INSTITUTE of
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Estimating the Return Periods of the 1978 and 1984 Droughts on the River Annan at Brydekirk

This report is prepared for
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by

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INTRODUCTION

This report revises a study carried out by the Institute of Hydrology (1980) for Sir Frederick Snow & Partners which provided estimates of the return period of the 1978 drought on the River Annan at Brydekirk. This review has been requested in order to improve estimates using an additional ten years of flow data, and in order to assess the return period of the 1984 drought. This report uses the same methods of analysis as in the earlier report but includes additional techniques for fitting a distribution to the annual minimum series and for illustrating the regional drought patterns in the area.

The Annan at Brydekirk is a natural velocity-area section with stable rock bar as the control. It is a primary gauging station. Figures 1 and 2 show the daily mean flow hydrographs for the Annan at Brydekirk for 1978 and 1984 respectively. The previous recorded daily maxima and minima are also shown for comparison. It can be seen that both 1978 and 1984 had significant periods when the flow was the lowest on record.

The return periods for different durations of the 1978 and 1984 droughts have been estimated using five different techniques and two different data sets.

The main data set consisted of the full record of gauged daily flows for selected gauging stations in the region held on the Surface Water Archive. The second data set comprised synthetic monthly flows for the Annan at Brydekirk for the first part (1938-1967(Sept)) and gauged monthly flows for the second part (1967(Oct)-1987).

Return periods were estimated from the following techniques:

- annual minimum plots of gauged daily flows for different durations for each gauging station.

- average regional annual minimum plots of gauged daily flows for different durations derived from the pooling of selected stations.

- fitting a 3 parameter Weibull distribution to annual minima of the extended record of monthly flows on the Annan derived from C. Wright's rainfall-runoff regression model.

- plot of annual maximum spell durations (Low Flow Study)

- plot of annual maximum spell volumes (Low Flow Study)

The return periods estimated from the first method have also been set in a regional context.

The latter two techniques employ the use of a threshold flow set at 5.20 m^3s^{-1} for the purpose of this study.

ANALYSIS

2.1 Individual station annual minima

Sixteen gauging stations were selected on the basis of having a similar geology, rainfall regime, and topography as that of the Annan basin. The shortest flow record used was 19 years; the longest available was 30 years. They are listed in Table 1 with statistics taken from the 'Hydrometric Register and Statistics 1981-1985' (IH, 1988), and located on a map of south west Scotland in Figure 3.

Table 1 Gauging stations used to give regional perspective to 1978 and 1984 droughts in south west Scotland

Station no.	Station name	MAR (mm)	Area (km^2)	ADF (m^3s^{-1})	BFI	MAM(10) (%ADF)	No Yrs
21003	Tweed/Peebles	1189	694	14.9	.54	22.99	29
21006	Tweed/Boleside	1205	1500	35.0	.50	18.82	27
21007	Ettrick Wtr/Lindean	1366	499	11.6	.40	11.99	27
•21008	Teviot/Ormiston Mill	966	1110	19.2	.45	16.05	28
•21012	Teviot/Hawick	1169	323	8.2	.43	12.87	25
•21013	Gala Wtr/Galashiels	935	207	3.6	.51	16.69	24
•21015	Leader Wtr/Earlston	828	239	3.5	.48	15.59	22
23005	North Tyne/Tarset	1237	285	7.9	.32	12.10	23
•77002	Esk/Canonbie	1455	495	16.4	.38	12.50	25
•78003	Annan/Brydekirk	1324	925	27.0	.43	12.05	20
78004	Kinnel Wtr/Redhall	1435	76	2.5	.28	5.26	19
•79002	Nith/Friars Carse	1496	799	25.7	.38	11.12	30
79005	Cluden W/Fiddlers Fd	1383	238	7.4	.38	7.55	24
80001	Urr/Dalbeattie	1287	199	5.7	.35	4.96	24
81002	Cree/Newton Stewart	1730	368	15.1	.27	6.36	24
84004	Clyde/Sills	1226	742	17.6	.52	20.59	30

MAR = mean annual rainfall
ADF = average gauged daily flow
BFI = base flow index
MAM(10) = mean annual 10 day minimum flow
• = stations used to derive an average regional annual minimum curve

The annual minimum series for seven different durations were derived for each of the above stations. The durations used were 10, 30, 60, 90, 120, 150, and

180 days. The series were plotted as fractions of the D-day mean annual minimum (MAM(D), where D corresponds to one of the above listed durations), against a transformed Weibull reduced variate. 1978 and 1984 minimum flows at each station were calculated and expressed as a fraction of their respective MAM(D). Curves for each series, for each station, were fitted graphically to the lower half of each series, and the return periods for the '78 and '84 D-day minimum flows read off. The results are given in Tables 2 and 3 for 1978 and 1984 respectively.

Table 2 1978 return periods for different durations derived from individual station annual minima series

Station	Duration (days)						
no	10	30	60	90	120	150	180
21003	2	2	5	2-5	5	5	2-5
21006	2-5	2	2-5	2-5	5	5	2-5
21007	10	5	10	5-10	5-10	5-10	5
21008	5-10	5	5-10	5	5	2-5	2-5
21012	10-25	5-10	10	5-10	5-10	10	5-10
21013	<2	<2	<2	2	2-5	2	2-5
21015	<2	<2	<2	<2	<2	<2	2
23005	5	5-10	2-5	2-5	5	2-5	2-5
77002	10-25	10	10-25	10	10-25	10-25	10
78003	10	10	10	10	10	10	5
78004	10	10	10	10	10	10	5
79002	5-10	5	5	5-10	5-10	5-10	5
79005	10	5-10	10	10	10	10	5-10
80001	25	10	10	10	10-25	10-25	10
81002	10	10	10	5-10	5-10	5	2-5
84004	2	<2	2	2-5	2-5	5	2

Figure 4 shows the distribution of return periods of the 1978 drought for the minimum 90 day flow at each station in the region. Figure 5 shows the same for the minimum 150 day flow in 1984. These two durations were selected to approximate the durations when the river was continuously below the threshold of 5.20 cumecs in 1978 and 1984. The actual return period values given on the maps are for comparison and should be interpreted in the light of return periods derived from the other methods of analysis used in this study.

It can be seen that the Annan basin was in the most severely affected region during the 1978 drought (Figure 4, Table 2). The severity experienced by the neighbouring Esk was generally slightly greater at other durations. The drought showed a fair degree of uniformity over the different durations with respect to both regional pattern and severity.

The 1984 drought (Figure 5, Table 3) was more widespread than that of 1978. It was again more concentrated on the Solway Firth area with the Annan basin at the centre of the affected region. The distribution of the drought

Table 3 1984 return periods for different durations derived from individual station annual minima series

Station no	10	30	Duration (days) 60	90	120	150	180
21003	10-25	25	25-50	10-25	10-25	10-25	10-25
21006	5-10	10	10	10-25	10-25	25	25-50
21007	<2	<2	5	5-10	10-25	10-25	25-50
21008	25-50	25-50	25	10-25	25	25	25-50
21012	10	10	10-25	10-25	10-25	25	50
21013	5-10	10-25	10-25	10-25	10-25	10-25	10-25
21015	5-10	5-10	5	5-10	10	10	10
23005	<2	<2	2-5	5	5-10	10	25
77002	50	25	25	25	25-20	50-100	100
78003	100	50-100	25	25-50	50	50	50-100
78004	25	10-25	25	25	50	100	50-100
79002	50	25	25	25	25-50	25-50	25-50
79005	10	10-25	10-25	20-25	25	25	25
80001	10-25	10	10-25	10-25	25	25-50	25
81002	5	5	5-10	10	25	25	10-25
84004	50	25	25	25	25	25	25

was quite complex on the short duration scale. As the duration is increased, so a greater homogeneity over the region is detected.

