LOW FLOW STUDIES

Report No 2.1

Flow duration curve estimation manual

PREFACE

This report describes the procedure for estimation of the flow duration curve 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	*River basin and regional monographs describing the relationship between the base flow index and catchment geology*

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 consists of a series of regional monographs which detail the relationships between the base flow index and catchment geology and enables the index to be estimated at an ungauged site.

CONTENTS

ILLUSTRATIONS

FIGURES

TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

ADF	average flow in cumecs
BFI	base flow index
D	duration (in days unless specified to be in months)
GRADMAM	rate of change of MAM(D)/MAM(10) with D
GRADQ95	rate of change of Q95(D)/Q95(10) with D
MAM(D)	mean annual D day minimum
MAM(10)	mean annual 10 day minimum
AMP(D)	annual minimum D day flow of annual exceedence probability P
Q95(D)	D day average flow exceeded by 95% of D day average discharges
Q95(10)	10 day average flow exceeded by 95% of 10 day average discharges
QP(D)	D day average flow exceeded by P% of D day discharges
SAAR	standard period (1941-1970) annual average rainfall in mm
TC	type curve for flow duration curve and flow frequency curve

Introduction

The flow duration curve is perhaps the most basic form of data presentation which has been used in low flow calculation. It shows graphically the relationship between any given discharge and the percentage of time that the discharge is exceeded. The curve can be drawn for daily or monthly flow data or for any consecutive D day or month period. It is frequently used for assessing the dilution rate of sewage effluent and for assessing licences to abstract water.

This estimation manual describes methods for drawing the curve for the case where adequate gauged information is available (two years for curves standardised by ADF), and for the case where no data are available. There is also a section on methods of incorporating short or discontinuous flow data at or close to the site of interest.

To help explain the technique, this manual includes a worked example, the River Pang at Pangbourne, for which all the calculations have been completed. This is laid out on right-hand pages. Details of three other catchments which can be used for practice are laid out on the left-hand side, set in italic type.

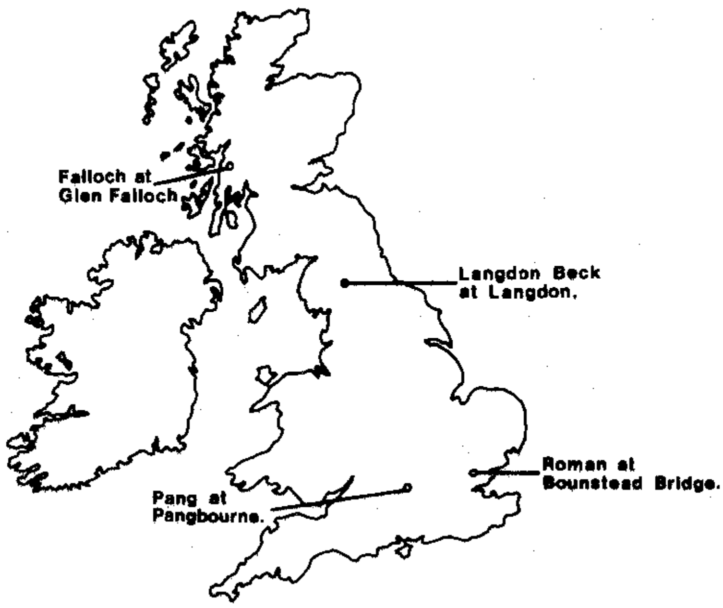


FIGURE 1.1 LOCATION OF ALL THE EXAMPLE CATCHMENTS

CALCULATION SHEETS
ON THIS SIDE

1.1 GENERAL INFORMATION FOR EXAMPLE CATCHMENTS

a. *The River Falloch at Glen Falloch is in hydrometric area 85. The site of interest is at grid reference NN321197 and the area of the catchment is 80.3 km² which includes the Dubh Eas catchment.*

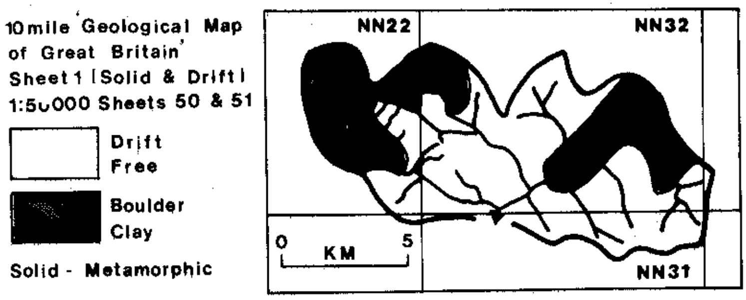


FIGURE 1.2b GEOLOGY AND KEY TO MAPS OF THE FALLOCH CATCHMENT

b. *The Langdon Beck at Langdon is in hydrometric area 25. The site of interest is at grid reference NY 852309 and the area of the catchment is 13.0 km².*

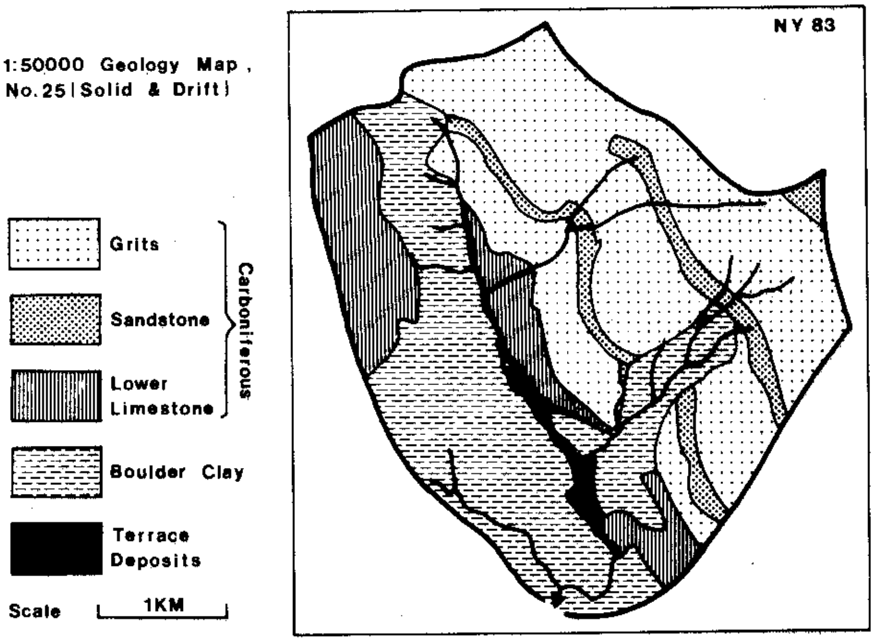


FIGURE 1.2c GEOLOGY AND KEY TO MAPS OF THE LANGDON CATCHMENT

1 Basic data

1.1 GENERAL INFORMATION

The River Pang at Pangbourne is in hydrometric area 39. The site of interest is at Grid Reference SU 634766 and the catchment area is 171 km^2.

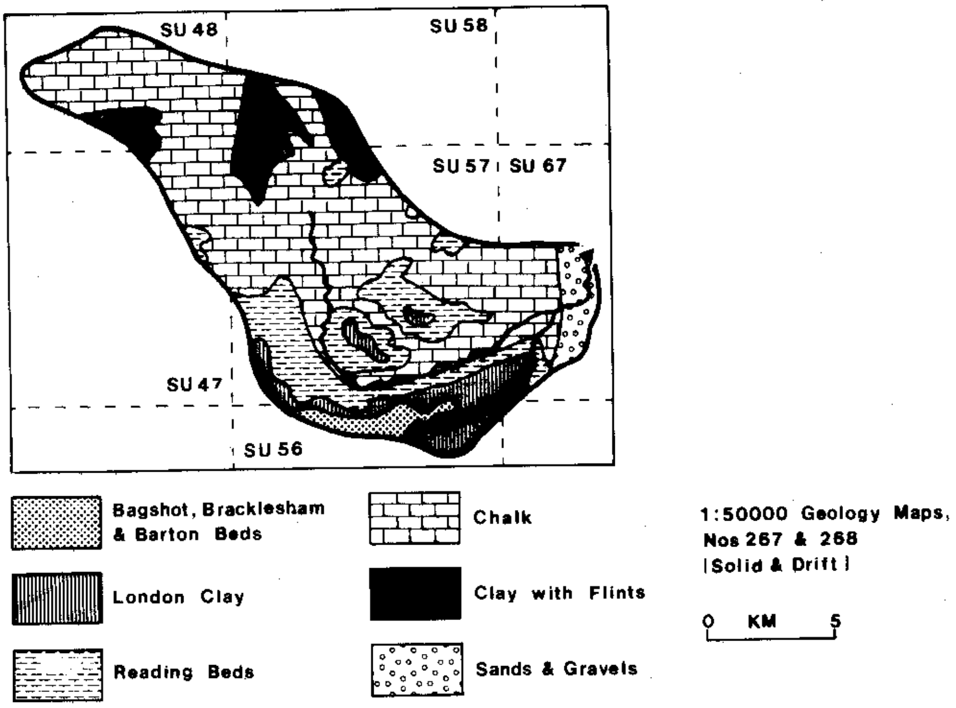


FIGURE 1.2a GEOLOGY AND KEY TO MAPS OF THE PANG CATCHMENT

c. *The Roman River at Bounstead Bridge is in hydrometric area 37. The site of interest is at grid reference TL 985205 and the area of the catchment is 52.6 km².*

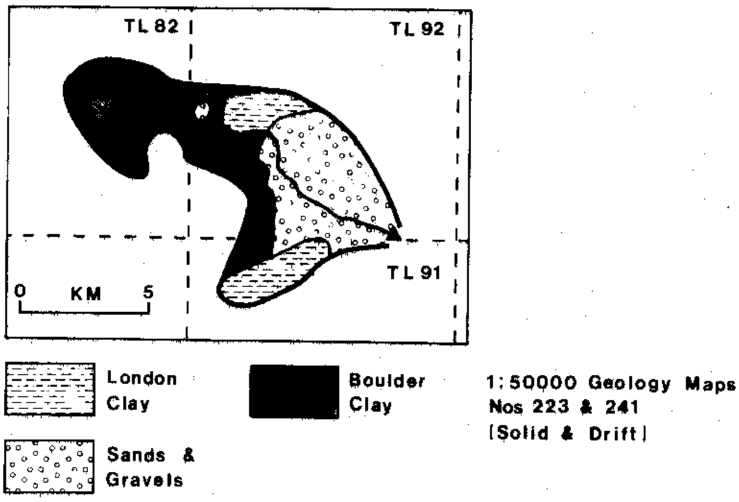


FIGURE 1.2d GEOLOGY AND KEY TO MAPS OF THE ROMAN CATCHMENT

1.2 FLOW DATA FOR DRAWING THE FLOW DURATION CURVE

Tables 1.1b, c and d contain the daily flow data that are assembled into Table 2.4b and from which the flow duration curve is prepared.

