LOW FLOW STUDIES

Report No 2.4

Seasonal flow duration curve estimation manual

PREFACE

This report describes the procedure for estimation of monthly and seasonal flow duration curves for both gauged and ungauged catchments. It forms one of a series of reports which document the work of the Low Flow Study carried out at the Institute of Hydrology and funded by the Department of the Environment.

The complete series of reports is as follows:

Report No 1	*Research Report*
Report No 2	*Manuals for estimating low flow measures at gauged or ungauged sites*
Report No 3	*A manual describing the techniques for extracting catchment characteristics*
Report No 4	*Low flow estimation in Scotland*

The first report outlines the scope of the Low Flow Study; it describes the analysis of the flow data, the derivation of the relationship between low flows and catchment characteristics and summarizes the estimation technique. The second report series takes the form of calculation sheets which describe the underlying principles of each low flow measure and enable the user to estimate them from flow data or catchment characteristics; procedures are also given for incorporating local gauged data at various stages in the estimation technique. Report No 3 describes the techniques for calculating catchment characteristics. Report No 4 contains the results of a low flow study of Scottish rivers, commissioned by the Scottish Development Department.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADF	average discharge (cumecs)
MRV	monthly runoff volume as percentage of annual runoff volume
AMD	average monthly discharge (cumecs)
BFI	base flow index
SAAR	standard period (1941-1970) annual average rainfall (mm)
Q95(10)	10 day average flow exceeded by 95% of 10 day average discharges (expressed as a percentage of ADF)
Q95	flow exceeded 95% of the time (expressed as a percent of AMD) - this always refers to a specific calendar month
Q5	flow exceeded 5% of the time (expressed as a percent of AMD) - this always refers to a specific calendar month

1. INTRODUCTION

1.1 OUTLINE AND SUMMARY

Seasonal flow duration curves illustrate, for any month (e.g. all Octobers) or group of months (e.g. all January-June periods), the relationship between discharge and the percentage of time that discharge is exceeded. They have application where the frequency distribution of flows is required for a particular month or group of months which is critical in a hydrological design problem. Examples are found in the licensing of river abstractions, in the determination of sewage effluent dilution and in assessing the compensation flows needed below reservoirs - in each case different standards may be applied to different times of the year.

Chapter 1 of this manual contains an outline of how monthly and seasonal flow duration curves are constructed and how they can be interpreted. It includes an insight into the factors affecting the shape of the curve and explains how the curves may be expressed either in discharge terms or alternatively as a percentage of the average discharge of the particular month or season. It concludes with an outline of the estimation strategy dependent upon requirement and data availability.

Chapter 2 explains how to derive a monthly or seasonal curve using flow data from a gauged catchment, and Chapter 3 details methods of deriving curves at ungauged sites. Chapter 4 illustrates how best to make use of local data.

This manual illustrates the estimation techniques by making use of a worked example, the River Pang at Pangbourne. Seasonal flow duration curves are constructed from gauged data collected at this site and the methods suggested for estimating seasonal curves at ungauged sites are also detailed for the same catchment. Information on three other catchments which can be used to practise the recommended techniques is given. Necessary information on all four catchments will be found in section 1.1 of Low Flow Studies Report 2.1. As far as is practical the worked example will be found on right-hand pages whilst the catchments included for practice will be found in italic type on left-hand pages.

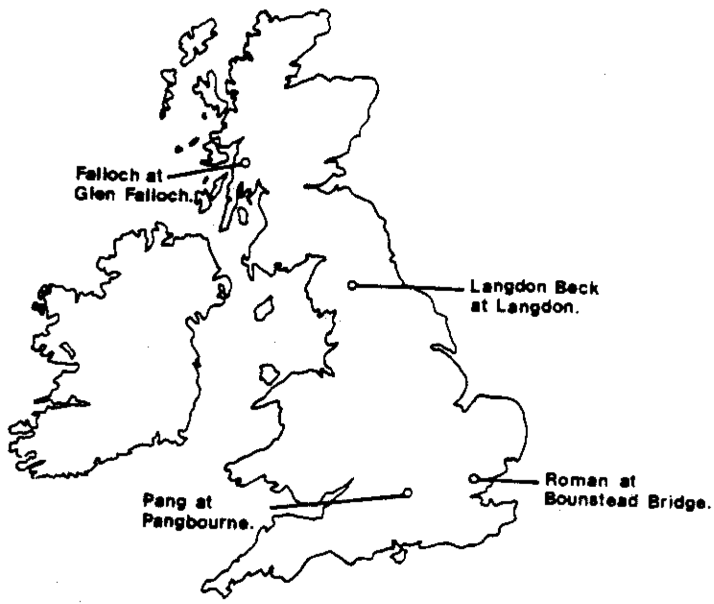


FIGURE 1.1 LOCATION OF ALL THE EXAMPLE CATCHMENTS

1.2 DERIVATION OF THE CALENDAR MONTH FLOW DURATION CURVE

A flow duration curve derived for a particular month is obtained by using all data in that month (e.g. October) from each year of record available. Figure 1.2 illustrates in diagrammatic form the data used in the creation of a monthly flow duration curve for October from a five year period of data.

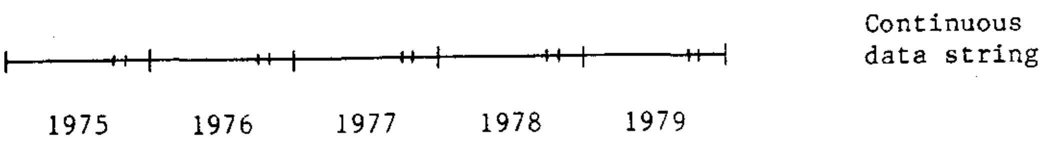


FIGURE 1.2 **DATA SELECTION IN THE DERIVATION OF A MONTHLY FLOW DURATION CURVE**

A monthly curve can be constructed from any length of record and will validly represent flow conditions for that particular period. However if the object is to represent long term average seasonal flow conditions, then of course the use of long records will reduce sampling variability.

Figure 1.3 is an example of a monthly flow duration curve. It has been derived from data gauged on the river Pang at Pangbourne during October. Fifteen years of record are available at this location which together give rise to 15 x 31 (i.e. 465) days of daily flow data which have been used in the derivation of this October curve. It can be seen that, for example, for five percent of the time (i.e. five out of every one hundred October days) the flow was greater than 0.65 cumecs or, again, that the flow exceeded on 95 percent of October days is 0.22 cumecs.

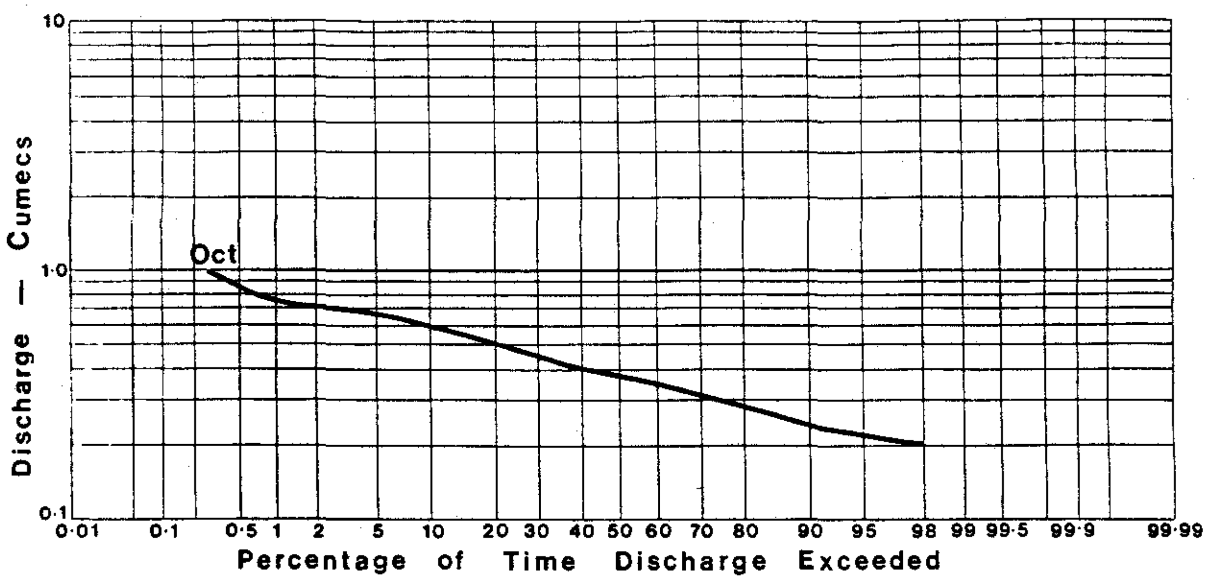


FIGURE 1.3 **OCTOBER MONTHLY FLOW DURATION CURVE FOR THE RIVER PANG**

1.3 VARIABILITY OF CALENDAR MONTH FLOW DURATION CURVES

There can be large differences in monthly flow duration curves between different months for the same catchment and also between different catchments for the same month. The position of the flow duration curve for any month is controlled primarily by the scale of the runoff process, that is large catchments in an area of high average annual rainfall will obviously have higher daily flows than small catchments in a low rainfall area. This pattern is also apparent when comparing monthly flow duration curves for the same catchment: the wetter winter months will generally have flow duration curves which plot above the drier summer months - this is illustrated in Figure 1.4. Thus the dominant variable controlling the position of any monthly flow duration curve is the average discharge in that month. A second order influence is the effect of geology on the flow regime which results in permeable catchments having flatter flow duration curves (i.e. small variation in mean daily flows) than impermeable catchments. These experience a wide range of daily flows and hence display steeper flow duration curves.

In this study it has thus been necessary to quantify both the location and the gradient of the monthly flow duration curves. Our analysis of over 500 catchments has indicated that the annual flow duration curve provides a good guide to the variability of monthly flow duration curves both in respect of the gradient and the position of the curves. Indeed, if the monthly curves are standardised by monthly runoff there is little variability between the twelve monthly curves through the year for a particular catchment. However, variations in the gradient of the curve between permeable and impermeable catchments do remain.

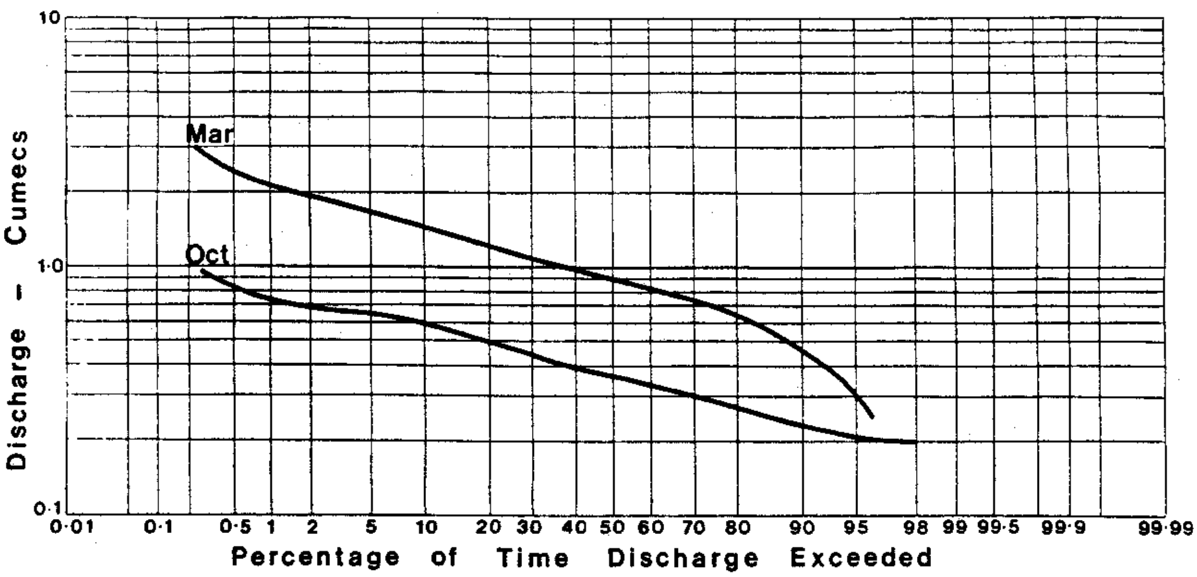


FIGURE 1.4 MARCH AND OCTOBER MONTHLY FLOW DURATION CURVES FOR THE PANG

1.4 SEASONAL FLOW DURATION CURVES

The previous sections have been concerned with the construction and explanation of individual calendar month flow duration curves; this section illustrates how two or more such monthly curves can be combined to form a seasonal flow duration curve. To avoid any confusion, all references to seasonal curves should be taken to mean flow duration curves covering two or more calendar months.