2.2 AVERAGE REGIONAL ANNUAL MINIMUM PLOTS

Annual minimum series for those stations marked with an asterisk in Table 1 were pooled for each duration. An average regional curve was calculated in the same manner as described in the previous report on the Annan (IH, 1980). This subset of stations was selected on the basis of having similar hydrology. Selection was more stringent than in the previous study because much longer record lengths were available. Figure 6 shows the flow duration curves for those stations used in deriving the regional average annual minimum curve and illustrates the close similarity of the hydrological regimes of the pooled stations. Figures 7 to 13 show the plots of average points used to define each curve for 10, 30, 60, 90, 120, 150, and 180 days respectively. Two graphical fitting techniques were used: the first was guided by the Low Flow Study (LFS; IH, 1980) type curves; the second was fitted directly to the averages of the pooled points. Return periods for the minimum flows for each duration in 1978 and 1984 for the Annan at Brydekirk (again expressed as a fraction of MAM(D)) were read from the appropriate curve. These are compared in Table 4 with return periods derived from the LFS type curves.

In view of the similarity between the two sets of return periods the regional curve was preferred to describe the results of this method of analysis.

Table 4 Return periods for different durations of minimum flow on the Annan at Brydekirk for 1978 and 1984 from pooled regional annual minima fitted graphically compared to LFS type curve fits.

	Duration (days)						
	10	30	60	90	120	150	180
LFS curve no	5	4	1	1	1	1-2	2-3
1978							
reg curve	5-10	5	10	5-10	5-10	5-10	5
LFS curve	5-10	5	10	10	5-10	5-10	5
1984							
reg curve	50-100	25-50	50	25-50	50	50	50
LFS curve	50-100	25-50	25-50	25-50	50	50-100	50-100

2.3 Annual minima of extended monthly flow series

Synthetic monthly flows from a rainfall-runoff regression model developed by C. Wright for the Annan at Brydekirk were combined with gauged flows. This gave a continuous monthly flow record from 1938 to 1987 - some fifty years of data. Of the twelve lowest 3 month annual minima in this fifty year period, 10 are found in the 20 year gauged record, and only 2 in the 30 years of synthetic record. The eight lowest all occur in the gauged record. Comparison of the synthetic data with gauged data on the Nith, described in the previous study, gave confidence in the modelled flows.

Fifty years of data was considered sufficient to fit a three parameter Weibull distribution (Polarski, 1989). The parameters were fitted independently for 1, 2, 3, 4, 5, and 6 month annual minima. The plots for 2 and 6 month durations are shown in Figure 14. 1978 and 1984 minima for the above durations were expressed as fraction of their respective MAM(D-month) and return periods read from the curves. They are given in Table 5.

Table 5 Return periods for 1978 and 1984 monthly minimum flows estimated from a three parameter Weibull distribution.

Year	1	2	3	4	5	6
1978	10-25	10-25	25	10-25	10	10
1984	200-500	200-500	200-500	200-500	200-500	500

2.4 DEFICIT ANALYSIS

Annual maximum spell durations and volumes below a threshold of 5.2 cumecs were calculated and plotted. A spell duration is the number of consecutive days that the flow is below a given threshold in any period. A spell volume is the deficiency volume below the threshold that accumulates during this duration. The annual maxima of these values are extracted and the volumes expressed as a percentage of annual runoff. Values are ranked, assigned a plotting position, and plotted on log-normal probability graph paper. Figures 15 and 16 show the plots for spell durations and spell volumes, respectively, using thresholds of 12.1% (the 95 percentile flow), 18.4% (= 5.2 m^3s^{-1}), 30%, and 40% of average daily flow (ADF).

Strictly, the 1978 spell below 5.2 cumecs was 46 days long, although the flow exceeded 5.2 cumecs for only one day in a 78 day period. By graphically fitting a straight line to the points, return periods for both of these durations may be estimated. The results are given in Table 6.

Table 6 Return periods (T) for deficit durations and volumes below 5.2 cumecs in 1978 and 1984

	1978		1984	
	maximum	T(yrs)	maximum	T(yrs)
Spell duration	46 days	5	138 days	200
	78 days	25		
Spell volume	0.82%	5	3.16%	200
(% Av Ann Runoff)	1.44%	25		

3. Summary

Estimated return periods for the Annan at Brydekirk are summarised in Table 7 for 1978 and Table 8 for 1984 from the above analyses.

It is apparent that the 1984 event was very much more extreme than that of 1978. For most durations the average flow in 1984 was almost half that of the previous lowest.

The highest return period estimated for the minimum flows of any duration in 1978 is 25 years, using the extended Annan record. Deficit analysis of the 78 day 'spell' also agrees with this estimate. However estimates for most durations based on the gauged minima and the pooled approach are of the

Table 7 Summary of estimated return periods for different durations from different methods of analysis on 1978 flow data. See text for explanation of analysis types.

Analysis type		Duration (days, (months)) 10	30 (1)	46	60 (2)	78	90 (3)	120 (4)	150 (5)	180 (6)
2.1		10	10		10		10	10	10	5
2.2	reg	5-10	5		10		5-10	5-10	5-10	5
2.3			10-25		10-25		25	10-25	10	10
2.4	durn			5		25				
	vols			5		25				

Table 8 Summary of estimated return periods for different durations from different methods of analysis on 1984 flow data. See text for explanation of analysis types.

Analysis type		Duration (days, (months)) 10	30 (1)	60 (2)	90 (3)	120 (4)	138	150 (5)	180 (6)
2.1		100	50-100	25	25-50	50		50	50-100
2.2	av	50-100	25-50	50	25-50	50		50	50
	LFS	50-100	25-50	25-50	25-50	50		50-100	50-100
2.3			200-500	200-500	200-500	200-500		200-500	500
2.4	durn						200		
	vols						200		

order of 10 years. The range in these estimates between 10 and 25 years is thus lower than the estimates published in the 1980 report which were of the order of 25 to 50 years.

The highest return period estimated for any duration in 1984 is 500 years, again using the extended Annan record and fitting a distribution to the annual minima series. Spell analysis suggests a return period of 200 years, and analysis of gauged annual minima suggests 100 years for the most severely affected duration. Return periods derived from annual minimum analysis of 1984 flows on the River Nith at Friars Carse (79002), reported in 'The 1984 Drought' (IH, 1985), are in the region of 20 to 50 years. The 1984 Solway RPB Annual Report also quotes the 1 day minimum flow return periods for the Annan and Nith as in excess of 100 years and 50 years respectively. These independent estimates agree well with the results of the present study (Table 3, Figure 5) thus verifying the regional extent of the drought. Return periods for 1984 April to August rainfall in the region are estimated to be between 100 and 200 years in 'The 1984 Drought'. The return period of the 1984 drought is estimated to be at least 100 years.

It is interesting to note that 9 out of the lowest 12 events in the extended 50 year record have occurred in the last 15 years. This recent occurrence of extreme events is consistent with low flow regimes throughout much of western Europe (Gustard et al., 1989). The implications of this sequence on the estimates of return period of 1978 and 1984 droughts have not been considered in this study.