TABLE 1.1b

85003 FALLOCH AT GLEN FALLOCH

YEAR 1971 NUMBER OF DAYS WITH DATA= 365 MEAN= 5.148 MINIMUM = .246 MAXIMUM = 88.025 (CUMECS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.523	1.201	3.798	1.499	.669	2.925	3.361	4.555	12.784	2.178	18.490	1.876
2	.627	16.631	3.173	1.208	.574	2.243	3.121	5.867	9.575	1.860	7.093	1.056
3	.900	6.465	2.039	.982	.491	1.743	2.711	2.063	3.498	1.179	20.051	16.939
4	.447	2.730	1.462	.901	.425	1.476	8.252	2.603	3.263	.897	9.466	6.059
5	.389	1.706	2.906	.981	.372	1.276	3.306	4.396	1.424	2.440	4.971	1.559
6	41.633	1.502	2.796	.853	3.263	1.136	2.548	5.002	1.005	9.883	5.338	1.169
7	20.491	1.730	1.961	.763	6.055	1.019	1.385	4.221	.767	7.270	19.247	1.073
8	11.116	1.849	1.435	.678	4.753	.933	1.195	4.921	.619	7.257	5.406	3.892
9	51.426	2.523	1.681	.609	3.136	.890	1.090	3.627	.507	13.764	2.038	7.993
10	4.051	7.501	1.314	.581	2.896	.359	.927	1.679	.429	60.302	2.424	2.777
11	1.949	11.562	13.342	.549	2.008	.983	1.219	1.219	.376	6.909	2.075	4.559
12	1.445	43.923	18.529	.517	1.830	1.406	.988	.971	.341	3.071	3.171	11.906
13	1.229	7.303	4.281	.490	1.414	1.182	.816	1.119	.331	1.754	2.636	4.407
14	1.113	10.356	2.059	.448	1.218	1.066	.843	.759	.692	1.322	2.820	13.988
15	1.045	3.921	1.406	.466	3.143	.976	.993	.550	.712	20.526	20.448	6.176
16	1.016	2.257	1.128	.904	7.515	.946	.812	.478	.561	8.682	4.321	9.120
17	5.371	2.525	.944	6.186	5.869	.889	.705	.423	1.705	30.352	3.419	2.606
18	18.602	2.136	.744	4.346	3.301	.829	.672	.363	1.147	11.888	1.842	24.959
19	17.318	9.664	.739	2.433	2.563	.757	.872	.315	1.494	17.033	1.288	20.524
20	7.278	18.016	.693	1.162	2.296	.769	.736	.281	1.816	10.569	1.458	49.229
21	7.506	5.244	.610	1.124	1.907	6.382	1.736	.261	2.526	88.025	1.329	10.630
22	4.806	2.596	.539	.929	1.624	3.261	1.774	.246	1.447	20.263	1.595	4.547
23	9.275	12.616	3.235	24.445	7.220	2.924	3.409	.304	1.684	7.383	2.759	14.974
24	22.228	5.053	12.195	3.987	4.728	8.044	6.176	.337	.942	6.161	6.002	5.337
25	13.200	3.247	5.593	1.553	2.865	19.823	11.107	.313	.685	2.318	6.904	5.786
26	4.517	2.114	4.298	1.072	5.293	17.571	5.655	3.283	3.146	1.663	8.121	8.323
27	2.752	2.532	3.151	.844	12.472	11.225	4.968	6.141	1.818	1.335	7.009	2.795
28	2.513	2.051	9.604	.696	4.721	4.841	2.593	8.473	1.407	1.099	2.475	1.253
29	2.241		8.266	.824	3.960	3.212	1.861	3.235	5.329	1.109	6.203	.913
30	1.530		2.491	.896	16.655	2.715	1.432	12.120	4.268	4.484	2.854	.661
31	1.174		1.788		4.298		10.547	14.832		4.483		.673

1.2 FLOW DATA FOR DRAWING THE FLOW DURATION CURVE

Table 1.1a contains the daily flow data that are assembled into Table 2.1 and from which the flow duration curve is prepared as described in Chapter 2.

<u>TABLE 1.1a</u>

39027 PANG AT PANGBOURNE

YEAR 1971 NUMHER OF DAYS WITH DATA= 365 MEAN= .805 MINIMUM = .408 MAXIMUM = 2.960 (CUMECS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.513	1.110	.749	.860	.993	.705	1.090	.819	.652	.519	.464	.567
2	.494	1.260	.899	.848	.955	.674	1.060	.797	.654	.495	.455	.557
3	.480	1.460	.826	.820	.900	.672	1.040	.804	.654	.544	.459	.538
4	.471	1.340	.776	.826	.855	.652	1.020	.789	.643	.499	.457	.521
5	.463	.904	.761	.839	.854	.667	1.030	.811	.632	.488	.558	.508
6	.467	.834	.748	.817	.878	.663	1.010	.817	.613	.481	.544	.506
7	.686	.816	.721	.811	.879	.670	.996	.780	.602	.474	.520	.496
8	.713	.789	.755	.819	.821	.689	1.010	.752	.602	.474	.513	.494
9	.588	.803	.750	.901	.811	1.170	.980	.749	.603	.487	.491	.509
10	.554	.785	.741	.888	.790	1.110	.964	.759	.607	.476	.484	.492
11	.541	.771	.714	.791	.783	2.960	.946	.739	.595	.473	.477	.484
12	.520	.769	.718	.829	.768	2.080	.929	.749	.590	.496	.485	.470
13	.503	.769	.722	.815	.775	1.480	.895	.758	.582	.573	.477	.465
14	.524	.794	.733	.815	.735	1.900	.800	.785	.594	.618	.455	.463
15	.546	.987	1.200	.802	.775	2.190	.796	.753	.596	.532	.444	.463
16	.622	.874	.968	.800	.793	1.580	.783	.719	.580	.655	.438	.455
17	.665	.907	1.190	.768	.742	1.330	.787	.693	.548	.769	.408	.452
18	.630	.889	2.290	.766	.726	1.650	.791	.702	.582	.612	.466	.454
19	.822	.793	1.700	.743	.710	2.710	.773	.851	.568	.576	.461	.666
20	.997	.854	1.390	.766	.708	2.230	.793	.834	.561	.566	.516	.589
21	1.620	.821	1.210	.761	.692	1.740	.824	.816	.540	.538	.689	.521
22	1.570	.783	1.090	.768	.706	1.490	.846	.764	.540	.516	.549	.603
23	2.080	.783	1.010	1.030	.773	1.360	.805	.724	.549	.474	.593	.626
24	1.740	.766	.991	1.520	.756	1.280	.844	.727	.548	.487	.547	.561
25	1.870	.761	.947	1.220	.875	1.230	.833	.689	.551	.481	.518	.516
26	1.910	.754	.938	1.670	.783	1.220	.797	.716	.559	.470	.534	.536
27	1.520	.745	.900	1.700	.791	1.210	.836	.707	.555	.473	.625	.558
28	1.200	.727	.883	1.300	.829	1.240	.829	.692	.551	.455	.893	.589
29	.987		.895	1.110	.795	1.140	.806	.670	.531	.480	.621	.552
30	1.180		.865	1.040	.773	1.120	.827	.654	.545	.468	.596	.529
31	1.210		.861		.728		.847	.658		.473		.518