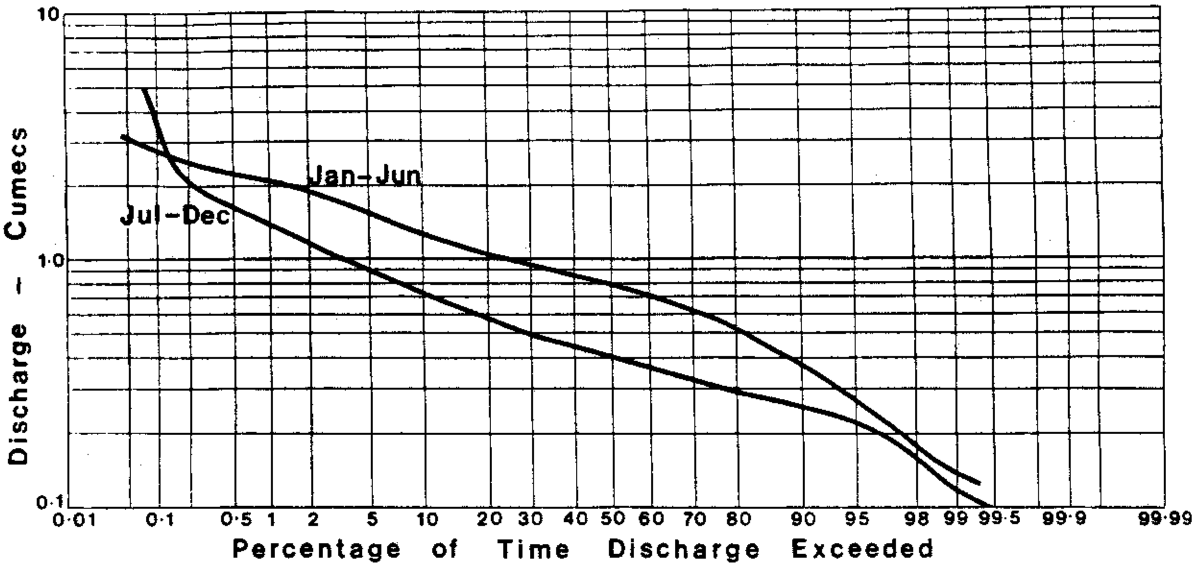


FIGURE 1.5 SIX MONTH SEASONAL FLOW DURATION CURVES FOR PANG

Figure 1.5 illustrates the differences between two six-month curves for the same catchment. As the Pang catchment is very permeable, the flows during the first six months of the year are in the main higher than for the rest of the year and this has resulted in the January-June curve being higher than that for July-December. It can be seen that the long term average flow of 0.65 cumecs is exceeded on 65% of days within the period January-June, but on only 15% of days during the rest of the year. The gradients of the two curves overall are similar indicating that whilst the daily flows over the period July-December are smaller in magnitude, they are just as variable.

The two curves on Figure 1.5 have been constructed for six month periods, but seasonal curves can be derived for between two and eleven month periods. An example in this manual calculates a seasonal curve covering the two month period July-August for the river Pang, both from data and using techniques recommended for the case where no data are available.

1.5 COMPARISON OF CURVES IN DIMENSIONLESS FORM

At this point, some nomenclature is outlined. Throughout the report, the average discharge over any particular month or season will be designated AMD with the period following immediately in brackets. Thus the average discharge for July is written AMD(July) and is expressed in cumecs. Later in the report, mention is made of the long term annual runoff volume ARV, and the percentage which occurs in each of the twelve calendar months. This monthly runoff is designated MRV with the appropriate calendar month in brackets following. The monthly runoff volume for August is thus designated MRV(Aug) and is always expressed as a percentage of the annual runoff volume. Daily mean discharge data provide adequate accuracy for constructing monthly and seasonal flow duration curves.

Thus far, all figures illustrating monthly and seasonal flow duration curves have had their ordinates expressed in cumecs. This is entirely desirable for practical applications where a particular curve is used in isolation, but is unsatisfactory where two or more curves need to be compared. For example flow duration curves drawn for two catchments, one very much larger than the other, would be difficult to compare because of the differences in magnitude of the daily flow values originating from the two catchments. This problem can be resolved by dividing the ordinates of the curve by the mean discharge. In addition to assisting the comparison of curves this also enables comparisons to be made with those estimated from the methods given in section 3 of this report. Figure 1.6 repeats the information of Figure 1.4 with the discharge axis standardised by the monthly average flow, AMD.

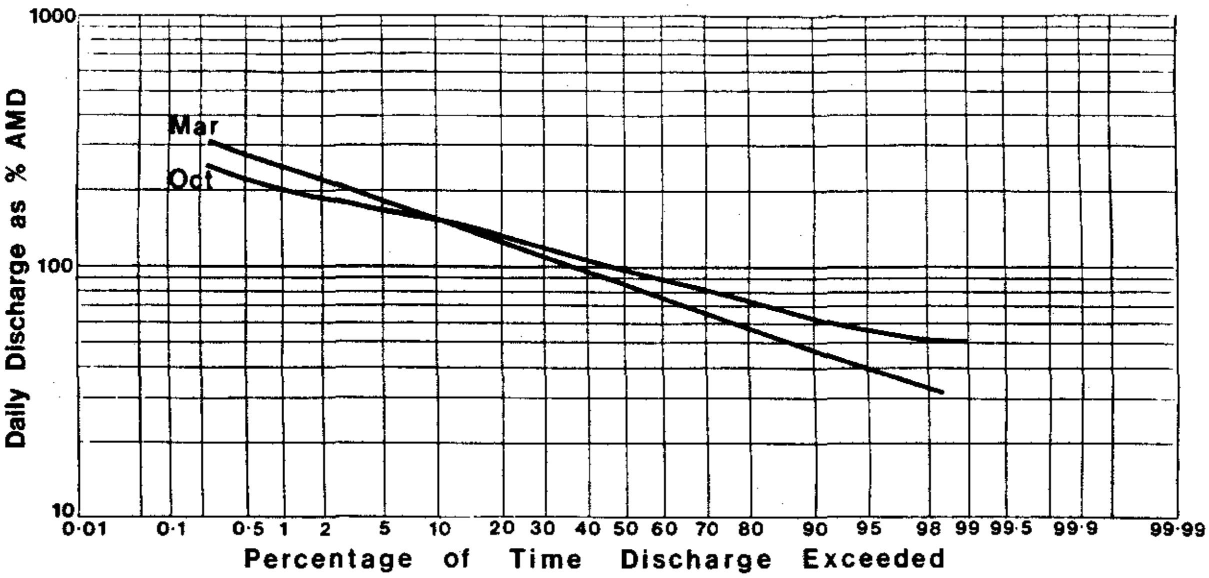


FIGURE 1.6 MARCH AND OCTOBER MONTHLY FLOW DURATION CURVES FOR THE PANG EXPRESSED AS PERCENTAGE OF AVERAGE MONTHLY DISCHARGE

1.6 OUTLINE OF ESTIMATION PROCEDURE

The procedure for estimating the seasonal flow duration curve depends on the length of data available at the site of interest. Figure 1.7 outlines the three main approaches and the sections where they are to be found, although an individual problem may well make use of elements from all three sections.

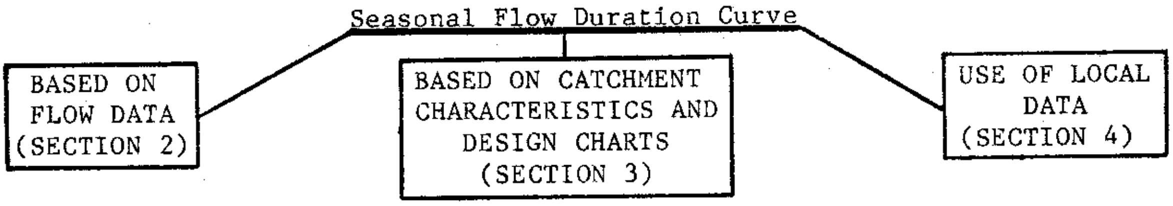


FIGURE 1.7 OUTLINE OF ESTIMATION PROCEDURE

Which of the three procedures to use depends on the amount of data available at the site of interest.

More than ten years	Use recommendations contained within section 2 in their entirety
Two to ten years	Use the data available to calculate a value of Q95(10) directly and then follow section 3.
Less than two years	Use section 3 recommendations in their entirety, although section 4.1 should be referred to if some data is available.

These are guidelines but there will be instances where departing from them is justified. If there were eight or nine years of data it could be useful to use both sections 2 and 3 and then to compare the two curves.

2.1 CONSTRUCTION OF MONTHLY FLOW DURATION CURVE ON LOG-NORMAL GRAPH PAPER

Table 2.1a shows the number of days which fall within each class interval for the three practice catchments. For the practice catchment selected, complete the table in a similar manner to that shown on Table 2.1, then plot the lower bound of each class interval against the corresponding entry in the final column on Figure 2.1a.

FALLOCH 11 YEARS (JAN)		LANGDON 11 YEARS (JAN)		ROMAN 14 YEARS (JAN)		NUMBER > BOTTOM OF c.i.	% GREATER THAN BOTTOM OF c.i.
c.i.	TOTAL IN INTERVAL	c.i.	TOTAL IN INTERVAL	c.i.	TOTAL IN INTERVAL		
0–1	49	0–0.1	48	0–0.1	28		
1–2	56	0.1–0.2	72	0.1–0.2	162		
2–3	34	0.2–0.3	49	0.2–0.3	86		
3–4	20	0.3–0.4	31	0.3–0.4	56		
4–5	17	0.4–0.5	21	0.4–0.5	31		
5–6	10	0.5–0.6	12	0.5–0.6	12		
6–7	11	0.6–0.7	10	0.6–0.7	14		
7–8	17	0.7–0.8	9	0.7–0.8	10		
8–9	4	0.8–0.9	8	0.8–0.9	7		
9–10	12	0.9–1.0	7	0.9–1.0	6		
10–11	11	1.0–1.1	7	1.0–1.1	1		
11–12	9	1.1–1.2	4	1.1–1.2	3		
12–13	2	1.2–1.3	8	1.2–1.3	2		
13–14	5	1.3–1.4	7	1.3–1.4	4		
14–15	6	1.4–1.5	3	1.4–1.5	3		
15–16	8	1.5–1.6	4	1.5–1.6	1		
16–17	6	1.6–1.7	4	1.6–1.7	–		
17–18	4	1.7–1.8	5	1.7–1.8	–		
18–19	8	1.8–1.9	3	1.8–1.9	1		
19–20	6	1.9–2.0	4	1.9–2.0	–		
20+	46	2.0+	25	2.0+	7		
Σ	= 341	Σ	= 341	Σ	= 434		

TABLE 2.1a **PREPARATION OF JANUARY FLOW DURATION CURVE DATA FOR PRACTICE CATCHMENT**

2. THE GAUGED CATCHMENT CASE

2.1 CONSTRUCTION OF MONTHLY FLOW DURATION CURVE ON LOG-NORMAL GRAPH PAPER

The particular example illustrated in this section shows the construction of a January monthly flow duration curve from data; however, the procedure is identical for any month.

The daily average flow data are sorted into conveniently chosen, equal and constant width class intervals (ci) expressed in discharge units. For the River Pang the discharges experienced during the month of January over the 16 year period between 1969 and 1984 range between 0.2 and 2.4 cumecs. The class interval width is chosen to give the degree of definition required; in the example case a figure of 0.1 cumecs is appropriate. Each day's discharge is assigned to its appropriate class interval (in Table 2.1) and a count made of the number of days within each interval. The number of days above the lower limit of each ci is entered in column 3 which is then expressed as a percentage exceedance in column 4 by dividing the entry in column 3 by 496, the total number of days in the record, and multiplying by 100.

The exercise has been completed for the river Pang, the results being entered into Figure 2.1.

(1) Class interval cumecs	(2) Total in class interval	(3) Number greater than bottom of ci	(4) Percentage greater than bottom of ci
2.4-2.5	0	0	0.0
2.3-2.4	1	1	0.2
2.2-2.3	3	4	0.8
2.1-2.2	3	7	1.4
2.0-2.1	3	10	2.0
1.9-2.0	8	18	3.6
1.8-1.9	3	21	4.2
1.7-1.8	5	26	5.2
1.6-1.7	6	32	6.5
1.5-1.6	14	46	9.3
1.4-1.5	8	54	10.9
1.3-1.4	11	65	13.1
1.2-1.3	14	79	15.9
1.1-1.2	22	101	20.4
1.0-1.1	19	120	24.2
0.9-1.0	40	160	32.3
0.8-0.9	51	211	42.5
0.7-0.8	38	249	50.2
0.6-0.7	74	323	65.1
0.5-0.6	74	397	80.0
0.4-0.5	59	456	91.9
0.3-0.4	15	471	95.0
0.2-0.3	25	496	100.0
	Σ = 496		