4. References

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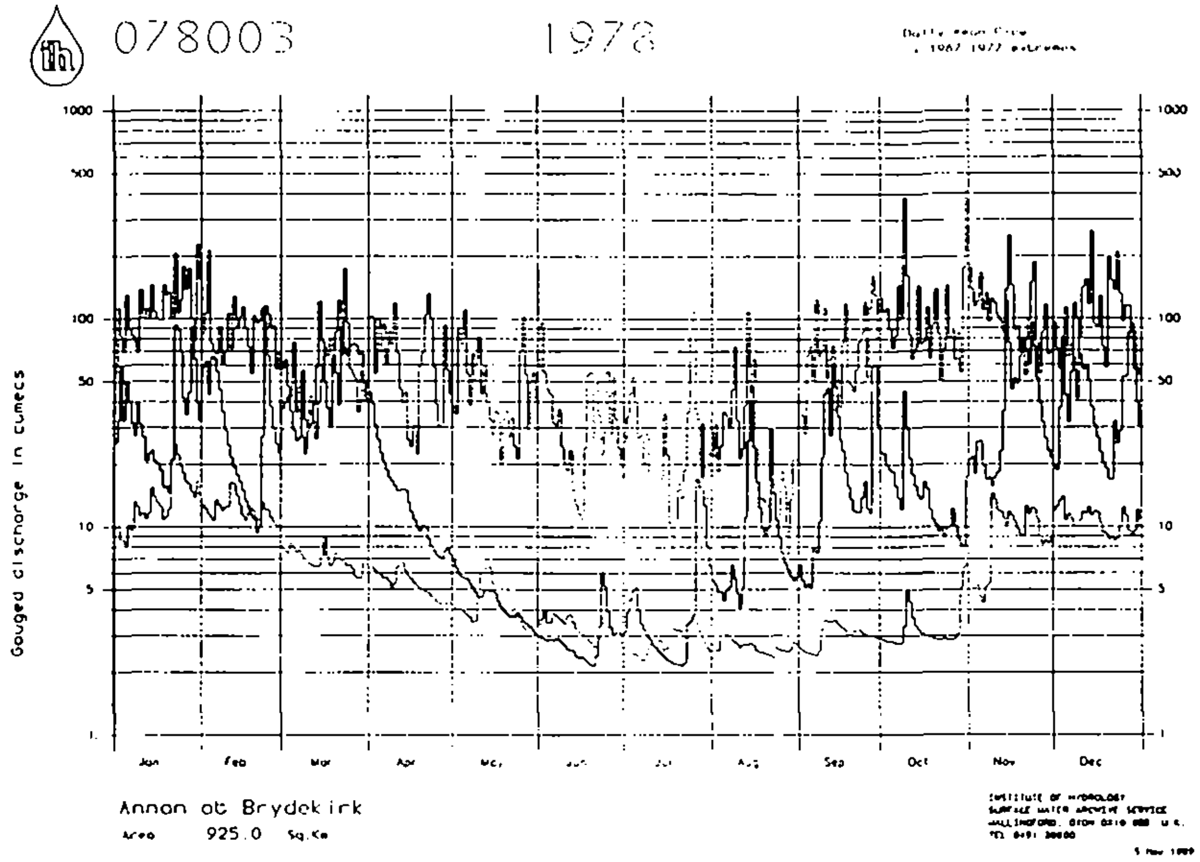