TABLE 1.1c

25011 LANGDON BECK LANGDON

YEAR 1971 NUMBER OF DAYS WITH DATA= 365 MEAN= .332 MINIMUM = .024 MAXIMUM = 6.252 (CUMECS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.185	.098	.100	.104	.067	.040	.122	.120	.120	.031	.065	.124
2	.128	.252	.143	.096	.059	.033	.079	.104	.186	.030	.069	.114
3	.221	.410	.109	.095	.051	.031	.059	.823	.204	.030	.073	.123
4	.182	.171	.100	.101	.046	.030	.053	1.297	.134	.032	.544	.191
5	.108	.135	.181	.128	.040	.031	.045	.436	.088	.030	1.067	.133
6	2.292	.118	.199	.100	.056	.043	.039	.433	.066	.027	.459	.111
7	6.252	.109	.545	.082	.063	.057	.035	.531	.054	.029	1.406	.097
8	1.758	.099	.841	.082	.050	.045	.033	.508	.048	.034	.477	.127
9	.950	.086	.449	.066	.043	.043	.033	.495	.043	.091	.184	.111
10	.282	.075	.378	.059	.053	.038	.032	.145	.040	.098	.141	.095
11	.165	.109	.461	.052	.046	.857	.029	.131	.038	.136	.132	.080
12	.132	4.061	.268	.048	.040	.266	.028	.100	.036	.074	.118	.184
13	.122	.860	.191	.046	.038	.162	.026	4.703	.035	.072	.114	.374
14	.119	.733	.374	.043	.036	.165	.026	3.750	.038	.055	.096	.288
15	.110	.422	.210	.041	.034	.096	.025	.460	.040	.102	.100	.202
16	.101	.242	.147	.049	.036	.331	.025	.200	.036	.357	.144	.162
17	.098	.184	.226	.047	.037	.161	.024	.130	.035	1.273	1.114	.151
18	.618	.452	2.194	.045	.038	.259	.024	.096	.033	3.435	.348	.140
19	1.088	.670	2.331	.039	.033	.854	.025	.075	.032	2.696	.154	1.367
20	.657	1.851	1.037	.038	.033	.928	.026	.060	.031	.742	.364	.501
21	2.053	.605	.554	.035	.030	.837	.034	.052	.030	.965	.697	.262
22	.372	.234	.382	.034	.033	.363	.033	.049	.030	.404	.332	.168
23	.504	.176	.751	1.777	.113	.144	.049	.048	.030	.223	.424	.144
24	1.923	.172	1.575	2.456	.148	.094	.193	.046	.030	.175	.798	.136
25	.894	.152	.468	.320	.087	.094	.376	.041	.029	.136	2.559	.136
26	.360	.128	.440	.180	.051	.138	.215	.038	.034	.110	.501	.118
27	.411	.111	.242	.138	.043	.111	.149	.035	.038	.095	1.326	.201
28	.463	.103	.187	.104	.037	.134	.089	.048	.033	.079	.321	.140
29	.273		.154	.094	.037	.917	.059	1.707	.037	.071	.174	.112
30	.191		.146	.080	.052	.231	.046	.545	.036	.077	.138	.099
31	.137		.115		.050		.057	.225		.072		.261

TABLE 1.1d

37021 ROMAN AT BOUNDSTEAD

YEAR 1971 NUMBER OF DAYS WITH DATA= 365 MEAN= .204 MINIMUM = .067 MAXIMUM = 1.879 (CUMECS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.530	.678	.294	.219	.161	.113	.115	.090	.091	.091	.097	.185
2	.432	.356	.366	.208	.153	.105	.114	.092	.088	.092	.101	.163
3	.366	.424	.333	.190	.143	.099	.109	.154	.090	.092	.100	.121
4	.327	.420	.303	.194	.140	.097	.108	.106	.090	.092	.098	.146
5	.192	.401	.278	.183	.137	.104	.103	.153	.090	.093	.128	.143
6	.238	.385	.275	.180	.134	.106	.104	.107	.089	.089	.115	.152
7	.836	.362	.258	.174	.225	.105	.099	.131	.087	.091	.118	.138
8	.884	.352	.260	.170	.164	.099	.099	.107	.084	.091	.108	.135
9	.452	.332	.248	.181	.148	.103	.089	.100	.083	.090	.102	.139
10	.443	.332	.220	.152	.142	.172	.084	.110	.085	.095	.101	.133
11	.422	.314	.224	.161	.133	.138	.082	.100	.090	.092	.097	.130
12	.319	.304	.226	.161	.124	.118	.095	.099	.085	.135	.105	.127
13	.271	.303	.226	.163	.114	.113	.091	.105	.086	.220	.108	.128
14	.176	.290	.228	.168	.117	.446	.091	.111	.089	.088	.102	.125
15	.305	.281	.235	.166	.140	.290	.088	.098	.087	.108	.095	.123
16	.252	.284	.220	.183	.166	.125	.103	.094	.085	.120	.104	.123
17	.252	.380	.257	.165	.142	.141	.067	.092	.085	.148	.100	.121
18	.091	.507	.371	.160	.134	.253	.087	.093	.086	.133	.175	.119
19	.446	.449	.355	.158	.124	.299	.092	.095	.082	.127	.132	.177
20	.544	.434	.350	.158	.119	.467	.088	.159	.087	.077	.178	.148
21	.816	.404	.356	.155	.115	.253	.096	.131	.085	.107	.278	.137
22	.798	.344	.366	.153	.122	.123	.097	.114	.085	.104	.226	.165
23	1.879	.306	.271	.275	.133	.141	.096	.110	.098	.101	.214	.249
24	1.518	.307	.260	.232	.132	.132	.099	.103	.102	.101	.183	.203
25	1.067	.247	.254	.252	.167	.124	.117	.097	.091	.099	.161	.171
26	1.390	.234	.245	.225	.141	.164	.103	.100	.107	.100	.186	.161
27	1.400	.246	.221	.161	.151	.073	.102	.093	.149	.097	.179	.149
28	.899	.260	.226	.167	.141	.133	.117	.092	.102	.097	.491	.143
29	.700		.225	.165	.129	.116	.105	.094	.094	.097	.317	.144
30	.799		.211	.164	.146	.111	.103	.093	.091	.097	.286	.173
31	.882		.206		.124		.084	.093		.095		.176

1.3 PLOTTING FLOW DURATION CURVES FROM DAILY FLOW DATA

The steps for preparing flow duration curves from the data of Tables 1.1a to 1.1d are given in Section 2 of this manual

1.3 PLOTTING FLOW DURATION CURVES FROM DAILY FLOW DATA

Figure 1.3 is an example of the flow duration curve produced by the Institute of Hydrology data processing system. Note the use of a logarithmic discharge axis and a Normal probability scale for the abscissa. Apart from the line labelled 1 day which is the conventional curve, Figure 1.3 shows curves produced for other durations in days. These are assembled from consecutive overlapping periods which are produced in the processing scheme by first passing a moving average of the desired duration through the data. The moving average data are treated in precisely the same manner as daily data. The interpretation of the curves is, for example, that the average flow of 95% of 10-day consecutive periods is greater than 38% of the average discharge.

Section 2 describes a manual method by which one day flow duration curves may be developed from the daily flow data.

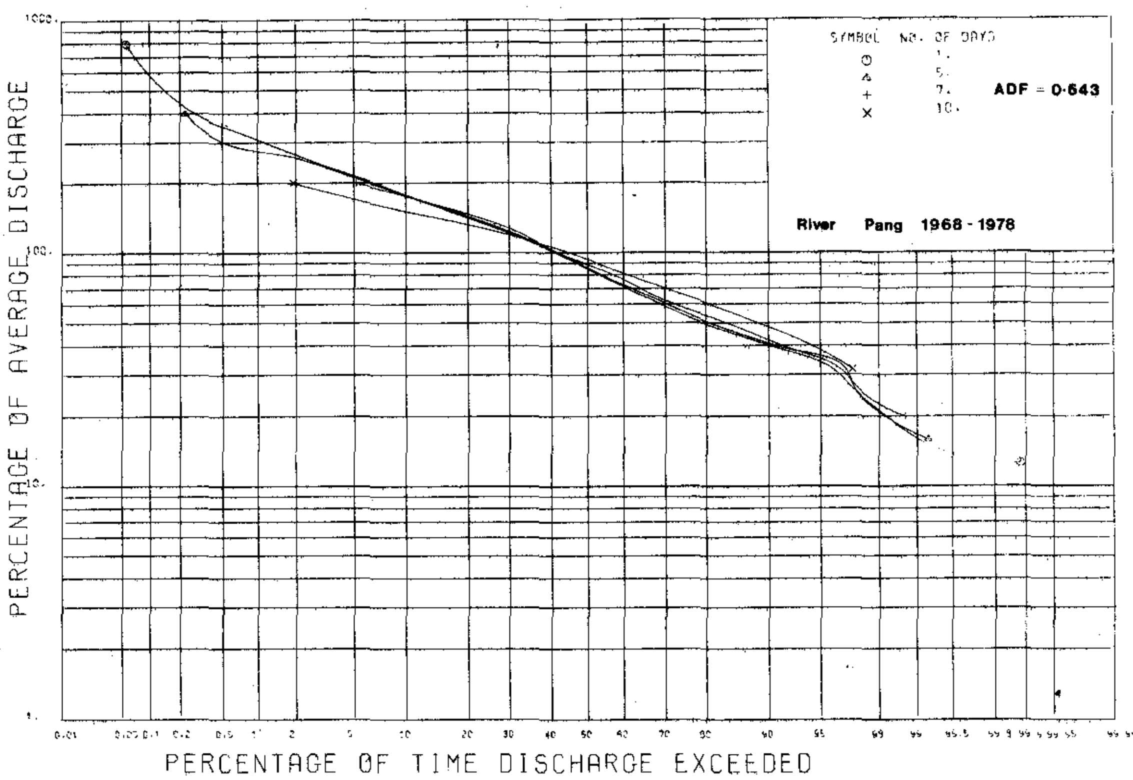


FIGURE 1.3 AUTOMATED FLOW DURATION PLOT FOR RIVER PANG

1.4 OUTLINE OF ESTIMATION PROCEDURE

The basic recommendations for drawing flow duration curves are given opposite. For purposes of practising the procedures we shall depart somewhat from these recommendations. Thus although there are some 8 years of data available at each of the example sites, Section 2.2 describes the construction of the flow duration curve from a single year's data. Moreover, having used a single year, the data have not been standardised by the average discharge of that year. Sections 2.3 and 2.4 pursue this same process but show the use of axis transformation to produce a more linear plot.