TABLE 2.1 PREPARATION OF JANUARY FLOW DURATION CURVE DATA FOR PANG CATCHMENT

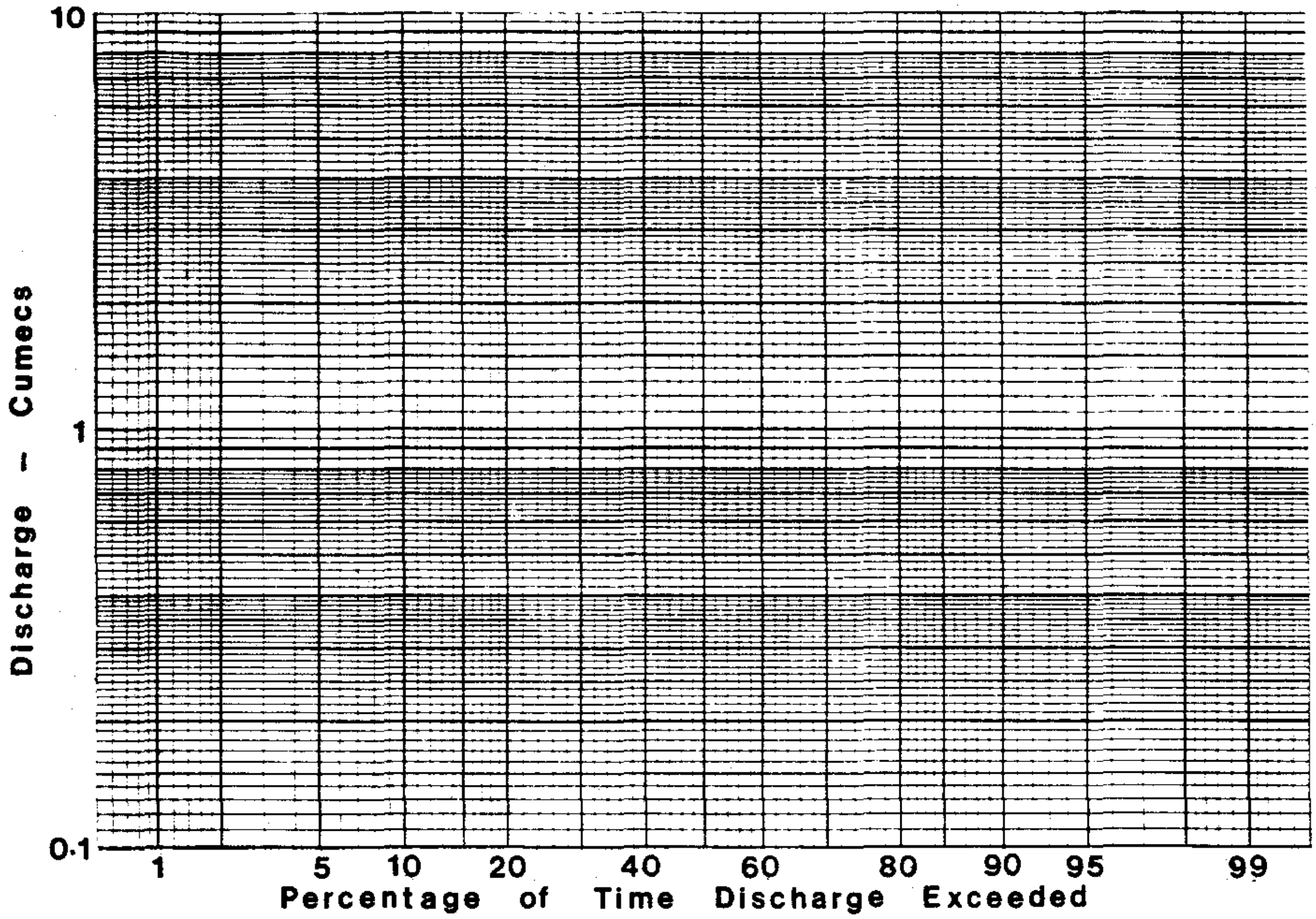


FIGURE 2.1a JANUARY MONTHLY FLOW DURATION CURVE FOR PRACTICE CATCHMENT

Figure 2.1 shows graphically the contents of Table 2.1. Each point on the figure is derived from the use of one row from Table 2.1. The lower bound of each class interval is used to fix the position on the ordinate, the corresponding point on the abscissa coming from column 4. For example, the class interval 1.0-1.1 cumecs has 120 of the total of 496 flow values greater than 1.0 cumec. Thus (120/496) x 100 or 24.2% of the time, the flow level 1.0 cumec is exceeded.

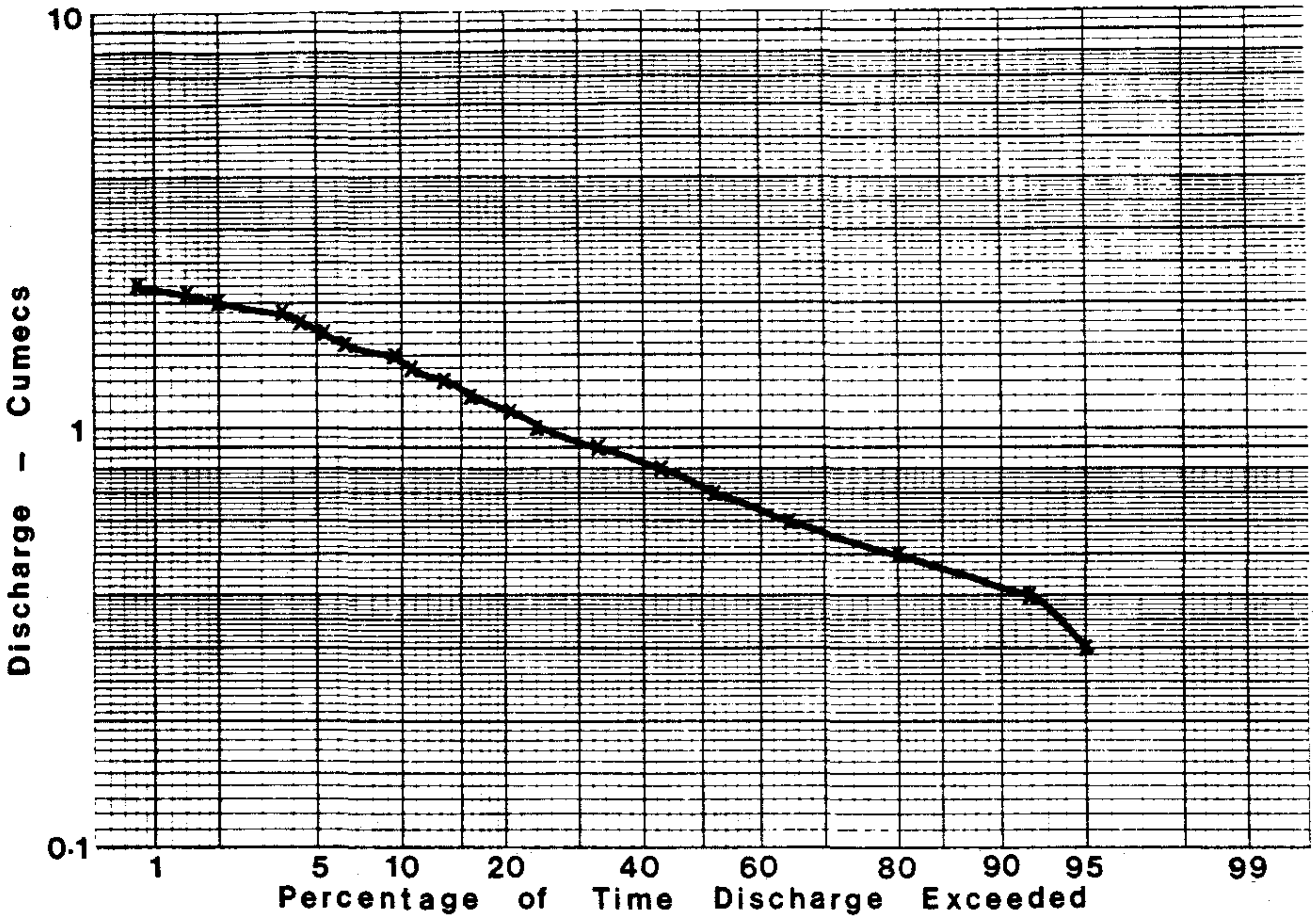


FIGURE 2.1 JANUARY MONTHLY FLOW DURATION CURVE FOR PANG CATCHMENT

Log-normal paper has been used to construct Figure 2.1. However, if none is available, linear graph paper can be used in conjunction with a technique for assigning a standard Normal deviate to the abscissa corresponding to the column 4 probabilities. In place of the daily flow values being plotted on a logarithmic ordinate, the logs of the daily flows can be plotted on a linear ordinate. The method itself is presented in detail in section 2.3 of Report 2.1. The result is identical to that produced by the method outlined in this report.

2.2 CONSTRUCTION OF SEASONAL FLOW DURATION CURVE ON LOG-NORMAL GRAPH PAPER

The technique for constructing a seasonal curve is practically identical to that for constructing a monthly curve. The only difference is that the daily flow data are taken from as many different calendar months as are required to make up the seasonal curve. Clearly seasonal curves will contain more daily flow values than a monthly curve constructed from the same flow record.

3.1 INTRODUCTION AND OUTLINE

Details of the three practice catchments can be found in Report 2.1, Chapter 1, Basic Data. Select the same catchment as was used in the gauged catchment case and complete the corresponding calculations as are executed for the River Pang.

3. THE UNGAUGED CATCHMENT CASE

3.1 INTRODUCTION AND OUTLINE

This section describes a procedure for estimating monthly and seasonal flow duration curves at sites where little or no flow data are available. The method is founded on estimating the 95 percentile, 10 day flow from the annual flow duration curve, Q95(10). The estimate of Q95(10) requires a knowledge of the catchment's annual average rainfall (SAAR) and baseflow index (BFI). The full method for estimating Q95(10) will be found in Report 2.1 and salient points for the ungauged case are repeated here in section 3.2.

Before embarking on the practice exercise it may be helpful to review the procedure in its totality. The following summary list of steps should assist in placing each step in the context of the entire calculation.

(1) Estimate Q95(10) from catchment characteristics. At this point the result is expressed as a percentage of the average discharge of the catchment (section 3.2).

(2) Enter Figures 3.2a and 3.2c with the previous result to determine Q95 and Q5 for the particular months of interest. At this point the results are expressed in terms of the average flow of those months (section 3.3).

(3) Using the suggested procedure of section 3.4 to derive the average flow, convert this to monthly runoff volume (MRV) with figures 3.6 and 3.7, or tables 3.2 and 3.2a.

(4) Rescale the results of step (2) to cumecs using the appropriate value from step (3).

(5) If seasonal flow duration curves are required, covering a period of two or more months, it will be necessary to combine the appropriate monthly curves. Instructions on how this is achieved are described in section 3.5.

The remaining steps in the procedure for estimating monthly and seasonal flow duration curves require no further use to be made of catchment characteristics, but depend on a set of tables and diagrams. The first of these diagrams, Figures 3.2 (a & c), allow the standardised Q95 and Q5 values to be obtained for any month which in turn, are rescaled to discharge terms using information on the mean monthly flow distribution contained in Figures 3.6 and 3.7, and Tables 3.2 and 3.2a. The relations apply to rivers of all types and in all parts of the United Kingdom.

3.2 ESTIMATION OF 95 PERCENTILE 10 DAY FLOW

The example catchment is in hydrometric area ------ and therefore in region ----. Substituting the catchment characteristic values into the appropriate equation.

$$\sqrt{Q95(10)} = \text{---}\sqrt{BFI} + \text{----}\sqrt{\quad} - \text{----}$$

$$=$$

$$\therefore Q95(10) = \text{-----} \text{ \% ADF}$$

Values of BFI, SAAR, and L would at an ungauged site be normally estimated from maps. However, in the case of the three practice catchments, these values are known and can be used instead of resorting to maps if desired.

	BFI	SAAR	L
Falloch	0.18	3030	-
Langdon	0.20	1621	-
Roman	0.62	581	15.35

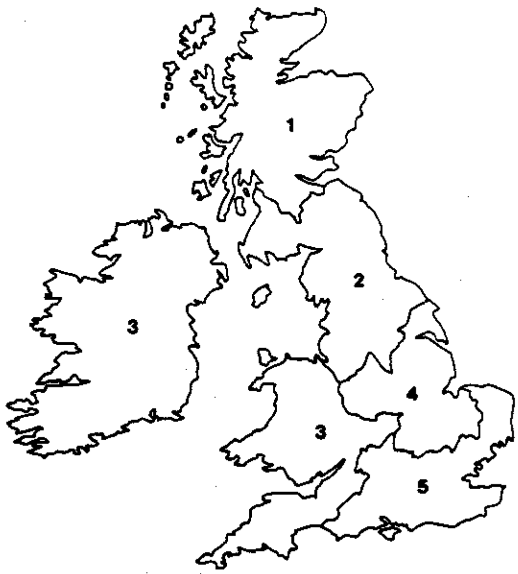
3.2 ESTIMATION OF 95 PERCENTILE 10 DAY FLOW

Table 3.1 shows the regression equations to use in the regions of the country shown in Figure 3.1. The equations give an estimate of the 95 percentile from the 10 day flow duration curve, Q95(10) in units of %ADF.

SAAR is the 1941-1970 standard average rainfall in mm and BFI is the catchment's baseflow index which is estimated at the ungauged site from catchment geology. Report No. 3, section 3.2 shows the procedure.

TABLE 3.1. Regional external relationship regression equations

Eqn No	Hydrometric areas	Equation $\sqrt{Q95(10)}$ =
1	1-19, 84-97, 104-108	$7.60\sqrt{BFI}+0.0263\sqrt{SAAR}-1.46$
2	20-25, 27, 68-83, 103	$7.60\sqrt{BFI}+0.0263\sqrt{SAAR}-1.84$
3	45-67, 102, 201-223	$7.60\sqrt{BFI}+0.0263\sqrt{SAAR}-2.16$
4	26, 28-33	$11.9\sqrt{BFI}+0.1150\sqrt{SAAR}-8.03$
5	34-44, 101	$8.51\sqrt{BFI}+0.0211\sqrt{L}-1.91$



Eqn.	Hydrometric Areas.
1	1-19,84-97,104-108
2	20-25,27,68-83,103
3	45-67,102,201-223
4	26,28-33
5	34-44,101

FIGURE 3.1 KEY MAP TO EXTERNAL REGIONAL RELATIONSHIP

Using equation 5 (the Pang catchment is in hydrometric area 39) and the value of BFI=0·9 and L=26·9 km

$$\sqrt{Q95(10)}=8.51\sqrt{0\cdot9}+0.0211\sqrt{26\cdot9}-1.91$$

$$= 6\cdot273$$

so $Q95(10)=39\cdot35$ %ADF

3.3 ESTIMATION OF FLOW DURATION CURVE AS PERCENTAGE OF AVERAGE MONTHLY DISCHARGE

Use Figures 3.2(a & c) in association with the value of Q95(10) derived for the practice catchment in section 3.2, to interpolate values for Q95 and Q5. This exercise must be done for each month to be incorporated in the seasonal curve, in this instance July and August.
Use Figures 3.3(a & c) to plot the values of Q95 and Q5 for both July and August, and hence draw the respective monthly flow duration curves.