Figure 1 1978 Daily Mean Flow Hydrograph for the River Annan at Brydekirk

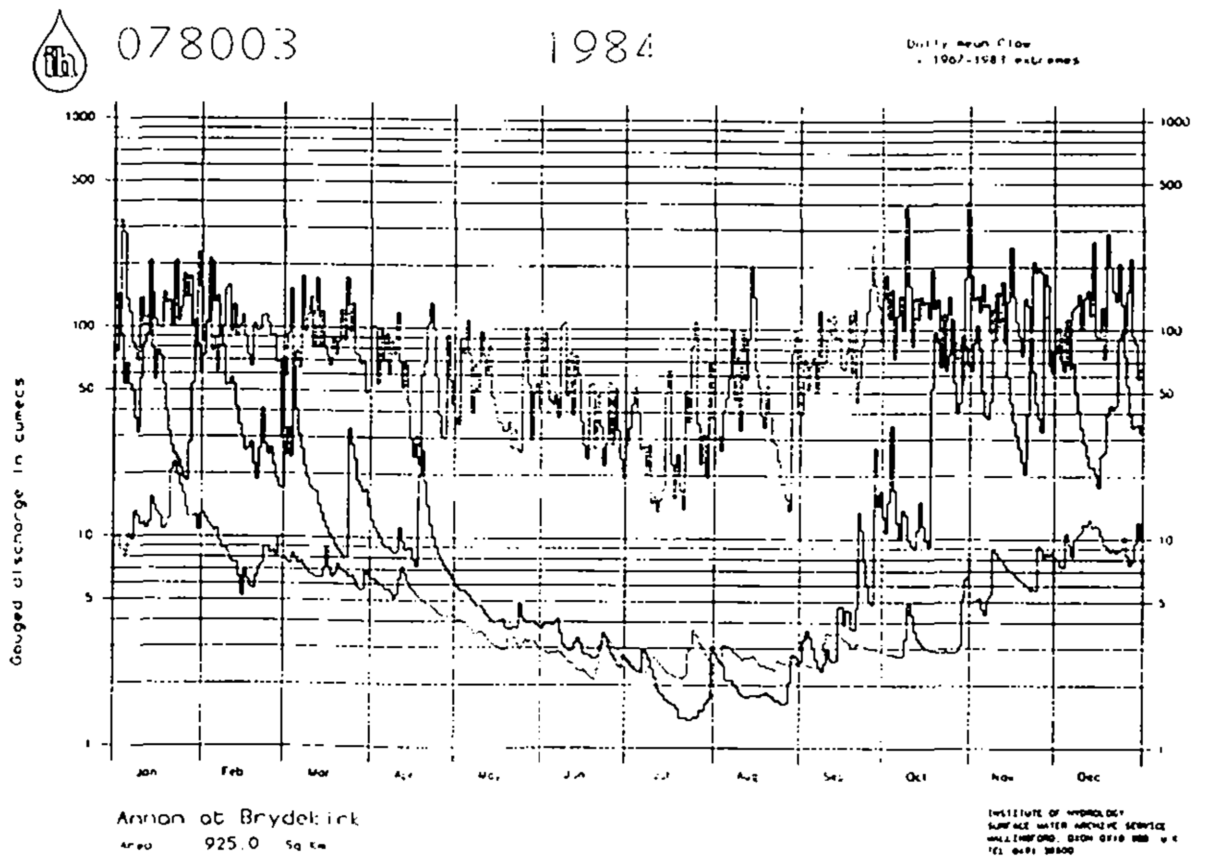

Figure 2 1984 Daily Mean Flow Hydrograph for the River Annan at Brydekirk

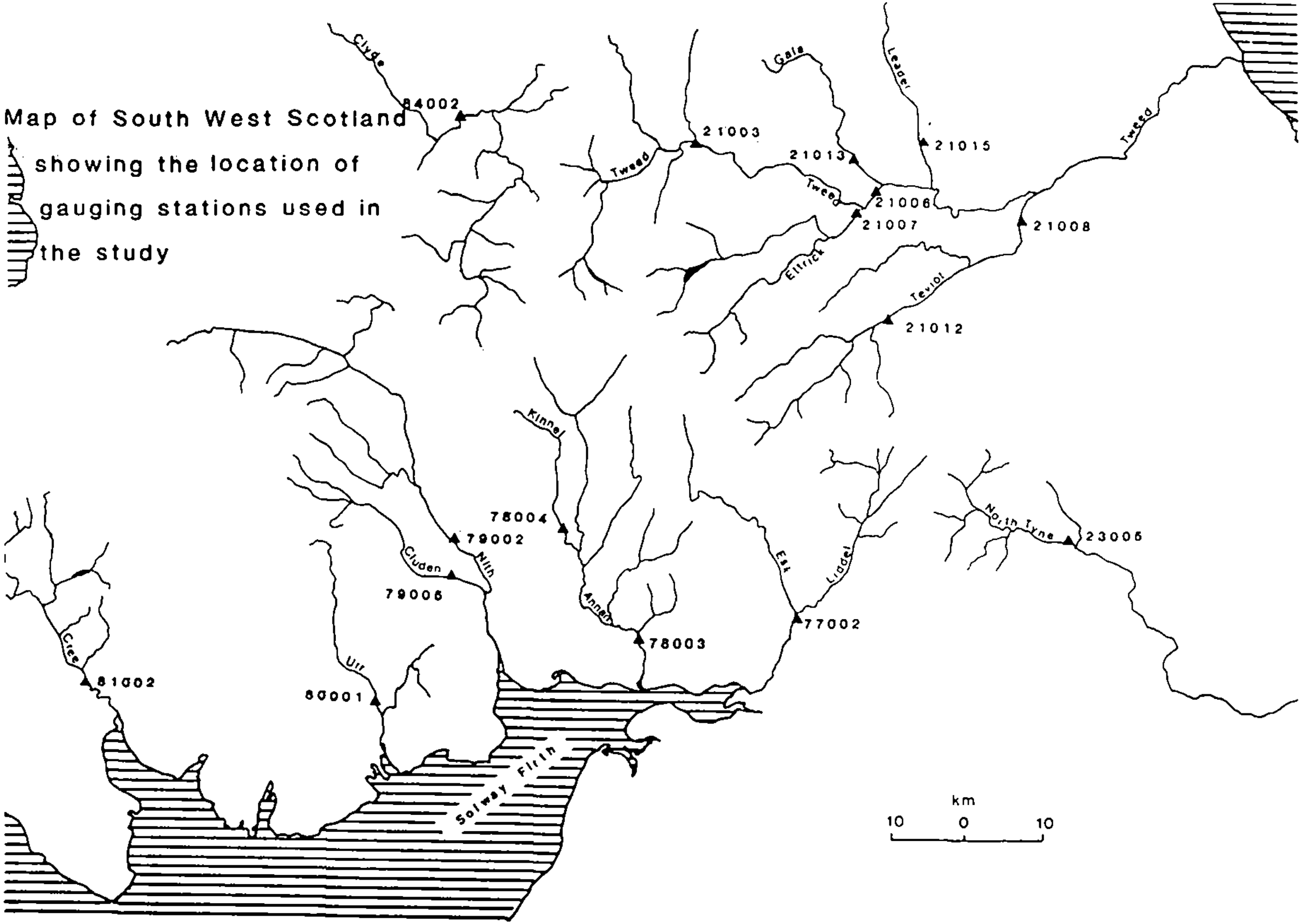

Figure 3 Map of south west Scotland showing location of gauging stations used in this study