Section 2.5 describes the procedure which is most suited to automatic data processing in which the data are standardised by the average flow. Section 2.6 describes the method to be used for durations other than one day.

1.4 OUTLINE OF ESTIMATION PROCEDURE

The procedure for estimating the flow duration curve depends on the availability of data at or near the site of interest. Figure 1.4 outlines three basic approaches and the corresponding section of this manual to use. The technique based on catchment characteristics refers to the Catchment Characteristic estimation manual - Report No. 3 of this series.

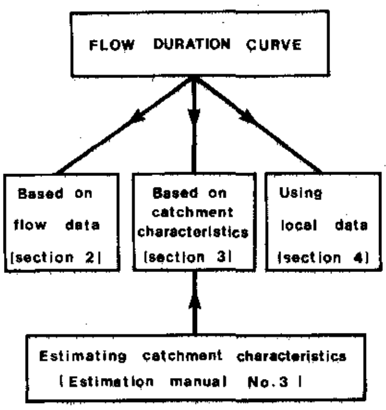


FIGURE 1.4 OUTLINE OF ESTIMATION PROCEDURE

Which of these three procedures to use or combination thereof, depends on the amount of data available. Suggested guidelines for a given length of record are summarized in Table 1.2 and described below.

More than ten years — Records of this length need no adjustment or standardisation as this period of data will probably provide a sufficiently accurate flow duration curve.

Two to ten years — Divide the daily flow data by the average flow over the period of record before analysis. This overcomes to a great extent the departures due to wet or dry years. The conversion to the long term flow duration curve is made using an estimate of long term average flow as described in Report 3, Section 2.5

Less than two years — Use Sections 3 and 4 of this manual, also refer to sections of Report 3 for use of short records for Base Flow Index and ADF calculations.

TABLE 1.2 Technique to use for given record lengths

Years of record	Technique	Section Nos	
> 10	Use data in cumecs	2	
2-10	Express data as % ADF type curve check	2	3
< 2	BFI from data	4	
No data	BFI from geology	3	

The worked example for the Pang which follows departs from the guidelines to the extent that flow units with and without adjustment are adopted even though a single year's data, 1970, alone, has been employed for illustration. Subsequent subsections described opposite also depart from the guidelines.

2.1 CONSTRUCTION OF FLOW DURATION CURVES ON LINEAR GRAPH PAPER

Select class intervals to simplify the tallying procedure and complete Table 2.1b using the daily data from Tables 1.1b-d.

TABLE 2.1b **Preparation of flow duration data for Falloch, Langdon, Roman catchments**

(1) Class interval cumecs	(2) Tally of days in class interval	(3) Total in class interval	(4) Number greater than bottom of c.i.	(5) Percentage greater than bottom of c.i. $P = \frac{col(4)}{\Sigma} \times 100$
		$\Sigma =$		

A simple graph of col(5) against the lower bound of the class interval can be drawn on linear paper.

2 The gauged catchment case

2.1 CONSTRUCTION OF FLOW DURATION CURVE ON LINEAR GRAPH PAPER

The data are sorted into constant width class intervals (ci) which are expressed in discharge units, and values selected for convenience in tallying. For the River Pang the discharge experienced in 1970 (see Table 1.1a for data) range from about 0.2 to 1.6 cumecs. Table 2.1a shows the procedure where for the Pang a class interval width of 0.10 cumecs was selected (column 1). Each day's discharge is assigned to its appropriate class interval and a tally made (Table 2.1a column 2) of the number of days in that interval. The total number of days in each ci is then found (Table 2.1a column 3) and the number of days above the lower limit of each ci is entered in column 4 and then expressed as a percentage exceedence in column 5 by dividing the entry in column 4 by the total number of days in the record (365 for the example of the Pang) and multiplying by 100.

TABLE 2.1a **Preparation of flow duration data for Pang catchment**

(1) Class interval cumecs	(2) Tally of days in class interval	(3) Total in class interval	(4) Number greater than bottom of ci	(5) Percentage greater than bottom of ci $P = \frac{\text{col (4)}}{\Sigma} \times 100$
1.5-1.6	|	1	1	0.27
1.4-1.5	|	1	2	0.55
1.3-1.4		0	2	0.55
1.2-1.3	|	1	3	0.82
1.1-1.2	|	1	4	1.10
1.0-1.1	卌	5	9	2.47
0.9-1.0	卌 卌 ||	12	21	5.75
0.8-0.9	卌 卌 卌	15	36	9.86
0.7-0.8	卌 卌 卌 卌 卌 卌 卌 卌 ||||	44	80	21.92
0.6-0.7	卌 卌 卌 卌 卌 卌 卌 卌 卌 卌 卌	55	135	36.97
0.5-0.6	卌 卌 卌 卌 卌 卌 卌 |||	38	173	47.40
0.4-0.5	卌 卌 卌 卌 卌 卌 卌 卌	40	213	58.36
0.3-0.4	(卌 卌 卌 卌 卌 卌 卌 卌) x2	80	293	80.27
0.2-0.3	(卌 卌 卌 卌 卌 卌 卌 |) x 2	72	365	100.00

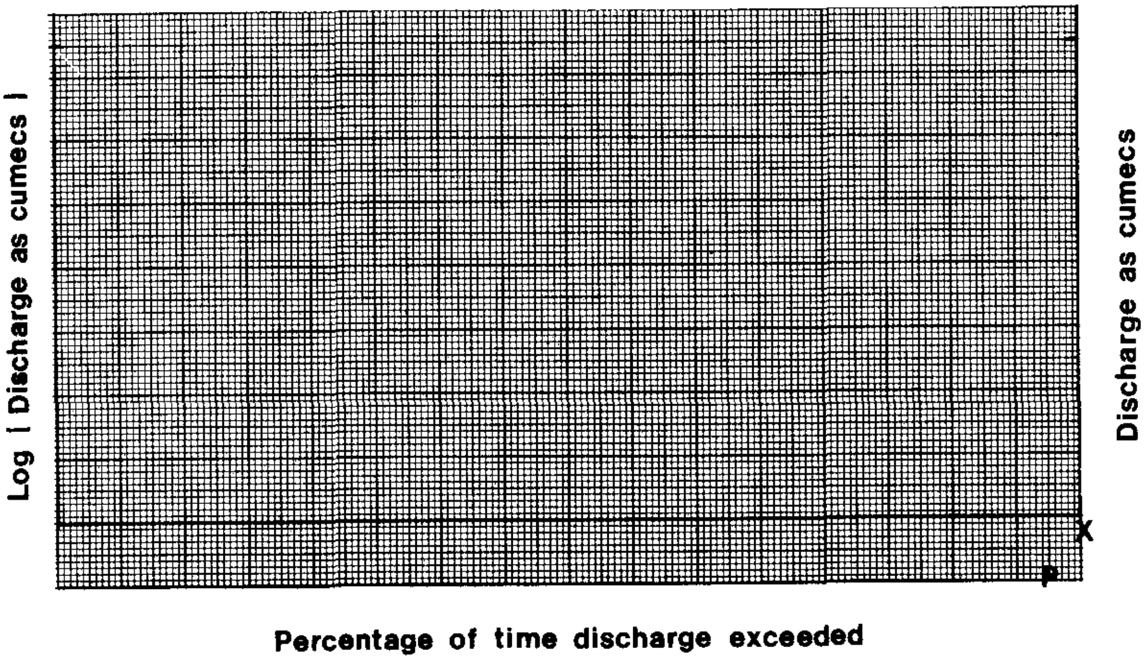
$\Sigma = 365$

The values from column 5 are plotted directly against the corresponding lower bound of column 1 on linear graph paper. However if lognormal probability paper is used the flow duration curve often approximates better to a straight line. This preferred method is explained in sections 2.2 and 2.3

2.2 DRAWING LOGNORMAL GRAPH PAPER

Assuming that only linear graph paper is available, draw up the discharge and probability axis on Figure 2.1b following the scheme opposite.

FIGURE 2.1b **ANNUAL FLOW DURATION CURVE FOR FALLOCH, LANGDON, ROMAN CATCHMENTS**



2.3 TRANSFORMING DATA AND PLOTTING ON LOGNORMAL GRAPH PAPER

Using the data from columns 1 and 5 of Table 2.1b, make the logarithmic and probability transformations as outlined opposite by completing Table 2.3b and using the formulae for x from a given probability of Section 2.2.

2.2 DRAWING LOGNORMAL GRAPH PAPER

If the appropriate graph paper is not available then the following method can be used to construct it. The probability axis is drawn such that the scale is linear in standard deviation x either side of the mean and for each value of x a corresponding value of p, the exceedence probability expressed as a proportion is given by

$$p = \int_x^\infty \frac{1}{\sqrt{2\pi}} \cdot e^{-x^2/2}\, dx$$

must be found. Tables of x values from given P values (expressed as a percentage exceedance probability) are available from which Table 2.2 has been extracted for commonly required P values.

TABLE 2.2 Values of x corresponding to commonly required P values

Probability P%	Normal variate x	Probability P%	Normal variate x	Probability P%	Normal variate x
99.99	3.715	90	1.280	5	-1.645
99.95	3.290	80	0.840	2	-2.055
99.90	3.090	70	0.550	1	-2.325
99.8	2.875	60	0.255	0.5	-2.575
99.5	2.575	50	0.000	0.2	-2.875
99	2.325	40	-0.255	0.1	-3.090
98	2.055	30	-0.550	0.05	-3.290
95	1.645	20	-0.840	0.01	-3.715
		10	-1.280		

Table 2.2 can be produced using accurate iterative techniques for obtaining x for any P. However the following direct solution gives adequate accuracy where p is the probability expressed in proportional terms:

$$x = \text{signum}\,(p-1/2)\ \{1.238t\ (1 + 0.0262t)\}$$

where

$$\text{signum}\,(p-1/2) = +1 \text{ where } p > 1/2,\ -1 \text{ where } p < 1/2.$$

$$t = \{-\ln 4p(1-p)\}^{\frac{1}{2}}$$

Figure 2.1a shows the probability axis P, linear in terms of the normal variate x. The ordinate scale is drawn such that it is linear in the logarithms of the discharge.