		July	August
Q95	=		
Q5	=		

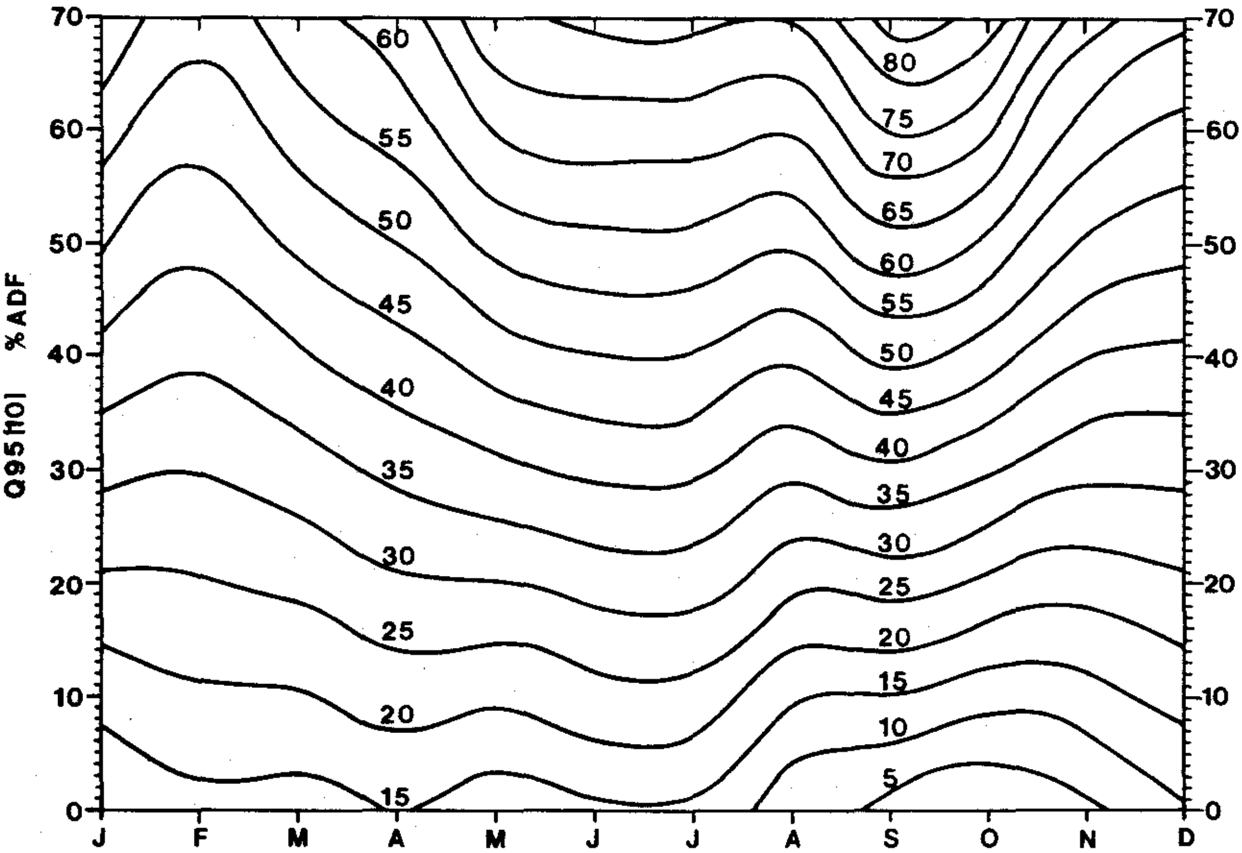


FIGURE 3.2a PREDICTION OF Q95 FOR EACH MONTH

3.3 ESTIMATION OF FLOW DURATION CURVE AS PERCENTAGE OF AVERAGE MONTHLY DISCHARGE

Estimates of Q5 and Q95 are needed for both July and August. Two figures are illustrated which allow the direct estimation of these two percentiles for each month. The value of Q95(10), 39.35% ADF, is used to enter the Figures on their respective ordinates, and to scale across each figure to read off the appropriate percentile for both months, on each figure. It will be found necessary to interpolate between contour lines to arrive at accurate estimates. The 95 and 5 percentiles for both July and August have been marked on Figures 3.2b and 3.2d

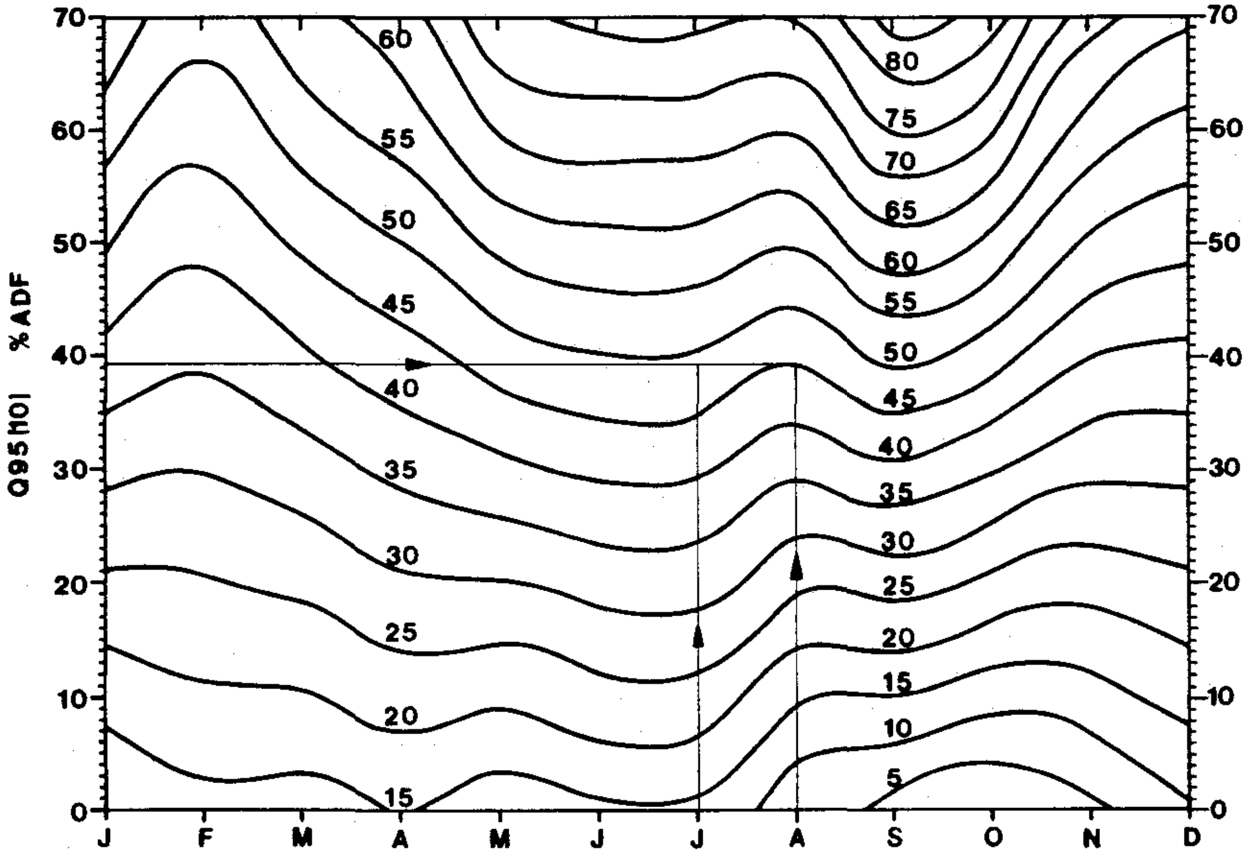


FIGURE 3.2b INTERPOLATING Q95 FOR JULY AND AUGUST

	July	August
Q95 =	49	45
Q5 =	155	175

It is emphasised that these results are expressed in terms of their respective month's AMD. For example, July's Q95 is 49% of the July AMD.

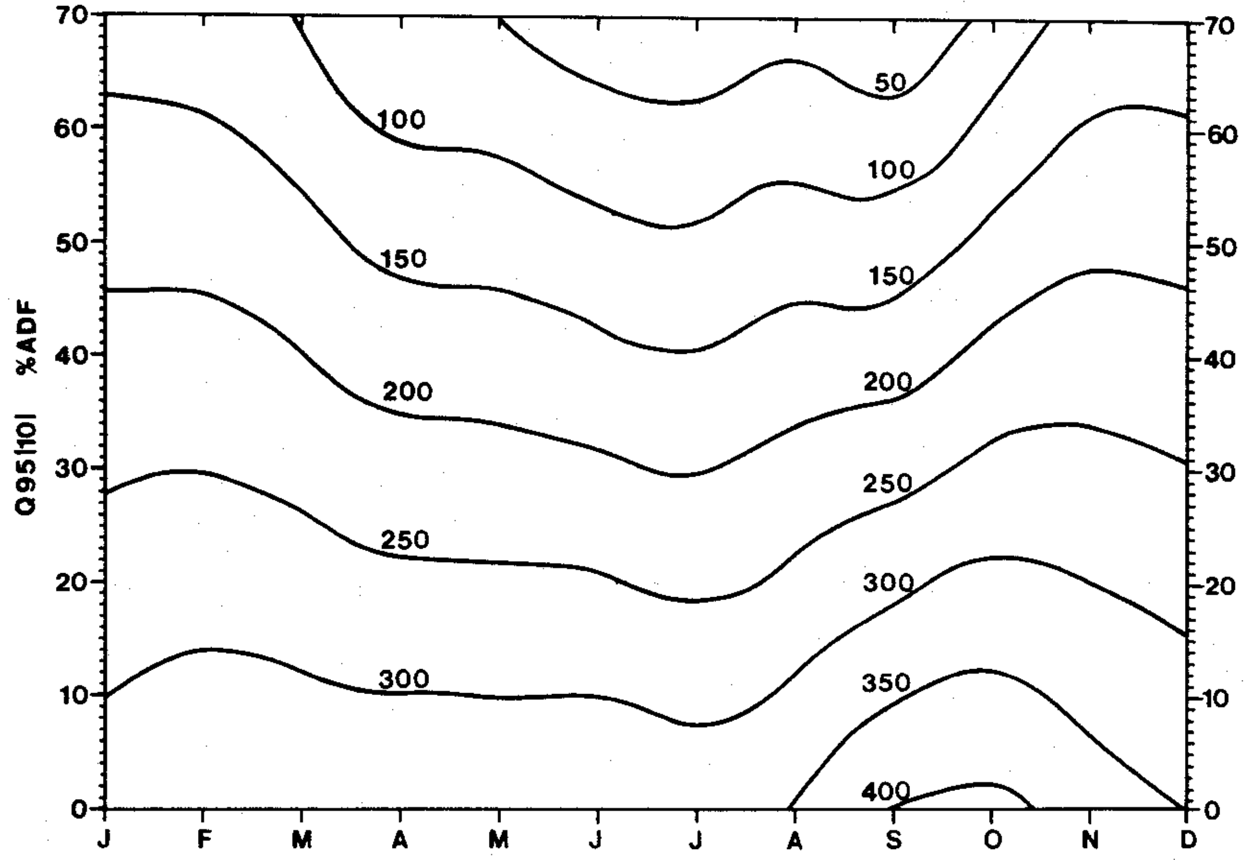


FIGURE 3.2c PREDICTION OF Q5 FOR EACH MONTH

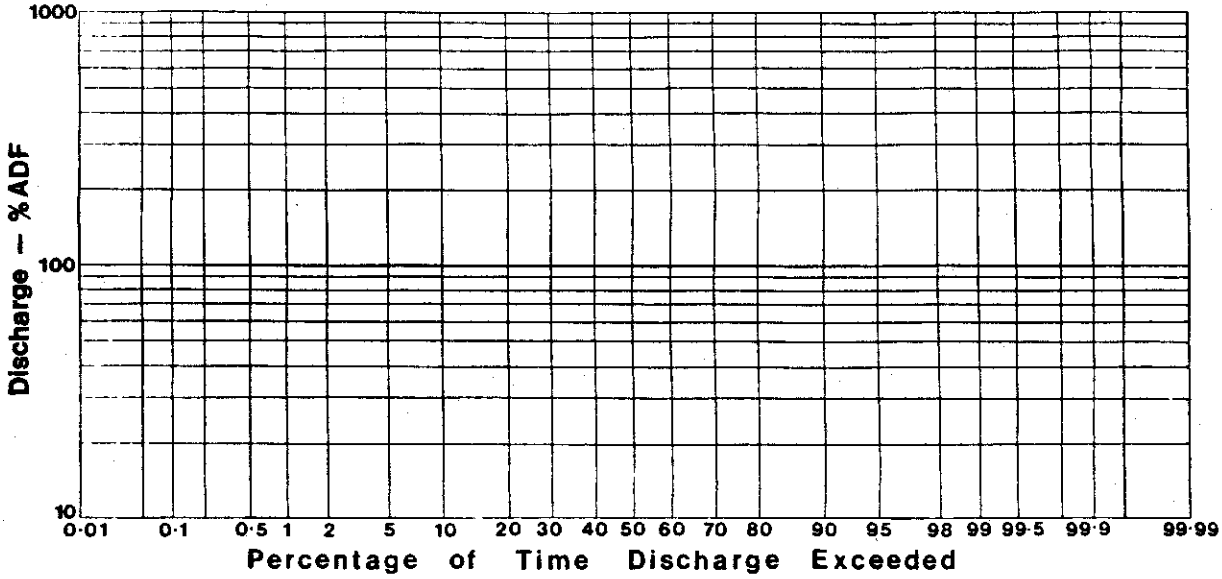


FIGURE 3.3a MONTHLY FLOW DURATION CURVES AS %ADF FOR PRACTICE CATCHMENT

A flow duration curve should be linearly interpolated and extrapolated using the 5 and 95 percentiles for each month required. Figure 3.3 is provided for this purpose. The next section describes how to rescale the ordinates to cumecs.