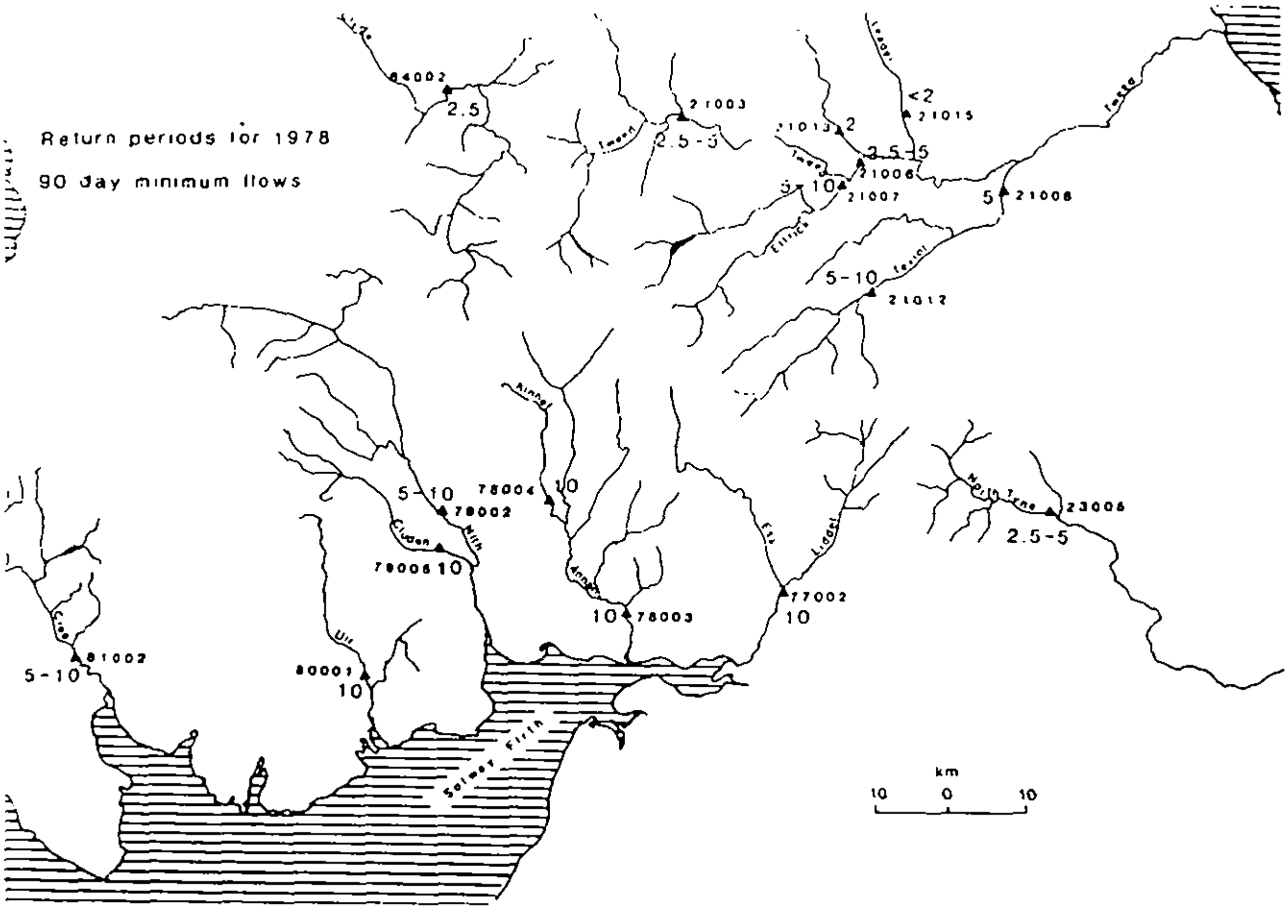

Figure 4 Regional distribution of return periods for 1978 90 day minimum flow

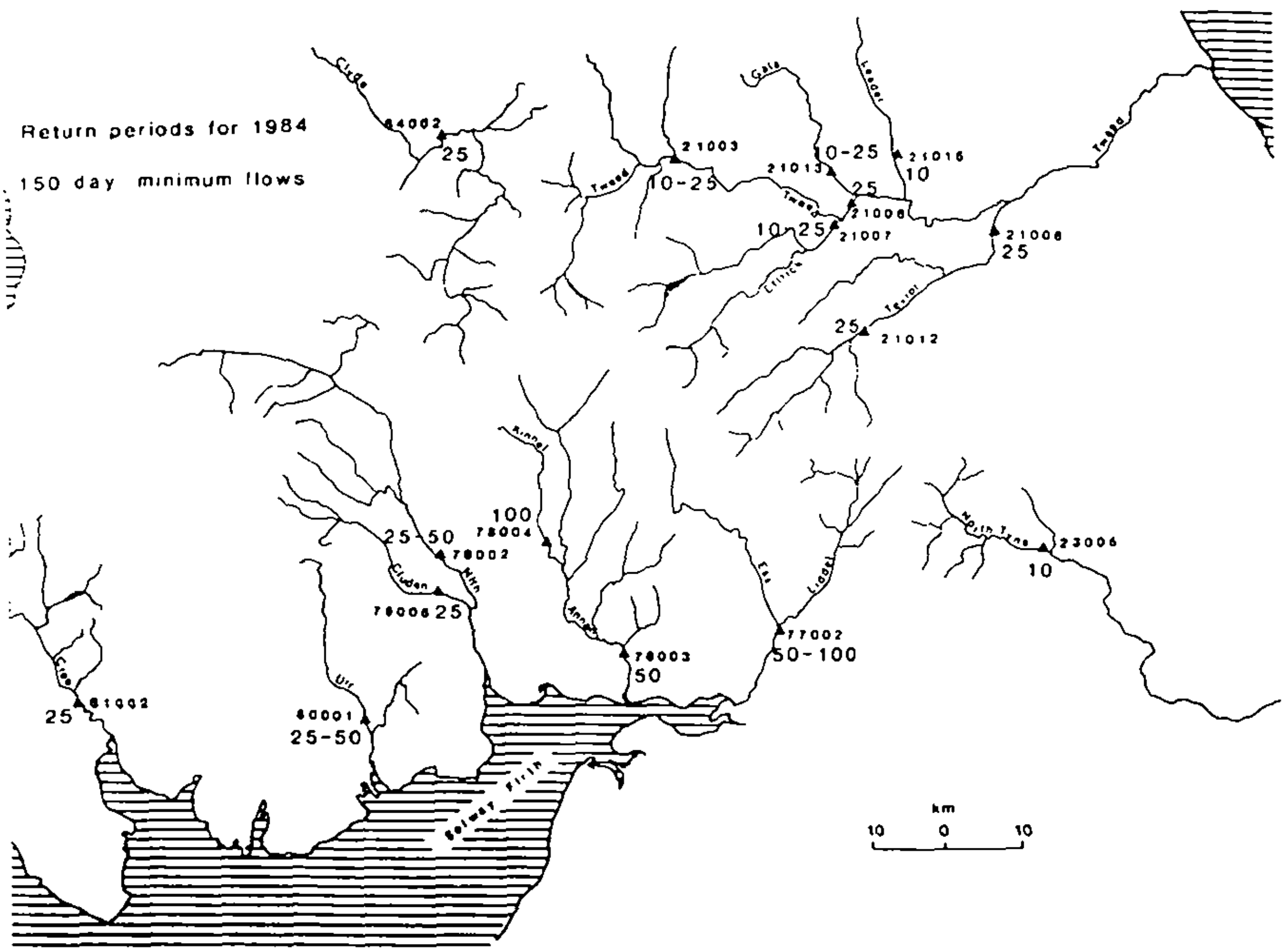

Figure 5 Regional distribution of return periods for 1984 150 day minimum flow

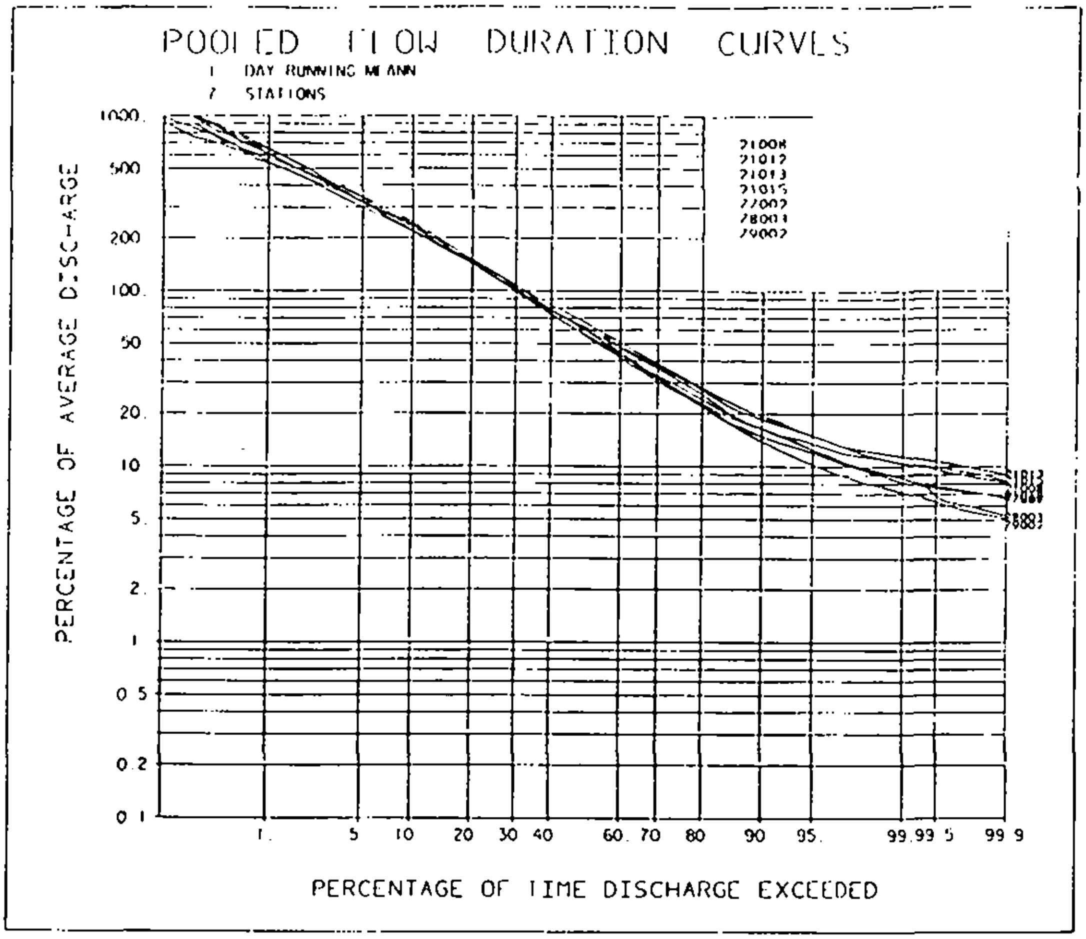

Figure 6 Pooled flow duration curves for stations used in deriving the regional annual minimum curve