2.3 TRANSFORMING DATA AND PLOTTING ON LOGNORMAL GRAPH PAPER

To plot the flow duration curve on the lognormal probability paper, the logarithms of the flow of column 1 of Table 2.1a and the reduced variate x from the percentage exceedence of column 5 must be calculated. Table 2.3a shows the transformation of the Pang data using the relationship between x and p from Section 2.2. Column 6 is then plotted against column 2 on Figure 2.1a.

TABLE 2.3b **Transformation of Falloch, Langdon, Roman data for lognormal probability plot**

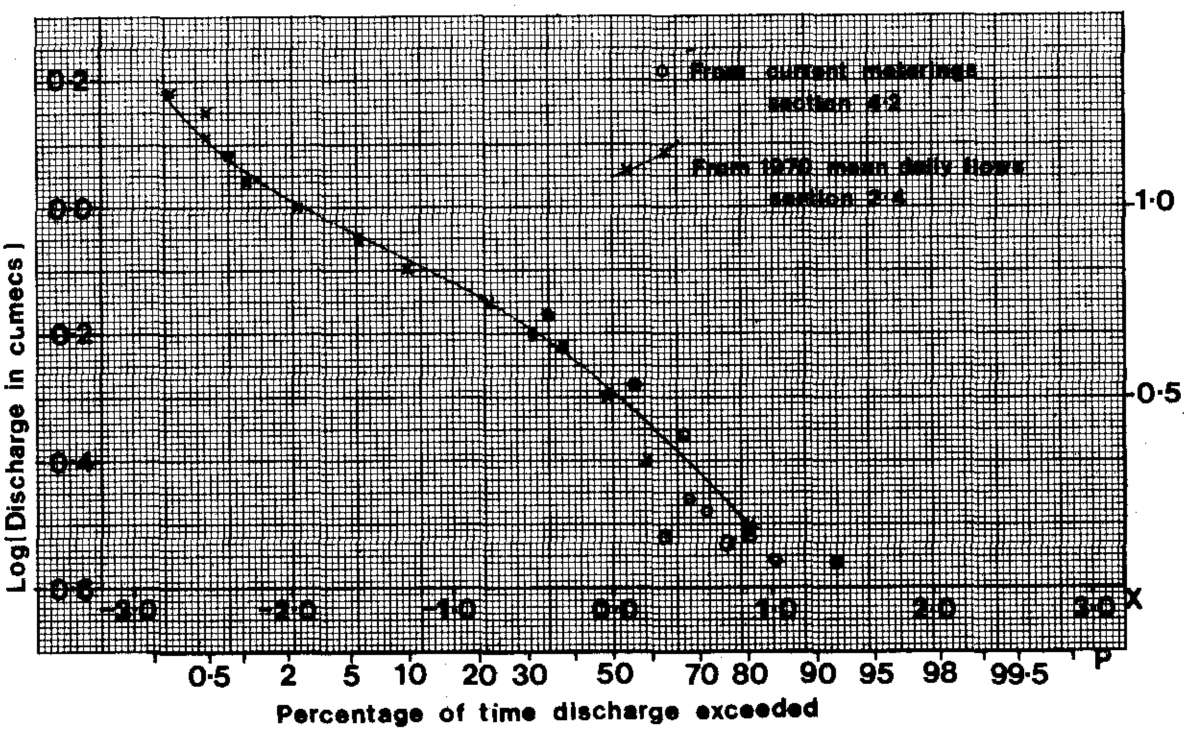
(1) *Class interval lower bound*	*(2)* *Logarithm of lower bound log (col. 1)*	*(3)* $p = P/100$	*(4)* $4p(1-p)$	*(5)* t	*(6)* x

Plot column (6) against column (2) on Figure 2.1b.

TABLE 2.3a   Transformation of Pang data for lognormal probability plot

(1) Class interval lower bound	(2) Logarithm of lower bound log (col.1)	(3) p = P/100	(4) 4p(1-p)	(5) t	(6) x
1.5	·18	·0027	·0108	2.128	-2.781
1.4	·15	·0055	·0219	1·955	-2·544
1.3	·11	·0055	·0219	1·965	-2·544
1.2	·08	·0082	·0325	1·851·	-2·403
1.1	·04	·0110	·0435	1·771	-2·294
1.0	·00	·0247	·0964	1·529	-1·969
0.9	- ·05	·0575	·2168	1·236	-1·580
0.8	- ·10	·0986	·3555	1·017	-1·293
0.7	- ·15	·2192	·6846	0·616	-0·775
0.6	- ·22	·3697	·9321	0·265	-0·3303
0.5	- ·30	·4740	·9973	0·052	-0.0645
0.4	- ·40	·5836	·9720	0·169	0·2101
0.3	- ·52	·8027	·6335	0·676	0·8517
0.2	- ·70	1·0000	0·0000		

FIGURE 2.1a   ANNUAL FLOW DURATION CURVE FOR PANG CATCHMENT (cumecs)



2.4 ALTERNATIVE METHODS FOR DRAWING THE CURVE

(a) *Using logarithmic class intervals*

ASSEMBLING DATA AND CHOICE OF CLASS INTERVALS

Assemble data from period of record required from Table 1.1b-d. The ADF value is computed for each case using the period of interest. For the three cases these are

Station	Period of record	ADF cumecs
Falloch	1971	5.145
Langdon	1971	.332
Roman	1971	.204

Normally the range of discharge encountered and sensitivity of the graph dictates class interval choice - the current example uses the system described opposite with equal logarithmic class intervals.

Complete as much of column (3) of Table 2.4b as is necessary by conversion to % ADF units using the above value of ADF.

CALCULATION OF EXCEEDENCE PROBABILITY

A tally of the days within the class interval is entered into column (4). The number of days is entered into column (5). The number of days with discharges in excess of the topmost limit can be obtained by subtraction from the total number of days in the year. Column (6) accumulates column (5) and column (7) expresses column (6) as a percentage of the total number of days of the year. Column (8) shows the reduced variate x for the value of P in column (7).

DRAWING LOGNORMAL GRAPH PAPER AND PLOTTING DATA

Plot column (8) as abscissa against column (2) as ordinate on Figure 2.2b. If log-normal paper is available this can be done directly. Assume here, however, that only linear paper is available to practise the construction of the scales. An x and P scale is formed following the scheme opposite and making use of Table 2.2. The logarithm of the % ADF class interval upper boundary is simply one-tenth of the class interval numbers of column (1) in this instance, eg log 1.26 = .1 etc.

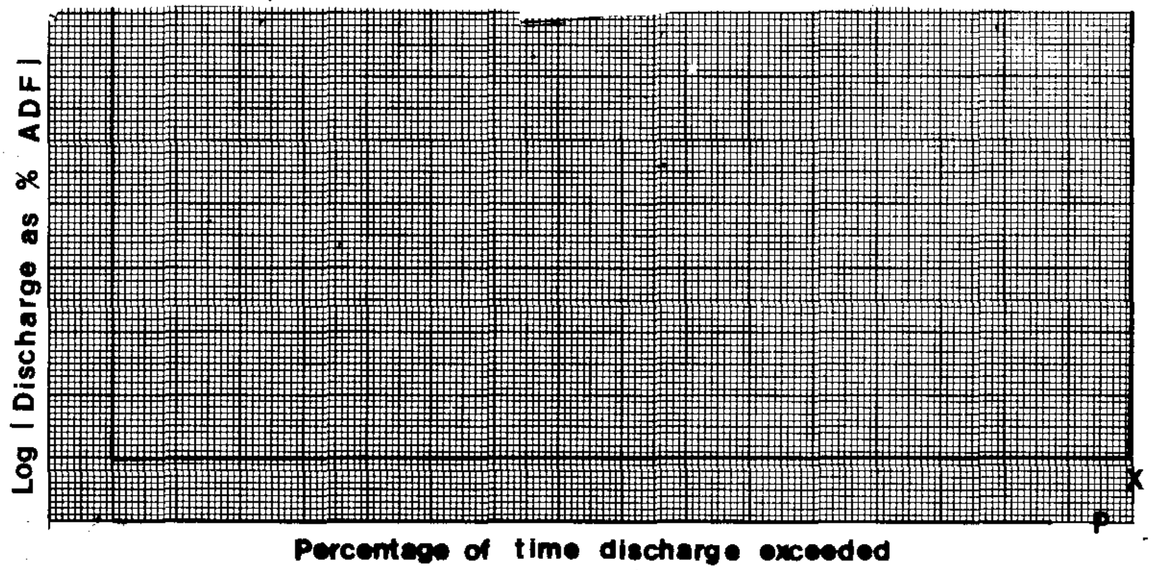


FIGURE 2.2b FLOW DURATION CURVE FOR FALLOCH, LANGDON, ROMAN (%ADF)

2.4 ALTERNATIVE METHODS FOR DRAWING THE CURVE

(a) Using logarithmic class intervals

The technique outlined above is suitable for manual construction of the flow duration curve. The following technique is suitable for computer based data processing systems, the main difference being in the discharge axis where a logarithmic division of class intervals is used and flow is expressed as a percentage of the average flow. The latter transformation enables curves to be compared more easily by reducing the effect on the slope and location of the flow duration curve of differences in catchment area, average rainfall or of the occurrence of higher or lower than average flows during the recorded period. This method was used for all the flow duration curves used in the Low Flow Study.