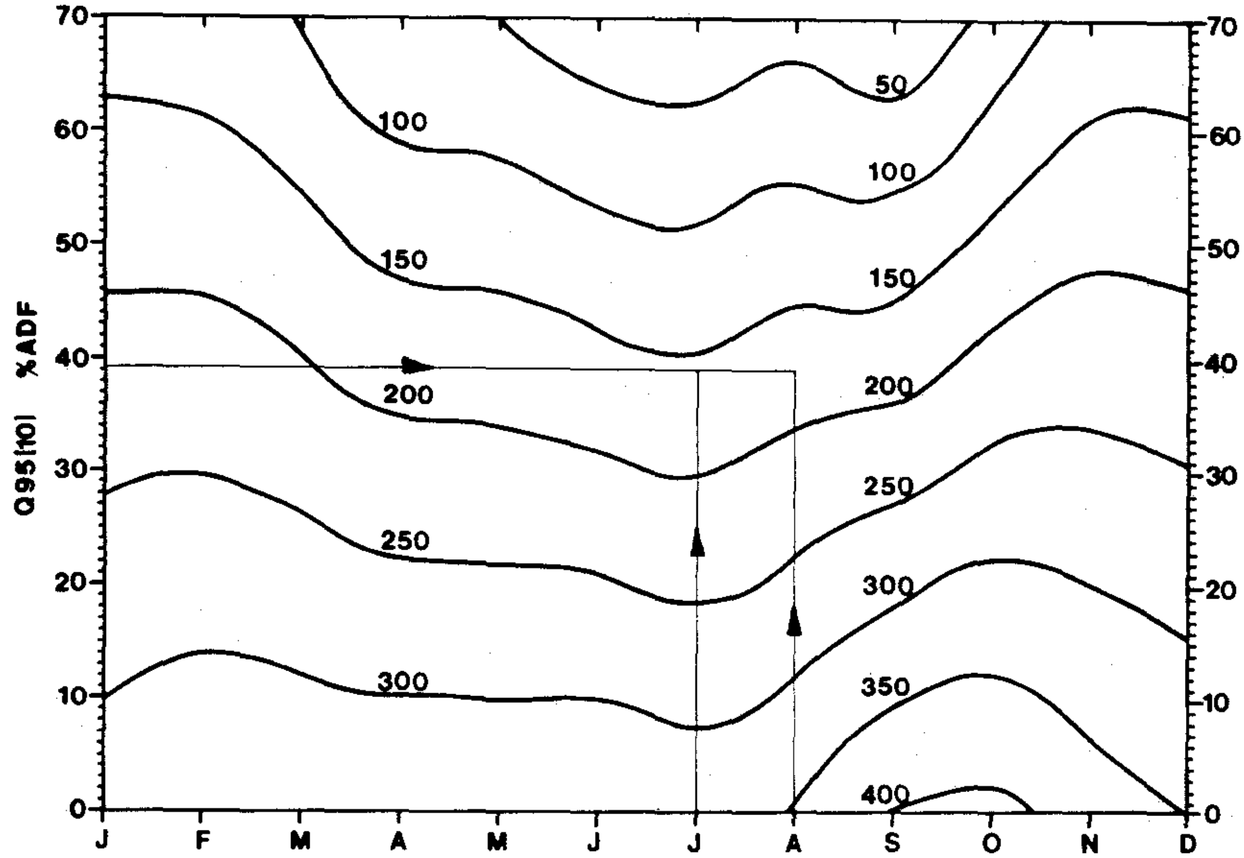


FIGURE 3.2d INTERPOLATING Q5 FOR JULY AND AUGUST

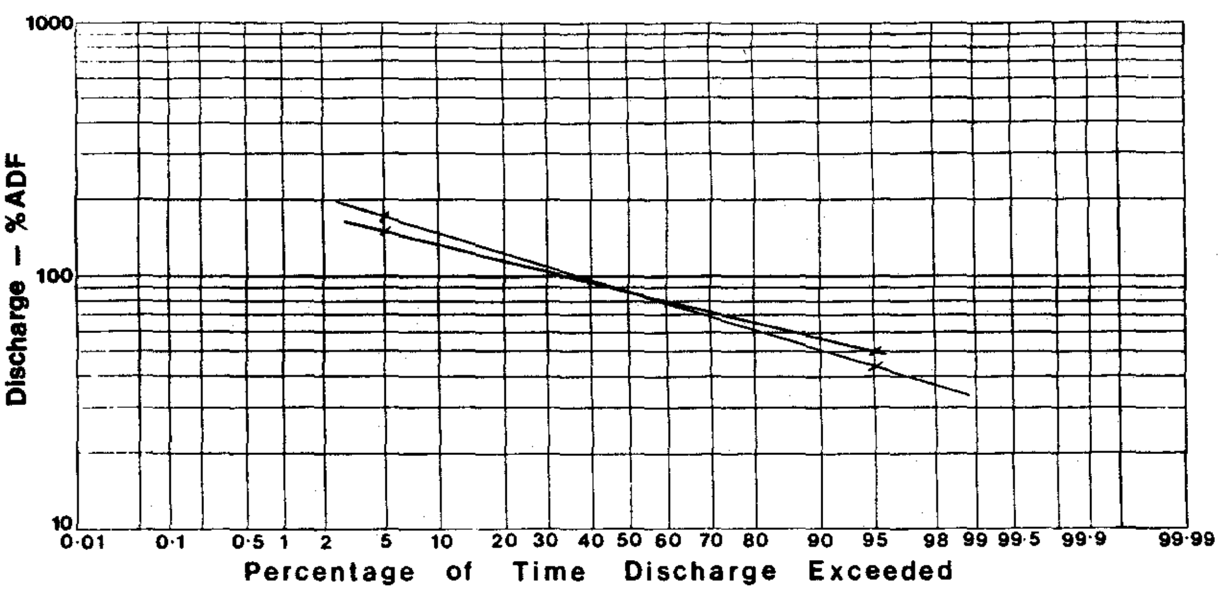


FIGURE 3.3 MONTHLY FLOW DURATION CURVES AS %ADF FOR JULY AND AUGUST FOR PANG

3.4 CALCULATION OF AVERAGE DISCHARGE (ADF)

The values of SAAR and PE can be abstracted from maps as detailed overleaf; however the values required are also listed for reference.

	SAAR(mm)	PE(mm)	AREA(km^2)
Falloch	2700	375	80.3
Langdon	1600	400	13.0
Roman	570	542	52.6

For the .... catchment, SAAR = ..., and

therefore the reduction ratio r is ....

$AE = r \times PE =$ .... x .... = ...

Annual runoff; $ADF = SAAR - AE =$ .... - .... = ... mm

$= 0.00003171 \times AREA \times$ *Annual runoff mm*

$= 0.00003171 \times$ .... x .... = ... cumecs

3.4 CALCULATION OF AVERAGE DISCHARGE (ADF)

Report 3 of the Low Flow Series, P9, contains recommendations for estimating the long term average flow, using mapped values of potential evaporation (PE), or long period data at a nearby site. Potential evaporation is estimated from the Meteorological Office 1:2,000,000 map of annual average potential evaporation.

PE = 540 mm

This figure is then reduced to actual evapotranspiration (AE) using the tabulated factor r and AE = r x PE.

SAAR	500	600	700	800	900	1000	1100
r	0.88	0.90	0.92	0.94	0.96	0.98	1.00

For the Pang catchment AE = 0·92 x 540 = 497 mm

Annual runoff = SAAR - AE = 722 - 497 = 225 mm

Convert mm to cumecs by multiplying the mm figure by 0.00003171 x AREA = 0·00542

ADF = 0·00542 x 225 = 1·22 cumecs.

3.5 ESTIMATION OF MONTHLY RUNOFF VOLUME (MRV)

None of the three practice catchments are in Northern Ireland, therefore use the value of Q95(10) estimated in section 3.1 to decide whether paragrpahs (b) or (c) opposite, are appropriate. Then use the appropriate figure or table to determine MRV for each month required.

Northern Ireland	*Use*
All catchments	*Table 3.2*
Great Britain	
0<Q95(10)<15	*Figure 3.6*
15<Q95(10)<30	*Figure 3.7*
30<Q95(10)	*Table 3.2a*

3.5 ESTIMATION OF MONTHLY RUNOFF VOLUME (MRV)

In this section, the procedure for estimating monthly runoff volume (MRV) at an ungauged site in the UK is presented. Remember that MRV is expressed as a percentage of long term annual runoff volume. All catchments fall within one of three categories leading to a different method of MRV estimation in each case.

(a) Catchments in Northern Ireland

(b) Catchments in Great Britain with Q95(10) ≤ 30%

(c) Catchments in Great Britain with Q95(10) ≥ 30%

(a) Table 3.2 gives MRV values for each month for all Northern Ireland catchments. The values shown are average ones for use throughout Northern Ireland and have been compiled from an anlaysis of 21 gauging records distributed across the country.

Table 3.2 **Monthly runoff volume (MRV) as percent for Northern Ireland catchments**

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16.8	12.3	8.7	5.3	3.9	2.7	2.4	3.4	5.9	9.9	12.9	16.0

There is insufficient regional variation to justify any attempt at a higher level of accuracy, as would be provided by a contour map of MRV for each month. Table 3.2 is used in an identical manner to Table 3.2a which is used to explain the Pang example at the end of this section.

(b) The more impermeable catchments within Great Britain, those with a Q95(10) of less than 30%, display a significant regional variation in MRV which is represented by two series of monthly maps as follows.

0 ≤ Q95(10) ≤ 15	Figure 3.6 (1-12)
15 ≤ Q95(10) ≤ 30	Figure 3.7 (1-12)

(c) Table 3.2a gives MRV values for each month for those catchments in Great Britain which have a Q95(10) value greater than 30%. Most of such catchments are to be found on the chalk aquifers in central southern England and East Anglia.

Table 3.2a **Monthly runoff volume (MRV) as percent for G.B. catchments with Q95(10) ≥ 30%**

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11.8	14.2	13.0	10.3	8.1	6.4	5.0	4.6	4.5	5.3	7.0	9.8

July MRV = _ _ _ _ _ _ _ _ _ _ _ _ _

Aug MRV = _ _ _ _ _ _ _ _ _ _ _ _ _

$$AMD(JULY) = \frac{\_\_\_\_\_\_ \; x \; \_\_\_\_\_\_}{(100/12)} \; cumecs$$

$$AMD(AUG) = \frac{\_\_\_\_\_\_ \; x \; \_\_\_\_\_\_}{(100/12)} \; cumecs$$

For the Pang Q95(10) = 39.35 %ADF and so Table 3.2a rather than either of Figures 3.6 or 3.7 must be used. The following equation should be used to derive average monthly discharge from MRV, irrespective of whether MRV originates from Table 3.2, Table 3.2a, Figure 3.6, or Figure 3.7.

$$\text{AMD} = \frac{\text{MRV x ADF}}{(100/12)}$$

The denominator arises from the fact that monthly and annual average discharge are calculated over different time periods and from the fact that MRV is expressed as a percent.

So for July: $\text{AMD} = \frac{5 \cdot 0 \text{ x ADF}}{(100/12)} = 0 \cdot 732$ cumecs

Similarly for August: $\text{AMD} = \frac{4 \cdot 6 \text{ x ADF}}{(100/12)} = 0 \cdot 673$ cumecs

3.6 CONVERSION OF MONTHLY FLOW DURATION CURVE TO ABSOLUTE UNITS

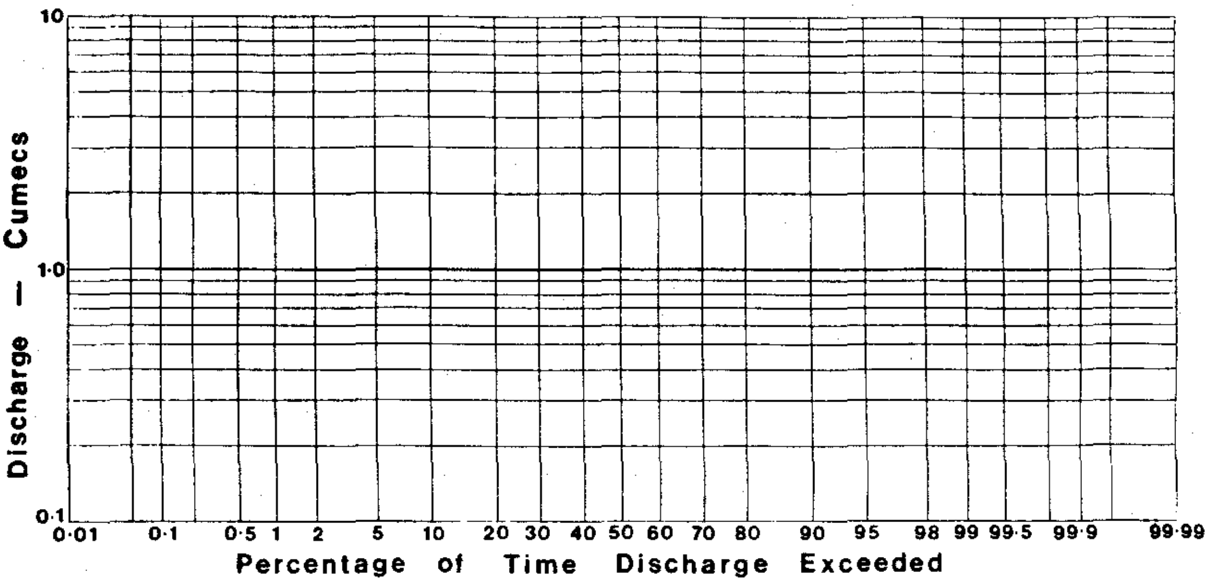


FIGURE 3.4a MONTHLY FLOW DURATION CURVES IN CUMECS FOR PRACTICE CATCHMENT

3.6 CONVERSION OF MONTHLY FLOW DURATION CURVE TO ABSOLUTE UNITS

Previously calculated values of Q95 and Q5 originally expressed as a percent of their own AMD can now be rescaled to cumec terms and then plotted on Figure 3.4. If all that is required is a one calendar month flow duration curve e.g. for July alone, then the procedure terminates here. If however a seasonal curve composed of two or more calendar months is required, the next section contains details of how curves can be combined.