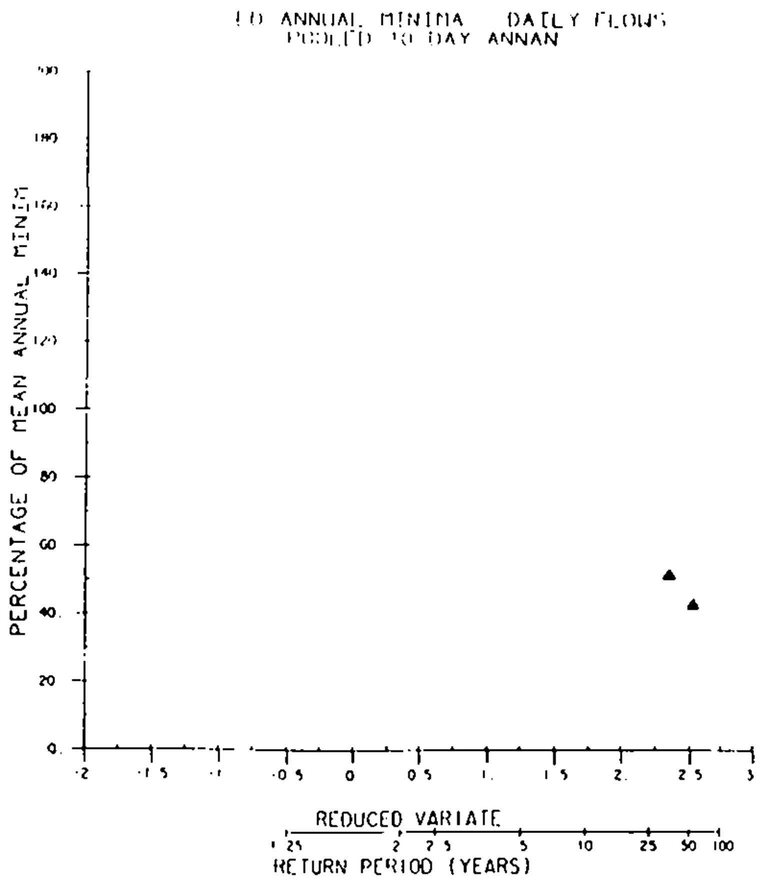

Figure 7 Regional flow frequency plot - duration 10 days

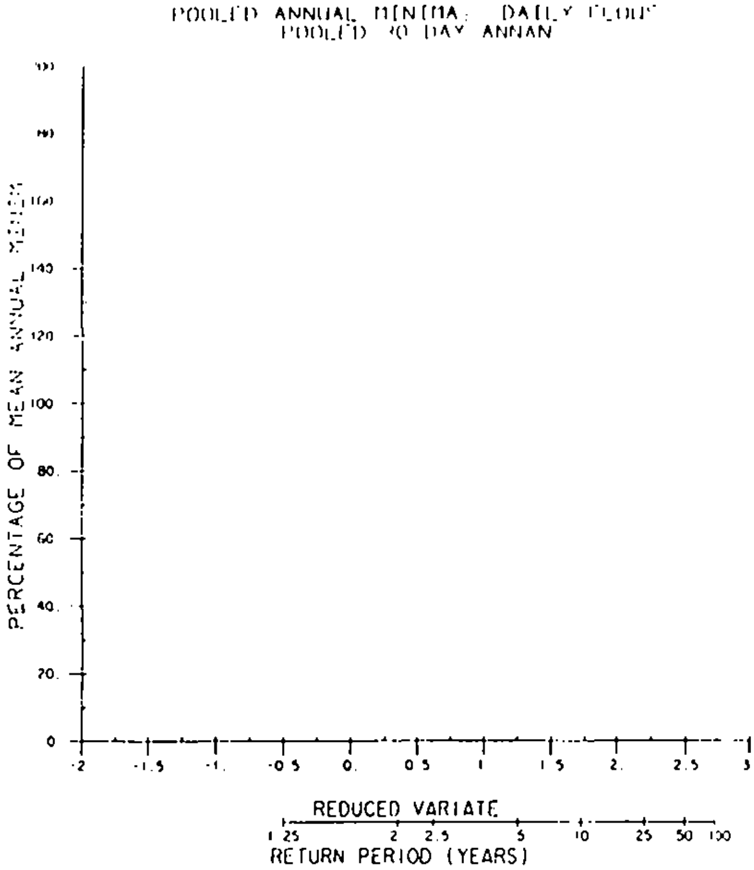

Figure 8 Regional flow frequency plot - duration 30 days

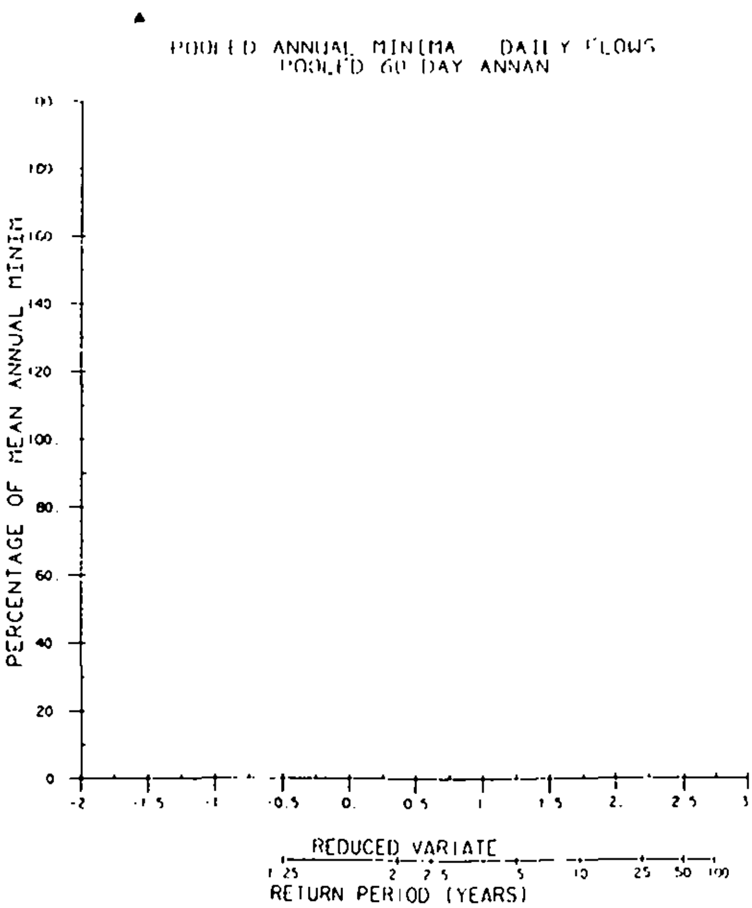

Figure 9 Regional flow frequency plot - duration 60 days

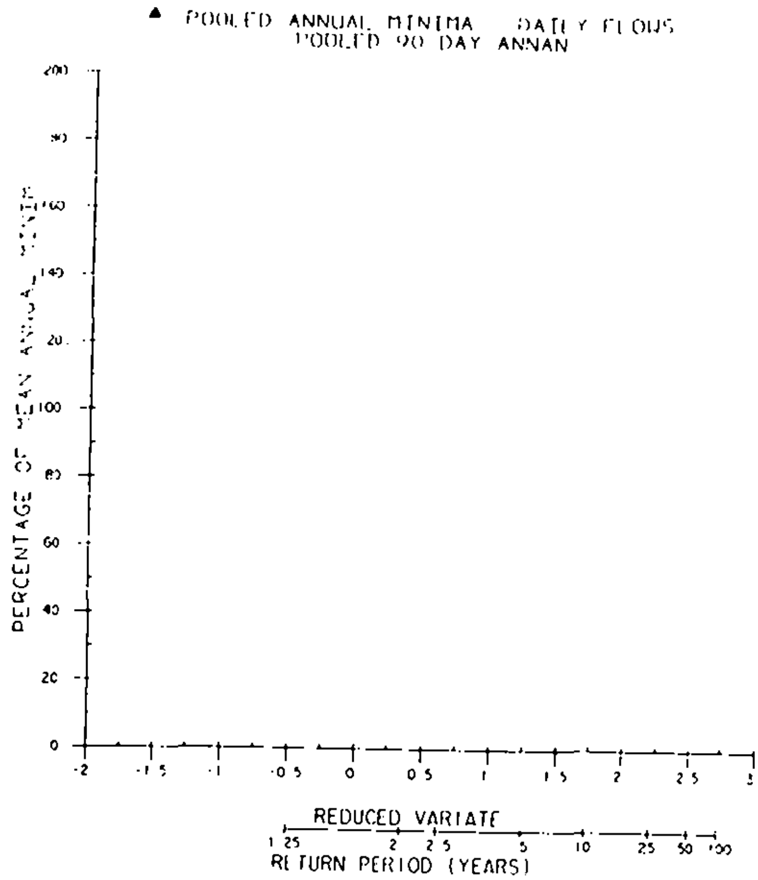

Figure 10 Regional flow frequency plot - duration 90 days