The procedure used for assigning class intervals was to divide the range of discharge into 30 class intervals on a logarithmic basis from 1% ADF (average daily flow) to 1000 % ADF. The upper limit of the ith class interval as shown in column 1, Table 2.4a is antilog {0.1(i)} in % ADF units and the lower limit is antilog .1(i-1). These are the figures shown in column 2 (for illustration, column 3 shows the class interval boundaries converted to cumec units). The ADF value to be used is calculated from the same period of record as used in deriving the curve. For the Pang, and for the calendar year 1970 this is 0.517 cumecs. Having converted each daily discharge to a % ADF, the computer program finds the logarithm of this discharge, multiples this value by 10 and assigns it to a given class interval by finding the integer equivalent of this real number.

This procedure was designed primarily for large scale automatic data processing but other equally valid class interval boundaries can be used to detail particular flow ranges or to simplify the numerical operation. The calculation of exceedence probability and the transformation to calculate x from p follows the procedure outlined in section 2.3. Table 2.4a shows the steps in this procedure and the graph of column 8 against the logarithm of the class interval boundary is shown in Fig. 2.2a.

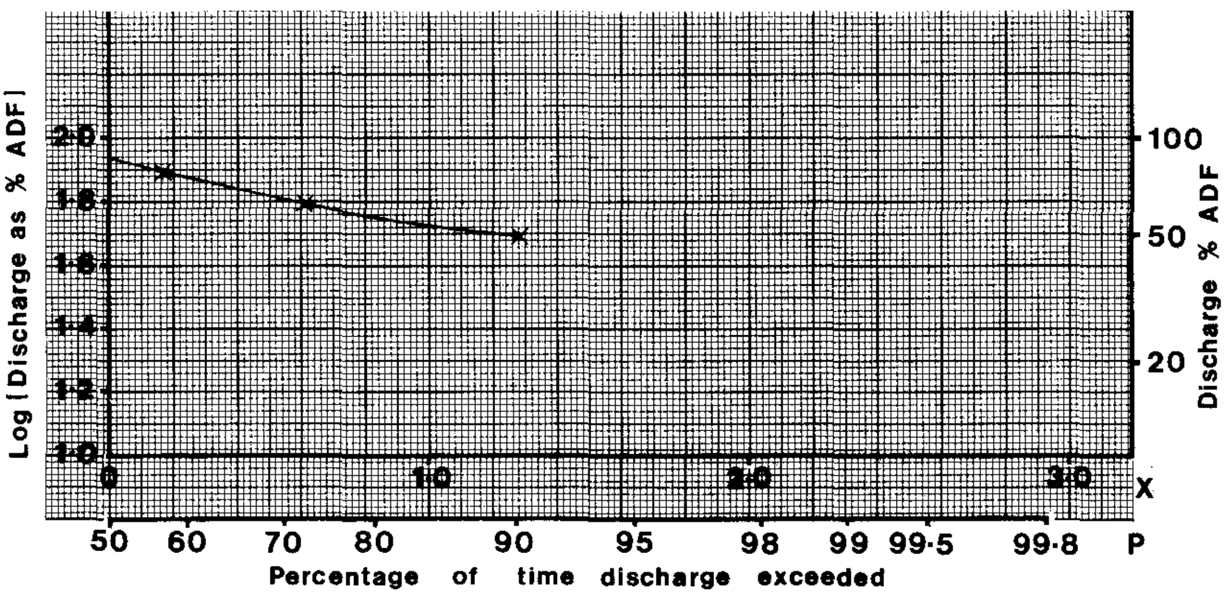


FIGURE 2.2a FLOW DURATION CURVE FOR PANG (% ADF)

TABLE 2.4b Preparation of flow duration curve data for Falloch, Langdon, Roman

(1) c.i. no	(2) Boundary of class intervals % ADF	(3) cumecs	(4) Tally of days in class interval	(5) Total in class interval	(6) Number greater than bottom of c.i.	(7) Percentage greater than bottom of c.i.	(8) x from p
	1000.00						
30							
	794.33						
29							
	630.96						
28							
	501.19						
27							
	398.11						
26							
	316.23						
25							
	251.19						
24							
	199.53						
23							
	158.49						
22							
	125.89						
21							
	100.00						
20							
	79.43						
19							
	63.10						
18							
	50.12						
17							
	39.81						
16							
	31.62						
15							
	25.12						
14							
	19.95						
13							
	15.85						
12							
	12.59						
11							
	10.00						
10							
	7.94						
9							
	6.31						
8							
	5.01						
7							
	3.98						
6							
	3.16						
5							
	2.51						
4							
	2.00						
3							
	1.58						
2							
	1.26						
1							
	1.00						

TABLE 2.4a Preparation of flow duration curve data for Pang

(1) c.i. no.	(2) Boundary of class intervals % ADF	(3) cumecs	(4) Tally of days in class interval	(5) Total in class interval	(6) Number greater than bottom of c.i.	(7) Percentage greater than bottom of c.i.	(8) x from p
	1000.00	5.170					
30	794.33	4.107					
29	630.96	3.262					
28	501.19	2.591					
27	398.11	2.058					
26	316.23	1.635					
25	251.19	1.299					
24	199.53	1.032					
23	158.49	0.819					
22	125.89	0.651		105	105	29	-.552
21	100.00	0.517		60	165	45	-.124
20	79.43	0.411		44	209	57	.175
19	63.10	0.326		59	268	73	.611
18	50.12	0.259		61	329	90	1.284
17	39.81	0.206		36	365	100	
16	31.62	0.163					
15	25.12	0.130					
14	19.95	0.103					
13	15.85	0.082					
12	12.59	0.065					
11	10.00	0.052					
10	7.94	0.041					
9	6.31	0.033					
8	5.01	0.026					
7	3.98	0.021					
6	3.16	0.016					
5	2.51	0.013					
4	2.00	0.010					
3	1.58	0.008					
2	1.26	0.007					
1	1.00	0.005					

(b) Ranking flow data

The data can be ranked following the scheme opposite and plotted on linear or log normal graph paper.

2.5 CURVES FOR DIFFERENT DURATIONS

Flow duration curves for different durations can be produced by passing a moving average through the data and treating this derived data set in the way outlined in Sections 2.1 - 2.4. The method is best suited to using a computer.
The flow duration curves overleaf allow comparisons to be drawn between the flow variability behavior of the three practice catchments. It can be seen from Fig. 2.3b (Rivers Falloch and Langdon) that the longer the time period that the data is averaged over, the less steep the flow duration curve. These results are typical of catchments having high annual average rainfall and impermeable geology. The third catchment, that of the River Roman, having a lower annual average rainfall and a permeable geology has a much smoother hydrograph and therefore shows very little difference in the position of the curves with the data averaged over different durations.

2.6 CURVES FOR DIFFERENT TIME PERIODS

Any time period can be used for producing the curve - particular years, seasons or months.

(b) Ranking flow data

The data are ranked, Q_1 being the lowest and Q_n the highest discharge.

The ith ranking daily flow is assigned an exceedence probability $P = (N-i)/N$. Q_i is then plotted against P_i as in Section 2.3. For samples of data longer than one year the improvement in accuracy given by this method will not be observable on the scale of paper used and the ranking of all the data is laborious.

2.5 CURVES FOR DIFFERENT DURATIONS

Sections 2.1 to 2.3 as described apply to daily data. Flow duration curves can be prepared for other durations, for example 10 day flows. This will in general require computer evaluation because of the considerable data handling that is involved.

The method consists of deriving a hydrograph whose values are not simply daily discharges but are average discharges over the previous 10 days. Thus the entry for January 1 1970 is in fact the average discharge over the period 23rd December 1969 to 1st January 1970 inclusive. Each day's entry can then be treated in the way described in previous sections. Another way of looking at this process is to regard the derived data as the outcome of passing a moving average of 10 (or in eneral D) days duration through the daily data. D Values of 1, 5, 7, 10, 30, 60, 90, 180 and 365 days were adopted as standards in the Low Flow Study. Curves drawn for these time periods are shown on Figure 2.3a which are typical of rivers having smooth hydrographs.

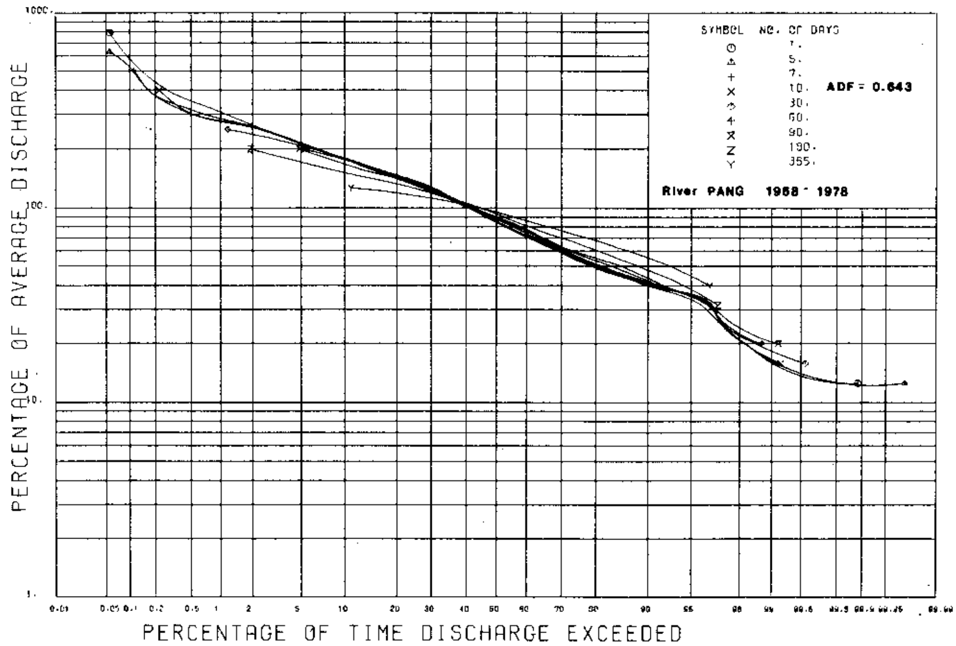


FIGURE 2.3a FLOW DURATION CURVE FOR PANG FOR DIFFERENT DURATIONS

2.6 CURVES FOR DIFFERENT TIME PERIODS

The most frequent requirement is to produce a FDC for all the recorded data on record. Other requirements for FDCs for individual years, or for summer and winter months separately, or sometimes for particular months, eg all Junes.