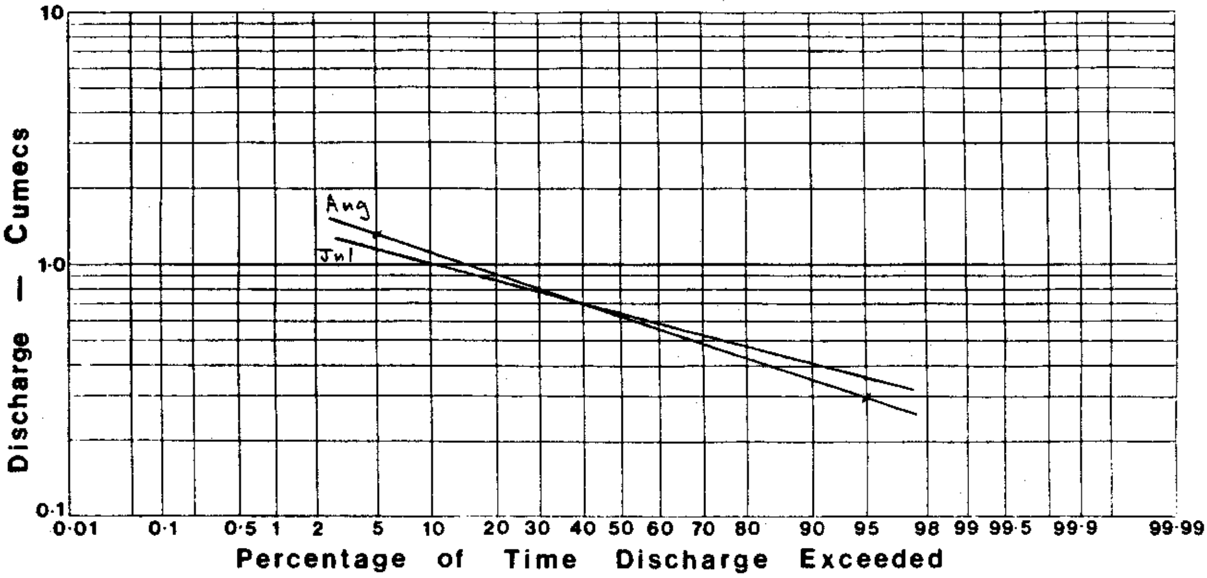


FIGURE 3.4 MONTHLY FLOW DURATION CURVES IN CUMECS FOR JULY AND AUGUST FOR PANG

3.7 CONSTRUCTING SEASONAL FLOW DURATION CURVES FROM TWO OR MORE MONTHLY CURVES

Complete Table 3.3a below using information taken from Figure 3.4a. Choose discharges for which percentiles can be used from all monthly curves to be incorporated within the seasonal curve.

FLOW CUMECS	J	F	M	A	M	J	J	A	S	O	N	D	SEASONAL PERCENTILE

TABLE 3.3a MONTHLY PERCENTILES TO BE AVERAGED FOR PRACTICE CATCHMENT

3.7 CONSTRUCTING SEASONAL FLOW DURATION CURVES FROM TWO OR MORE MONTHLY CURVES

The example below shows the derivation of a flow duration curve for a season composed of July and August. The procedure is similar if three or more months are to be used. Percentiles from the curves for July and August, expressed in cumecs on Figure 3.4, are entered into Table 3.3 below.

Flow cumecs	J	F	M	A	M	J	J	A	S	O	N	D	SEASONAL PERCENTILE
0·3							98	95					96·5
0·4							90	84					87
0·5							73	69					71
0·6							57	55					56
0·7							40	40					40
0·8							27	30					28·5
0·9							17	20					18·5
1·0							10	15					12·5
1·1							5	10					7·5

TABLE 3.3 MONTHLY PERCENTILES TO BE AVERAGED FOR PANG

Average the percentiles for each month of the required season across the table. The resulting average figures are entered into the final column. This column when completed, becomes the abscissa of the seasonal curve, whilst column 1 provides the corresponding ordinate information. Figure 3.5 has been drawn using the first and final columns of Table 3.3, and is the end result of the method.
Any seasonal curve of between two and eleven months can be constructed in this way. Do not be tempted to average monthly flow duration curves vertically. This will give incorrect results especially if the individual curves are far separated. Also it is invalid to average standardised curves at the Figure 1.3 stage. The method presented above is the only correct approach.

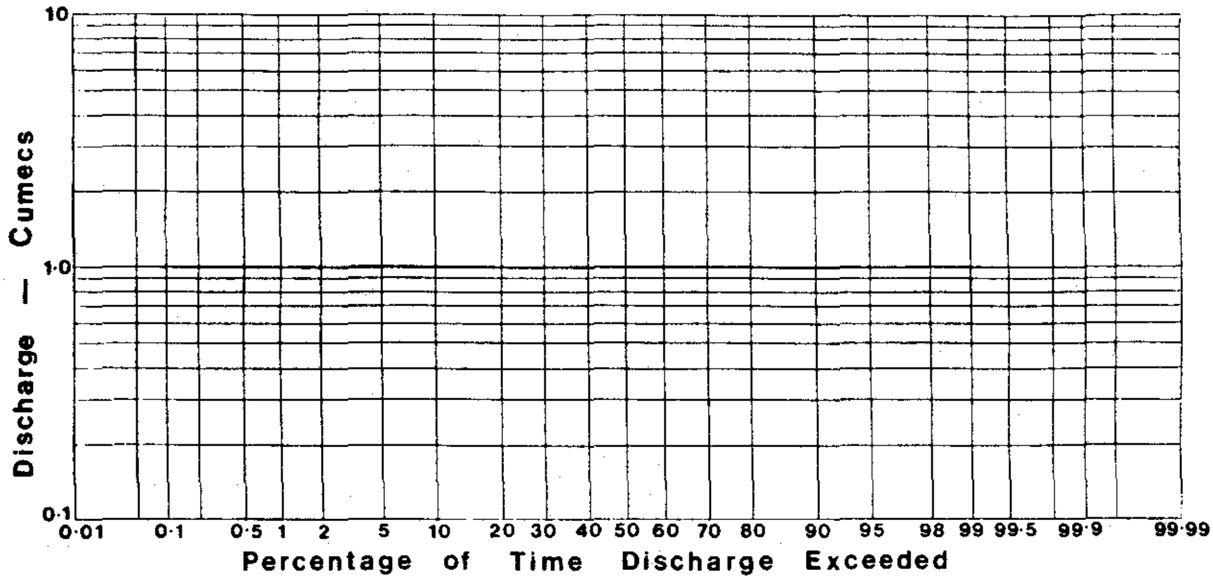


FIGURE 3.5a SEASONAL FLOW DURATION CURVE IN CUMECS FOR PRACTICE CATCHMENT

Note that seasonal flow duration curves constructed from two or more calendar months need no longer plot as a straight line on the lognormal graph paper. It is suggested that an eye guided straight line is drawn through the plotted points.

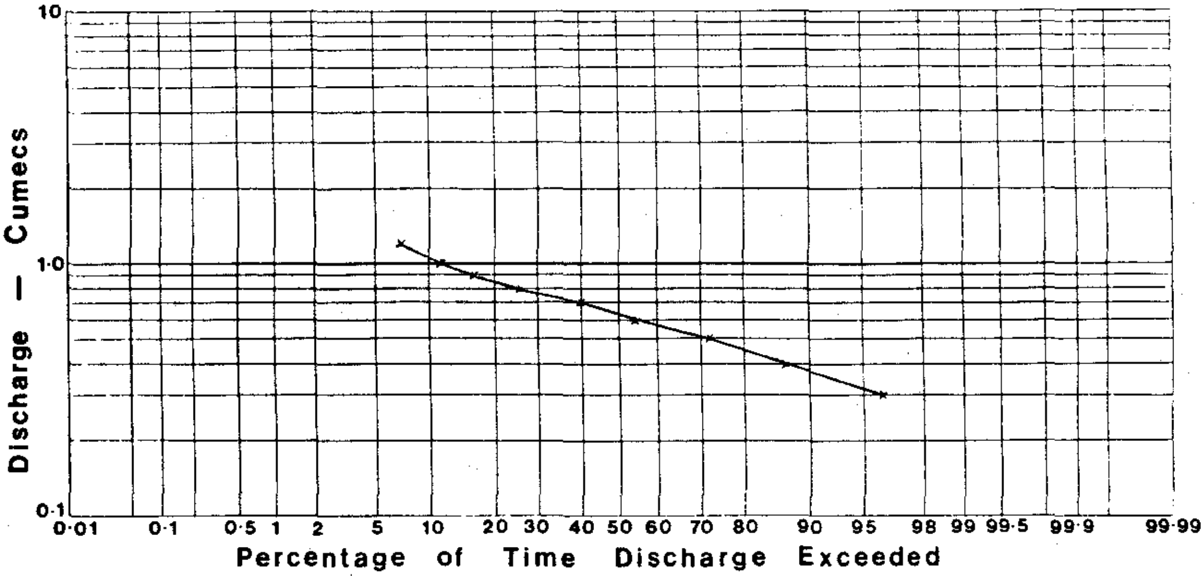


FIGURE 3.5 SEASONAL FLOW DURATION CURVE IN CUMECS FOR JULY AND AUGUST FOR PANG

4. USE OF LOCAL DATA

In this chapter a number of methods of incorporating short data records from or near the site of interest are outlined.

4.1 Data from the site of interest

If a temporary gauging structure has been installed at a site where a seasonal flow duration curve is needed, it is possible to make use of the short data period resulting

(a) If 1 or 2 years of data are available, use the ungauged technique outlined in Chapter 3 and make use of the data to calculate a BFI value by the method given in Report No.3, section 3.1. The BFI can then be used in the regression equation to allow a more accurate estimate of Q95(10) than would result by using a value of BFI arrived at by consideration of geological maps.

(b) If between 2 and 10 years data are available, use them to calculate a value of Q95(10) directly, Report 2.1, section 2.1, and continue with the ungauged recommendations in section 3.3 of this report. In addition use the data to calculate the percentage of the annual runoff occurring in each of the twelve months as a check on the value given by Figures 3.6, 3.7 or Table 3.2.

(c) If more than 10 years data are available, use the techniques of Chapter 2.

4.2 Data from a nearby site

The monthly flow duration curves are controlled primarily by the MRV distribution around the year. If there is a nearby site with sufficient record (e.g. 10 years) then we recommend strongly that its data be used to provide an estimate of MRV for the site and months of interest, especially if the respective Q95(10) values place the two catchments in the same section 3.4 category. In such a case one may apply the ungauged techniques of section 3.3 and 3.4 to obtain Q95, Q5 and ADF for the site of interest. These quantities would then be rescaled using the data-based values of MRV in equation 3.1 to yield a better estimate of the monthly flow duration curve.

4.3 Monthly data

Monthly data at or near the site of interest can be used to determine the monthly runoff volume, either in absolute or MRV terms. The weight that can be attached to the resulting figures will be dependent on the period of data available. This information can then be used in preference to Figures 3.6, 3.7 or Table 3.2 in section 3.4.

4.4 Current metering

Section 4 of Report 2.1 describes a method of using several current meterings at the site of interest in association with a known annual flow duration curve at a nearby gauged site to construct an annual flow duration curve at the required site. The technique is identical for a monthly or seasonal curve except that clearly the current meterings must all be made during the calendar months for which the curve is intended.