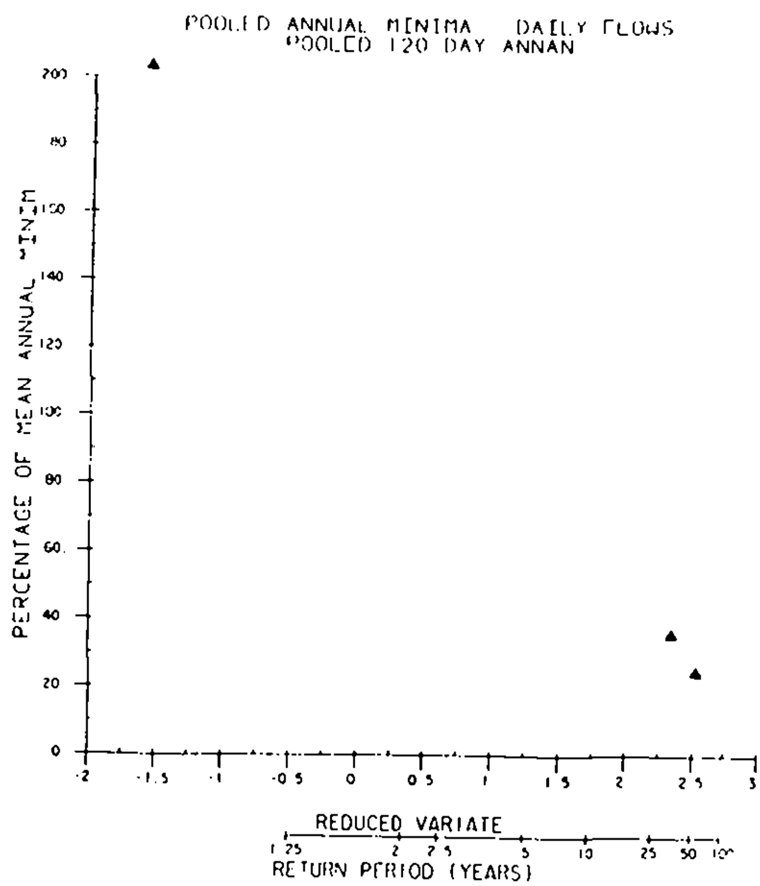

Figure 11 Regional flow frequency plot - duration 120 days

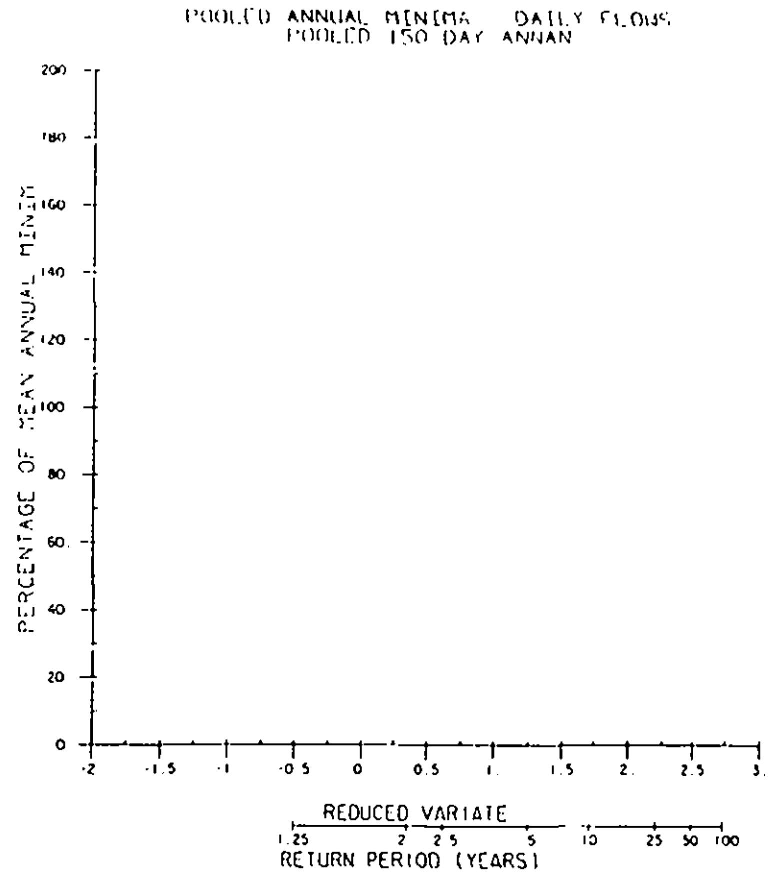

Figure 12 Regional flow frequency plot - duration 150 days

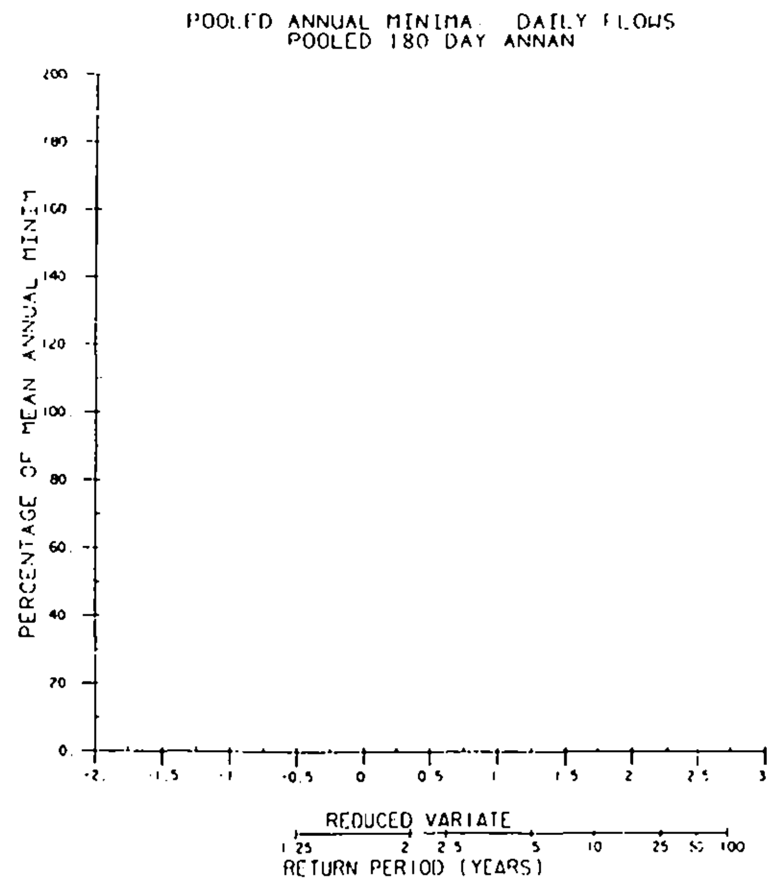

Figure 13 Regional flow frequency plot - duration 180 days

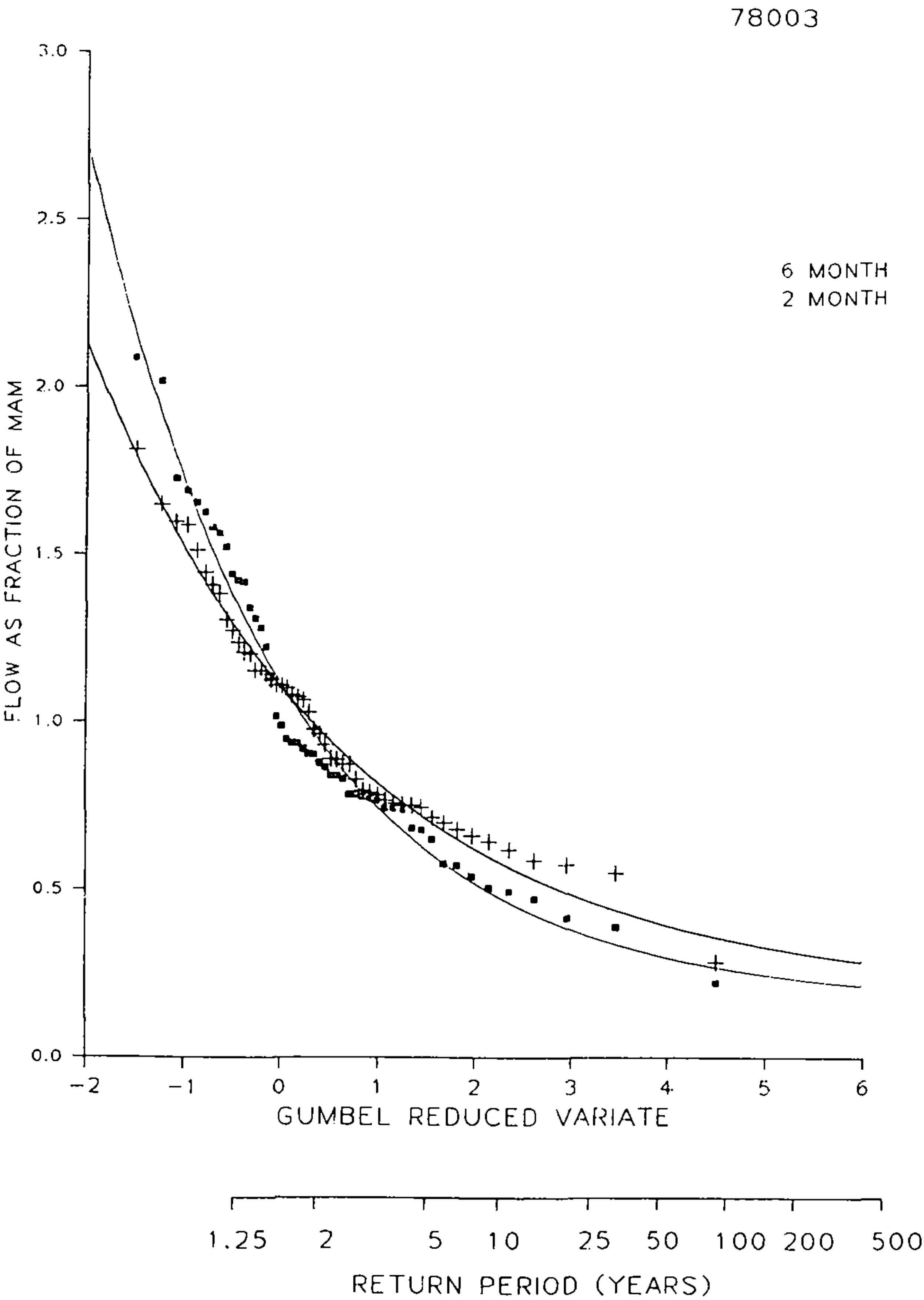