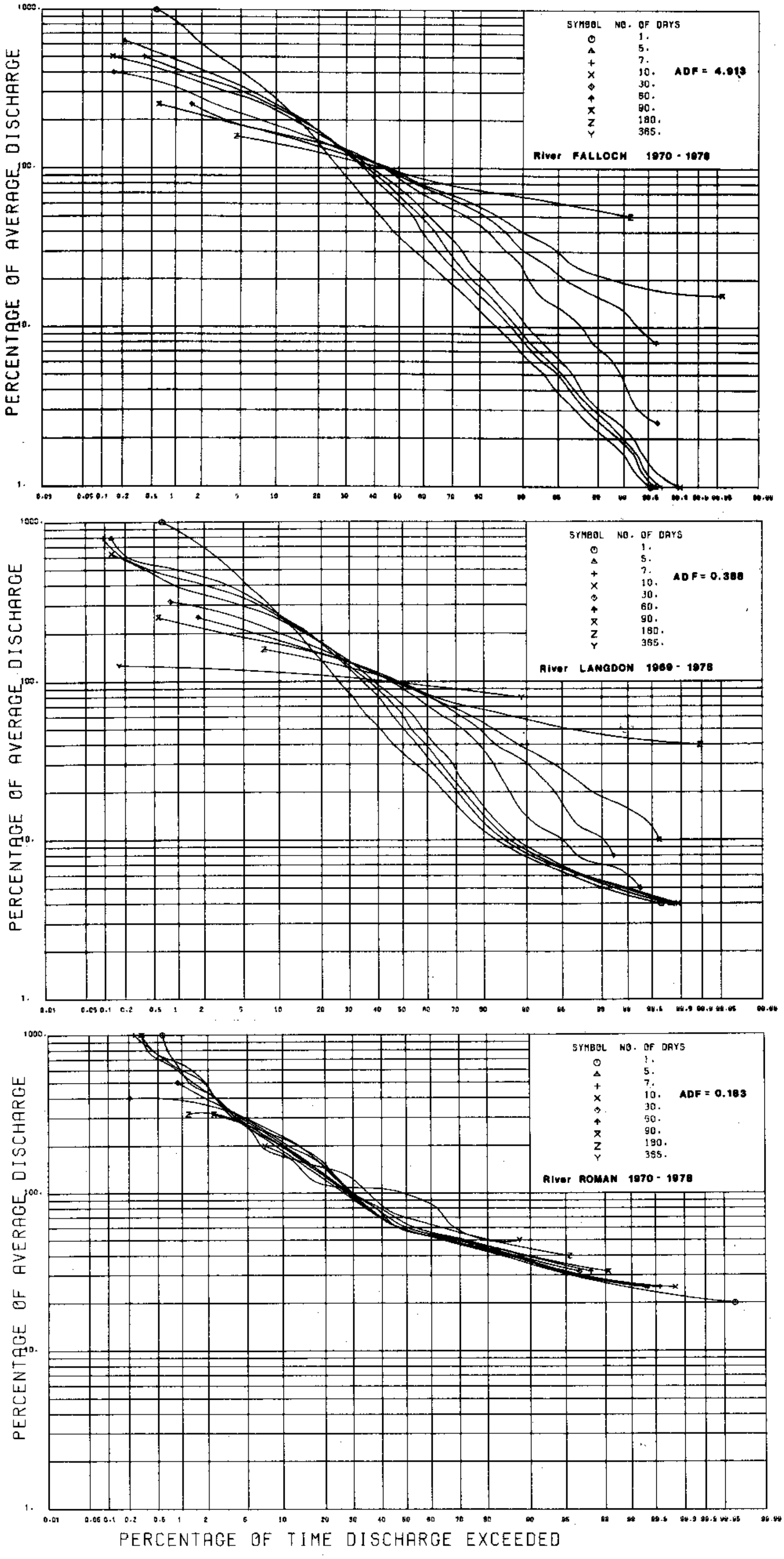


FIGURE 2.3b FLOW DURATION CURVES FOR FALLOCH, LANGDON AND ROMAN FOR DIFFERENT DURATIONS

3 The ungauged catchment case

3.1 INTRODUCTION

This section describes how the flow duration curve of any duration can be estimated at the ungauged site. The method is based on the relationship between the flow duration curve and catchment characteristics. The latter include catchment rainfall, stream length and a base flow index (BFI) which can be estimated from catchment geology and are described in estimation manual No. 3. The methods can however be used in conjunction with flow data by for example using estimates of BFI from data in preference to geology-based estimates. The procedures for estimating the curve for any duration D is divided into three components, as shown in Fig. 3.1.

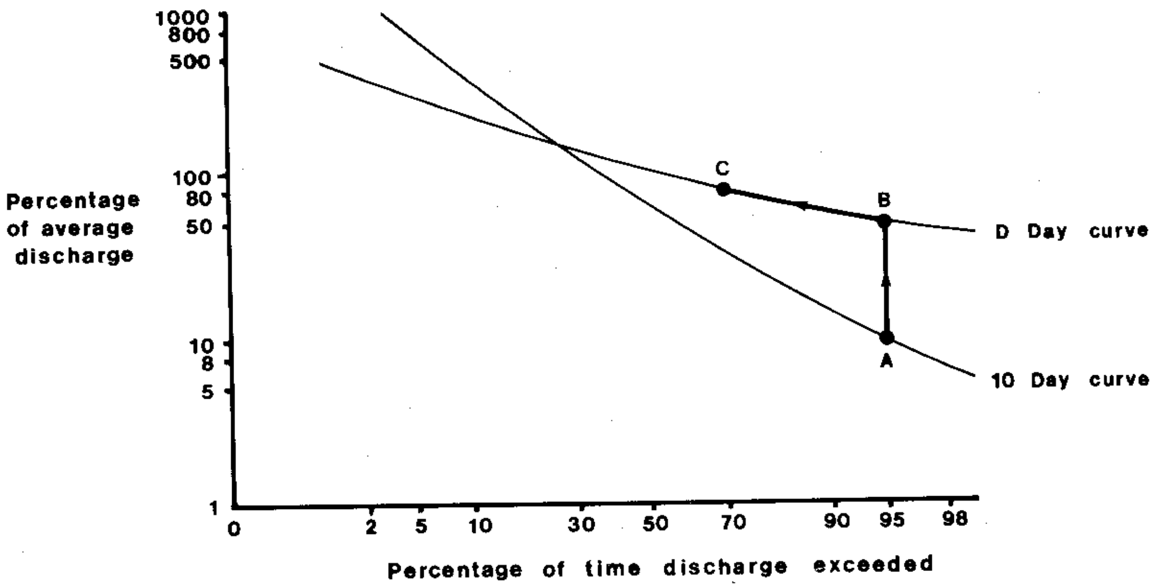


FIGURE 3.1 ESTIMATION PROCEDURE FOR UNGAUGED CASE

(a) estimation of the 95 percentile from the 10 day flow duration curve, Q95(10) expressed as a % ADF. This locates point A on the diagram which has in this example a discharge of 10% ADF. This calculation is explained in section 3.2 and is referred to as the External relationship (with catchment characteristics).

(b) estimation of the 95 percentile for durations other than the 10 day duration to give Q95(D). This locates point B on the diagram which in this example has a value of Q95(D) of 50% ADF. This calculation is described in section 3.3 and is referred to as the Internal duration relationship.

(c) estimate a percentile other than the 95 percentile, QP(D) (eg Q70(D) = 80%). This locates point C on the diagram which has a value of 80%. This is described in section 3.4 and is referred to as an Internal frequency relationship.

If only the 95 percentile 10 day discharge is required, then both steps (b) and (c) can be omitted. If the 95 percentile 10 day value is required, step (c) can be omitted.

3.1 INTRODUCTION

The basic steps in the estimation procedure are explained on the previous page. The flow duration curve will be estimated using BFI from catchment geology (Report No. 3) to construct the entire curves. An alternative procedure would be to use BFI from 8 months flow data (Report No. 3, section 3.1 If only Q95(10) is required, steps b and c can be omitted, while if Q95(D) is required step c can be omitted.

3.2 EXTERNAL RELATIONSHIP

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

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

$$=$$

$$Q95(10) = \_\_\_\_\_ \quad \% \ ADF$$

3.2 EXTERNAL RELATIONSHIP

Table 3.1 shows the regression equations to use in various regions of the country shown in Fig. 3.2. The equations give an estimate of the 95 percentile from the 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.