FIGURE 3.6 (JAN) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10)< 15% ADF

FIGURE 3.6 (FEB) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

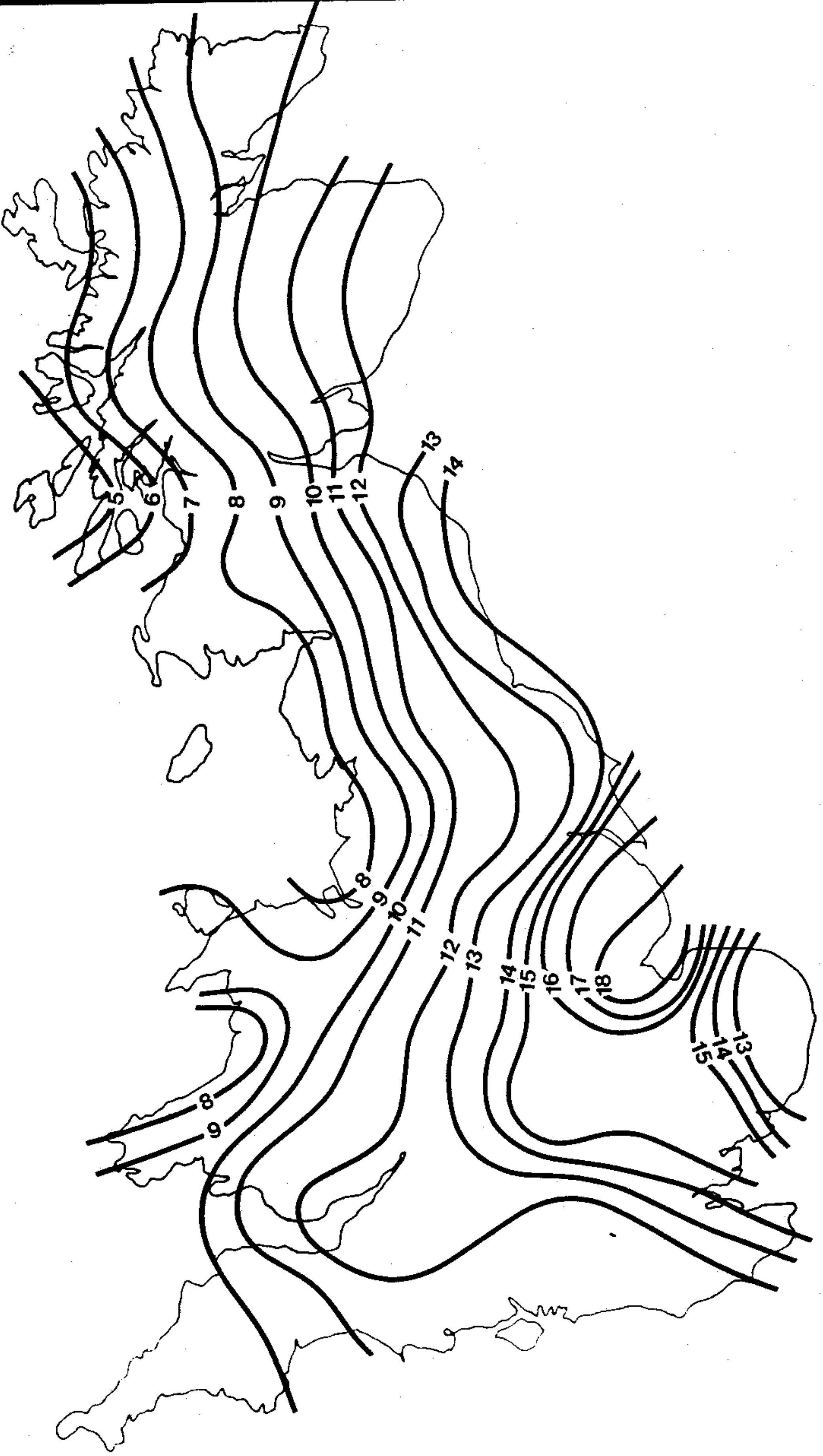


FIGURE 3.6 (MAR) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

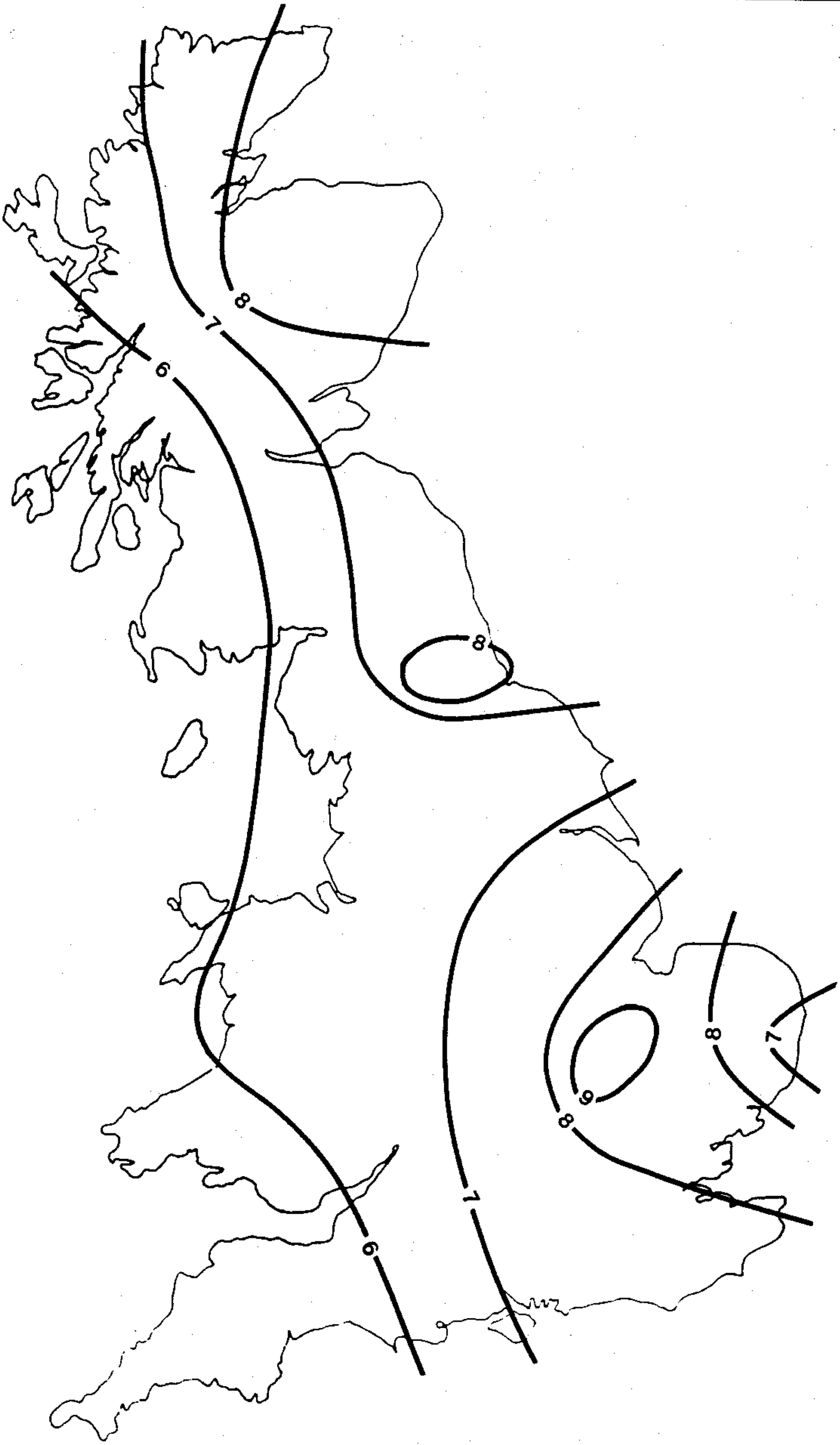


FIGURE 3.6 (APR) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (MAY) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH
0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (JUN) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (JUL) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (AUG) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (SEPT) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH
0% ADF < Q95(10) < 15% ADF

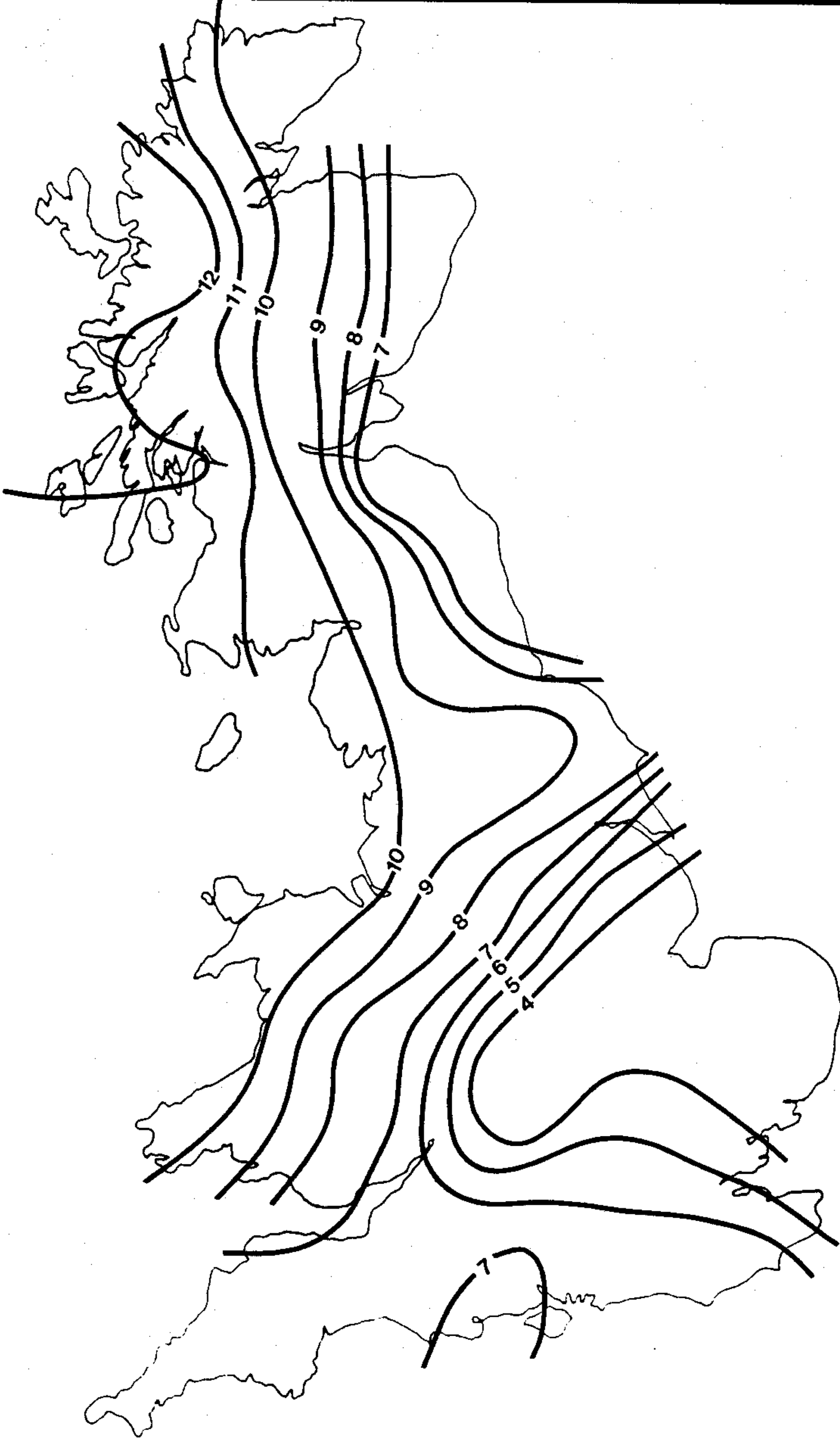


FIGURE 3.6 (OCT) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (NOV) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.6 (DEC) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 0% ADF < Q95(10) < 15% ADF

