.71	670.17
0.11.79	138.0	1350	1316	87.48	93.43	50.52	44.57	1.13	1989.1	1229.8	12745	759.23	714.74

Date	Rain	No. of Tips 1	No. of Tips 2	Net Rain 1	Net Rain 2	Int. Loss 1	Int. Loss 2	Cumulative Values Rain	Cumulative Net Rain 1	Cumulative Net Rain 2	Cumulative Int. Loss 1	Cumulative Int. Loss 2
.11.79	0.0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
.11.79	27.1	218	197	14.13	13.98	12.97	13.12	27.1	14.13	13.98	12.97	13.12
2.11.79	49.8	379	366	24.56	25.98	25.24	23.82	76.9	38.69	39.96	38.21	36.94
9.11.79	102.4	1116	1105	72.32	78.47	30.08	23.93	179.3	111.01	118.43	68.29	60.87
6.12.79	42.0	347	344	22.48	24.39	19.52	17.61	221.3	133.49	142.82	87.81	78.48
3.12.79	92.0	983	969	63.69	68.80	28.31	23.20	313.0	197.18	211.62	116.12	101.68
30.12.79	37.5	119	134	7.71	9.51	29.79	27.99	350.8	204.89	221.13	145.91	129.67
4.1.80	85.0	646	770	41.86	54.67	43.14	30.33	435.8	246.75	275.80	189.05	160.00
10.1.80	20.0	110	118	7.13	8.38	12.87	11.62	455.8	253.88	284.18	201.92	171.62
17.1.80	8.5	59	75	3.82	5.32	4.68	3.18	464.3	257.70	289.50	206.60	174.80
24.1.80	13.0	44	38	2.85	2.70	10.15	10.30	477.3	260.55	292.20	216.75	185.10
31.1.80	23.5	190	180	12.31	12.78	11.19	10.72	500.8	272.86	304.98	227.94	195.82
7.2.80	20.0	43	39	2.78	2.70	17.22	17.30	520.8	275.64	307.68	245.16	213.12
14.2.80	35.0	302	308	19.57	21.87	15.43	13.13	555.8	295.21	329.55	260.59	226.25
21.2.80	55.0	460	525	29.81	37.27	25.19	17.73	610.8	325.02	366.82	285.78	243.98
28.2.80	16.0	136	160	8.87	11.36	7.19	4.64	626.8	333.83	378.18	292.97	248.62
13.3.80	31.5	439	440	28.45	31.24	3.05	0.26	658.3	362.28	409.42	296.02	248.88
20.3.80	8.4	55	50	3.56	3.55	4.84	4.85	666.7	365.84	412.97	300.86	253.73
27.3.80	43.5	335	320	21.71	22.72	21.79	20.78	710.2	387.55	435.69	322.65	274.51
3.4.80	17.6	99	87	6.41	6.18	11.19	11.42	727.8	393.96	441.87	333.84	285.93
0.4.80	0.8	0	0	0.0	0.0	0.8	0.8	728.6	393.96	441.87	334.64	286.73
7.4.80	7.5	42	34	2.72	2.41	4.78	5.09	736.1	396.68	444.28	339.42	291.82
4.4.80	1.6	0	0	0.0	0.0	1.6	1.6	737.7	396.68	444.28	341.02	293.42
2.5.80	0.5	0	0	0.0	0.0	0.5	0.5	738.2	396.68	444.28	341.52	293.92
5.5.80	0.6	3	2	0.19	0.14	0.41	0.46	738.8	396.87	444.42	341.93	294.38
22.5.80	10.2	93	91	6.03	6.46	4.17	3.74	749.0	402.90	450.88	346.10	298.12
9.5.80	22.6	264	258	17.10	18.32	5.50	4.28	771.6	420.00	469.20	351.60	302.40
5.6.80	44.0	273	358	17.69	25.42	26.31	18.58	815.6	437.69	494.62	377.91	320.98
2.6.80	29.3	271	277	17.56	19.67	11.74	9.63	844.9	455.25	514.29	389.65	330.61
9.6.80	62.0	602	627	39.00	44.51	23.00	17.49	906.9	494.25	558.80	412.65	348.10
6.6.80	29.0	235	239	15.23	16.70	13.77	12.30	935.9	509.48	575.50	426.42	360.40

Date		No. of Tips		Net Rain		Int Loss		Cumulative Values	Net Rain		Int Loss	
	Rain	1	2	1	2	1	2	Rain	1	2	1	2
3.7.80	14.5	33	48	2.14	3.41	12.36	11.09	950.4	511.62	578.91	438.78	371.49
10.7.80	22.5	181	178	11.73	12.64	10.77	9.86	972.9	523.35	591.55	449.55	381.35
17.7.80	27.0	125	158	8.10	11.22	18.90	15.78	999.9	531.45	602.77	468.45	397.13
23.7.80	70.7	No Mechanical counter numbers taken.						1070.6				
31.7.80	46.0	1173	1071	76.04[2][*]	76.04	40.66	40.66	1116.6	60749	67881	509.11	437.79
7.8.80	33.5	277	255	17.95	18.10	15.55	15.40	1150.1	625.44	696.91	524.66	453.19
14.8.80	25.4	217	206	14.06	14.63	11.34	10.77	1175.5	639.50	711.54	536.00	463.96
20.8.80	48.1	441	434	28.57	30.81	19.53	17.29	1223.6	668.07	742.35	555.53	481.25
28.8.80	13.5	100	116	6.48	8.24	7.02	5.26	1237.1	674.55	750.59	562.55	486.51
4.9.80	71.5	772	742	50.02	52.68	21.48	18.82	1308.6	724.57	803.27	584.03	505.33
11.9.80	62.0	587	560	38.04	39.76	23.96	22.24	1370.6	762.61	843.03	607.99	527.57
19.9.80	124.0	1168	1150	75.68	81.65	48.32	42.35	1494.6	838.29	924.68	656.31	569.92
25.9.80	26.0	218	225	14.13	15.97	11.87	10.03	1520.6	85242	94065	668.18	579.95
2.10.80	47.5	444	442	28.77	31.38	18.73	16.12	1568.1	881.19	972.03	686.91	596.07
9.10.80	111.0	1086	1086	70.37	77.10	40.63	33.90	1679.1	951.56	1049.13	727.54	629.97
23.10.80	62.0	474	463	30.71	3287	31.29	29.13	1741.1	982.27	1082.00	758.83	659.10
30.10.80	89.0	878	940	56.89	66.74	32.11	22.26	1830.1	1039.16	1148.74	790.94	681.36
13.11.80	12.0	15	14	0.97	0.99	11.03	11.01	1842.1	1040.13	1149.73	801.97	692.37
20.11.80	99.0	931	910	60.33	64.61	38.67	34.39	1941.1	1100.46	1214.34	840.64	726.76
27.11.80	68.0	711	691	46.07	49.06	21.93	18.94	2009.1	1146.53	1263.40	862.57	745.70

NOTE 1. Mechanical counters at fault on Sheet 2. The value for net rain 2 was the ratio of sheet 1 to sheet 2.

2. Mechanical counters at fault on Sheet 1. The value for net rain 1 was the value for net rain 2 substituted.