Figure 14 Annual minimum curve defined by a Weibull fit to the extended Annan record for 2 and 6 month durations

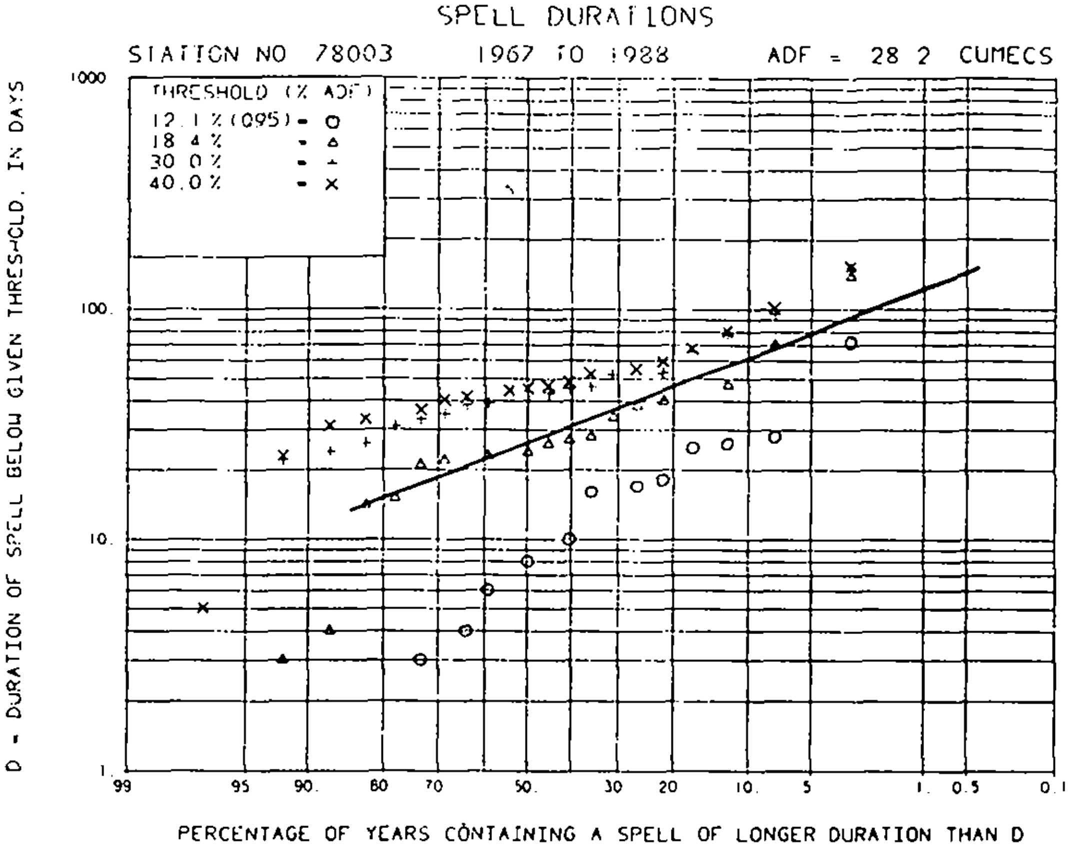

Figure 15 ***Plot of spell durations below given thresholds of flow from the gauged record on the Annan at Brydekirk***

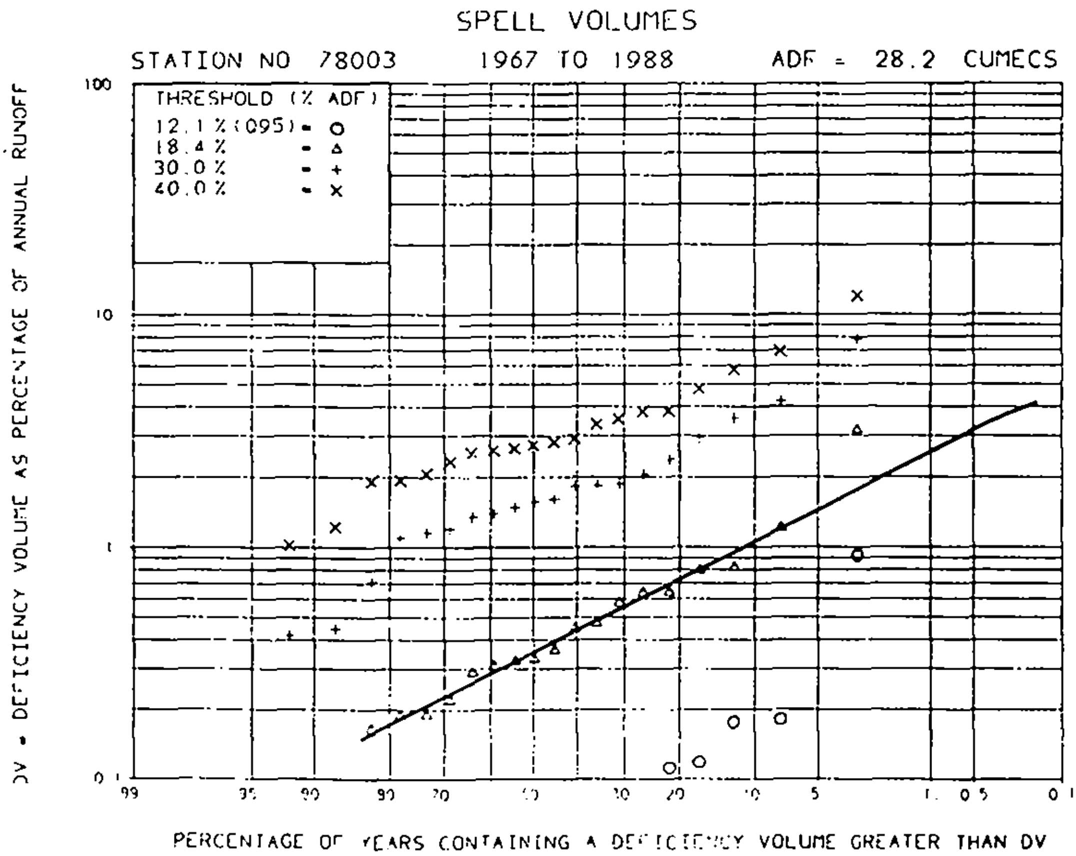

Figure 16 ***Plot of spell volumes below given thresholds of flow from the gauged record on the Annan at Brydekirk***