FIGURE 3.7 (JAN) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

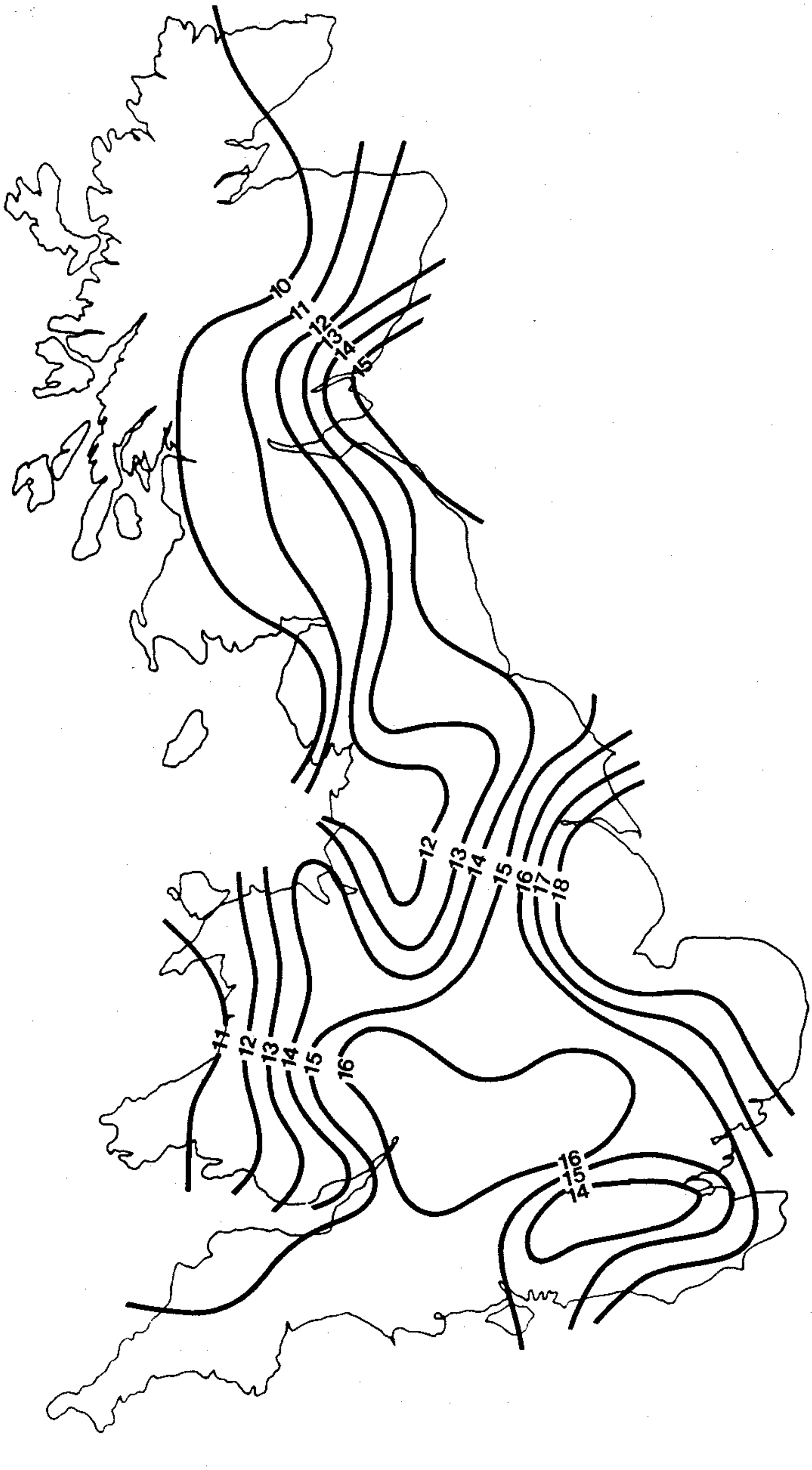


FIGURE 3.7 (FEB) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

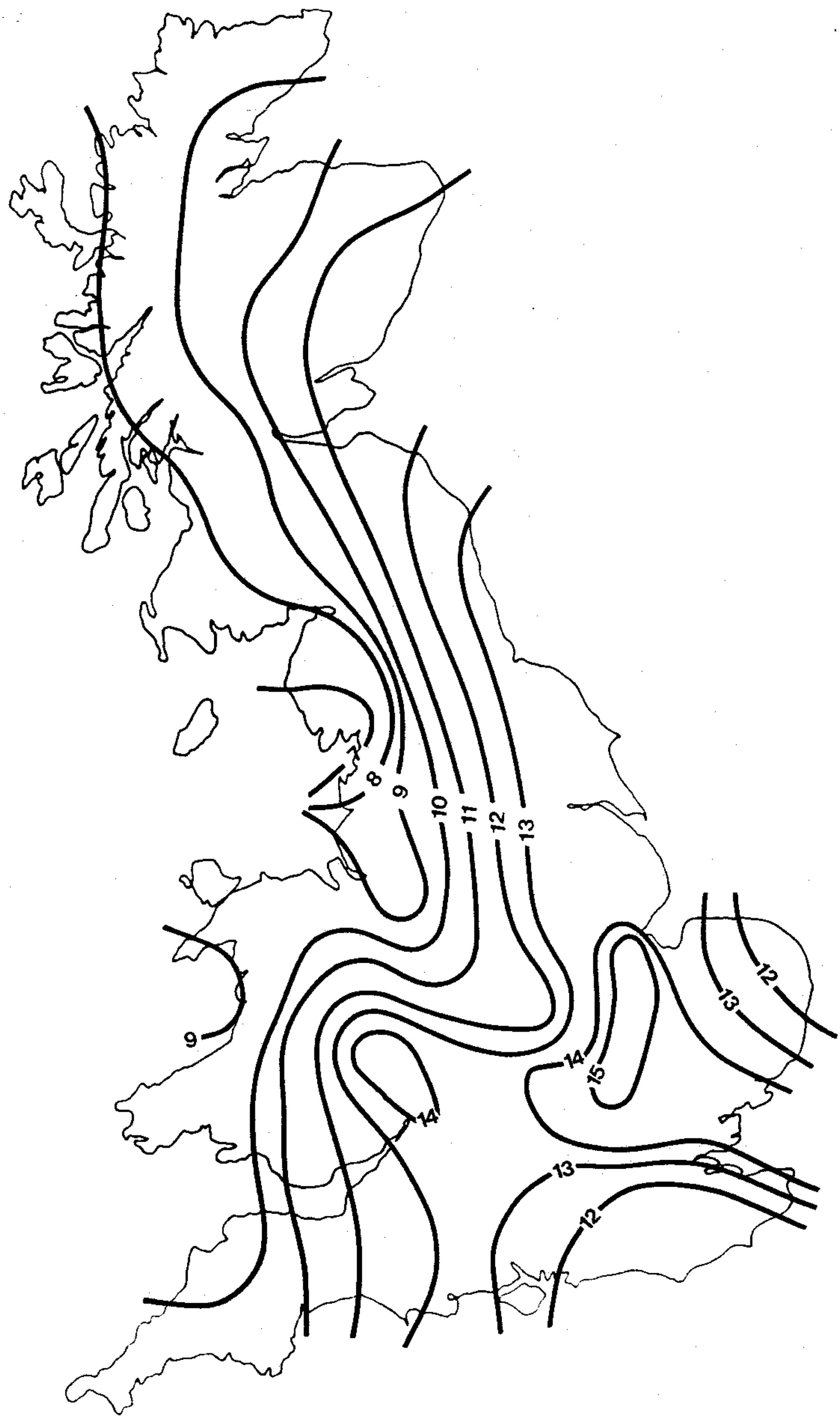


FIGURE 3.7 (MAR) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (APR) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH
15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (MAY) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (JUN) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (JUL) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (AUG) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (SEPT) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

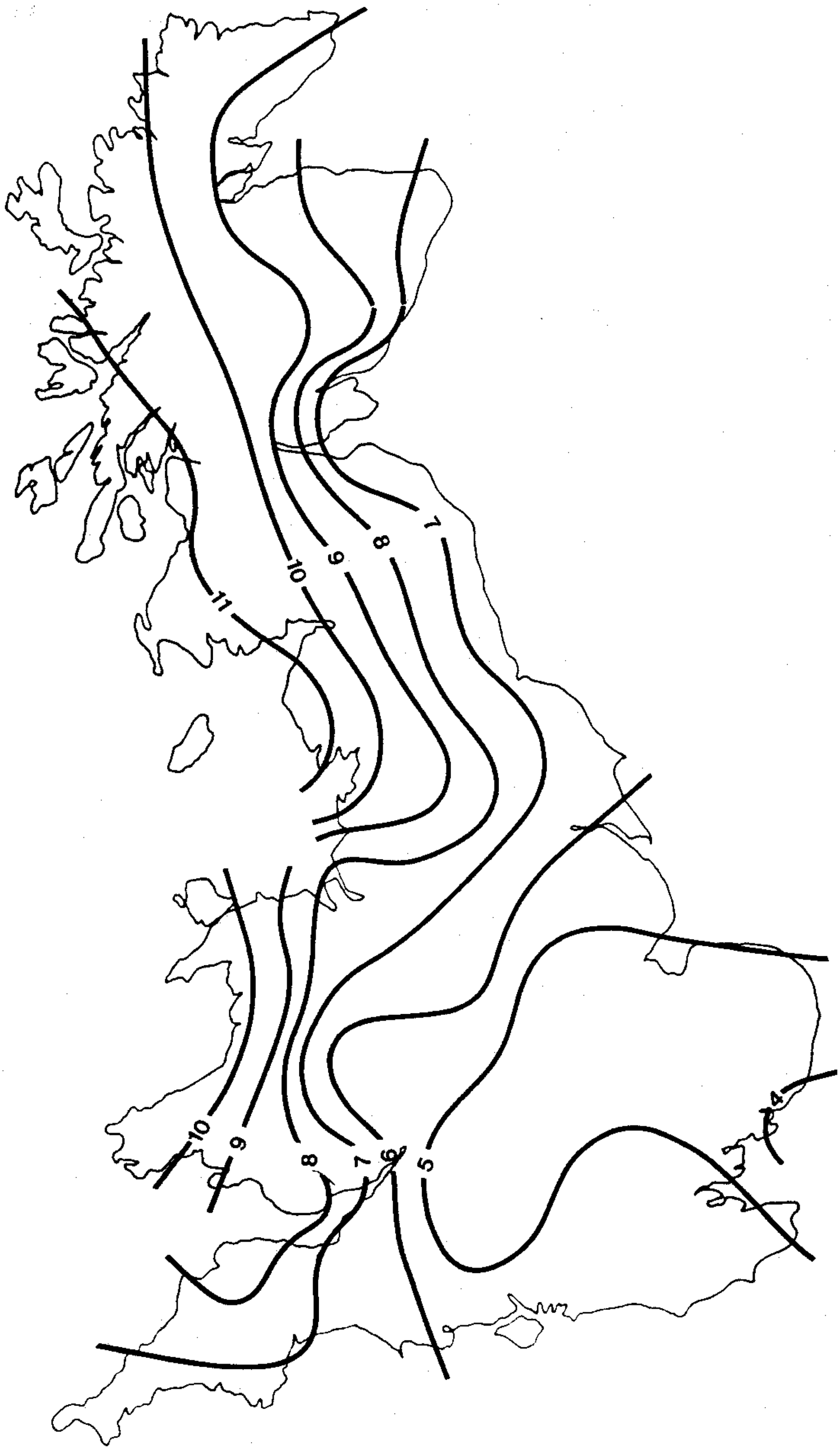


FIGURE 3.7 (OCT) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

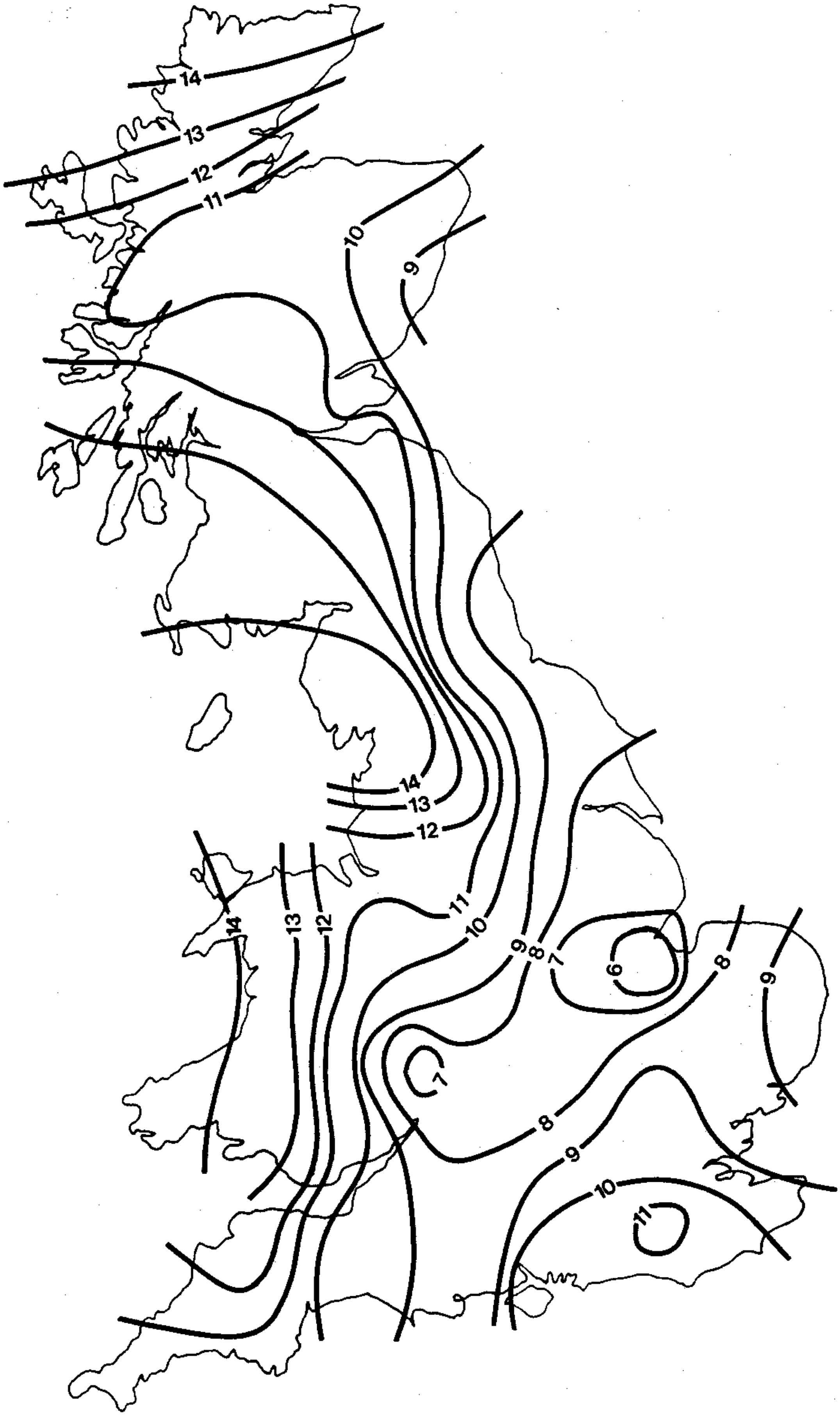


FIGURE 3.7 (NOV) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF

FIGURE 3.7 (DEC) PERCENT OF ANNUAL RUNOFF OCCURRING ON CATCHMENTS WITH 15% ADF < Q95(10) < 30% ADF