TABLE 3.1 **Regional external relationship regression equations**

Eqn	Hydrometric areas	Equation Q95(10) =
1	1-19, 84-97, 104-108	$7.60\sqrt{BFI} + .0263\sqrt{SAAR} - 1.46$
2	20-25, 27, 68-83, 103	$7.60\sqrt{BFI} + .0263\sqrt{SAAR} - 1.84$
3	45-67, 102, 201-223	$7.60\sqrt{BFI} + .0263\sqrt{SAAR} - 2.16$
4	26, 28-33	$11.9\sqrt{BFI} + .115\sqrt{SAAR} - 8.03$
5	34-44, 101	$8.51\sqrt{BFI} + .0211\sqrt{L} - 1.91$

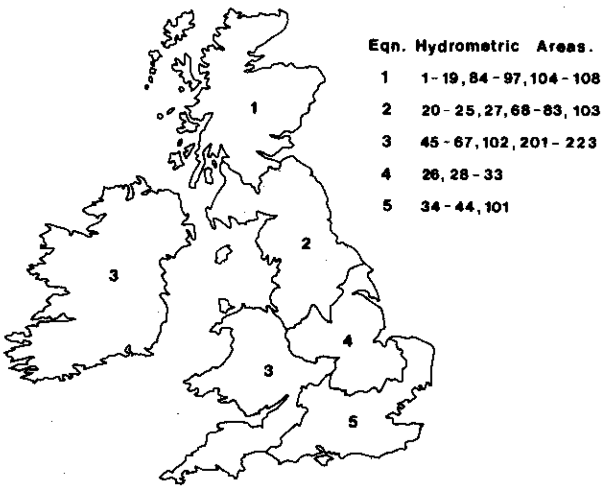


FIGURE 3.2 KEY MAP TO EXTERNAL REGIONAL RELATIONSHIP

Using equation 5 (the Pang catchment is in hydrometric area 39) and a value of BFI = 0.90 and L = 26.9 km

$$\sqrt{Q95(10)} = 8.51\sqrt{0.90} + .0211\sqrt{26.9} - 1.91$$

$$= 6.273$$

so $Q95(10) = 39.35$ %ADF

3.3 INTERNAL RELATIONSHIP (DURATION)

For the ______________ catchment SAAR = _____________ and Q95(10) is_________ therefore:

$$\log_{10}(GRADQ95) = .0230 \sqrt{\quad\quad} - .194 \sqrt{\quad\quad} - 2.11$$

$$= \_\_\_\_\_\_\_\_\_\_$$

$$\therefore \quad GRADQ95 = \_\_\_\_\_\_\_\_\_\_$$

The following can be completed using the Q95(D) expression opposite

D	1	10	30	60	90	180	
1 + (D-10)GRADQ95	___	___	___	___	___	___	
Q95(D)	___	___	___	___	___	___	% ADF

These values may be plotted on Figure 3.4b

3.4 INTERNAL RELATIONSHIP (FREQUENCY)

For the ___________ catchment complete the table of Q95(D) and TC.

Q95(10) is _________% ADF so the following type curves are calculated from the expression opposite

D	1	10	30	60	90	180
Q95(D) %ADF	___	___	___	___	___	___
Type curve, TC	___	___	___	___	___	___

Factors to be applied to Q95(D) are read from Figure 3.3 and entered on the table overleaf.

3.3 INTERNAL RELATIONSHIP (DURATION)

Having estimated Q95(10) the next step (if required) is to estimate the 95 percentile flow for the duration of interest.

This process of obtaining Q95(D) is in two steps: the first is to obtain the gradient or rate of change of Q95(D)/Q95(10) with D, (GRADQ95); the second is to use this gradient to calculate Q95(D).

The gradient is obtained from the equation:

$$\log(\text{GRADQ95}) = 0.0230\sqrt{\text{SAAR}} - 0.194\sqrt{\text{Q95(10)}} - 2.11$$

$$= 0.0230\sqrt{722} - 0.194\sqrt{39.35} - 2.11$$

$$= -2.7089$$

$$\text{GRADQ95} = 0.00195$$

The variable GRADQ95 is then substituted into the equation:

$$\text{Q95(D)} = (1 + (\text{D}-10).\text{GRADQ95})).\text{Q95(10)}$$

to give the 95 percentile flow of any duration, D, in % ADF units.

DURATION D	1	10	30	60	90	180	
Q95(D)	38·66	39·35	40·88	43·19	45·49	52·39	(% ADF)

3.4 INTERNAL RELATIONSHIP (FREQUENCY)

The process of obtaining flow duration percentiles other than 95 consists of multiplying Q95(D) by a factor that is read off a particular type curve from Fig. 3.3. The type curve is determined solely by the value of Q95(D) using

$$\text{TC} = \text{nearest integer } [10 \log \{\text{Q95(D) as \% ADF}\}]$$

Find the multiplying factor, r, from Fig. 3.3 equal to QP(D)/Q95(D)

For the Pang for D = 30 days Q95(D) = 40·88 and so the type curve is given by

$$\text{TC} = \text{nearest integer } [10 \log 40{\cdot}88] = 16$$

Calculation of flow of other percentiles QP(D)

Complete the following table using the results of Section 3.4 and Figure 3.3 factors:

D TC		P	
	20	60	99.9
1____r	____	____	____
QP(1) % ADF	____	____	____
5_____r	____	____	____
QP(5) % ADF	____	____	____
10____r	____	____	____
QP(10) % ADF	____	____	____
30____r	____	____	____
QP(30) % ADF	____	____	____
60____r	____	____	____
QP(60) % ADF	____	____	____
90____r	____	____	____
QP(90) % ADF	____	____	____
180___r	____	____	____
QP(180)%ADF	____	____	____

The % ADF values of QP(30) should be added to Figure 3.4b to complete the synthesised flow duration curve for that duration.

The following factors can be obtained:

Percentile	20	60	99.9	
r	3·1	2·1	0·57	
QP(30)	127	86	23·3	(% ADF)

These points and others are plotted on Fig. 3.4a

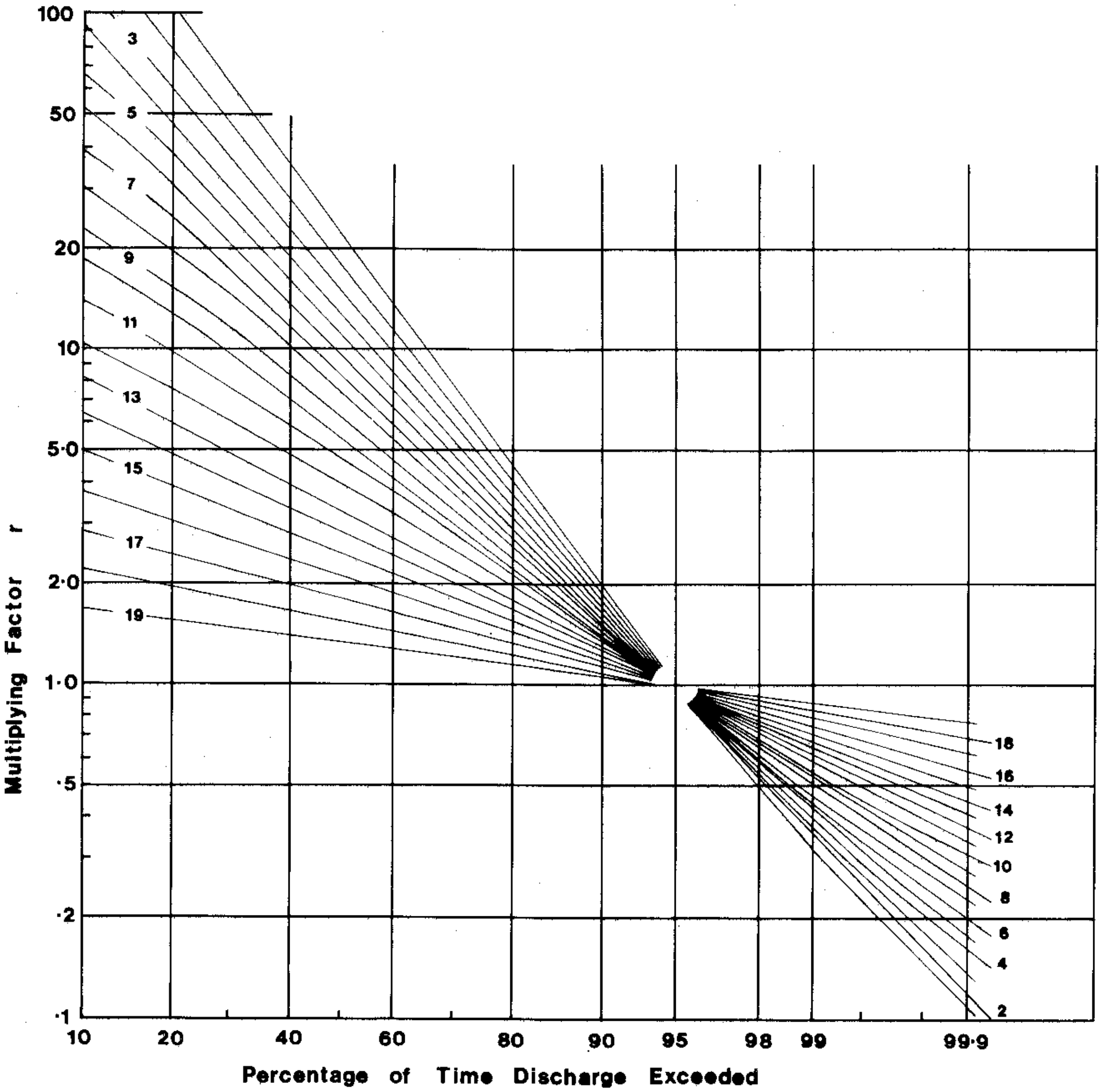
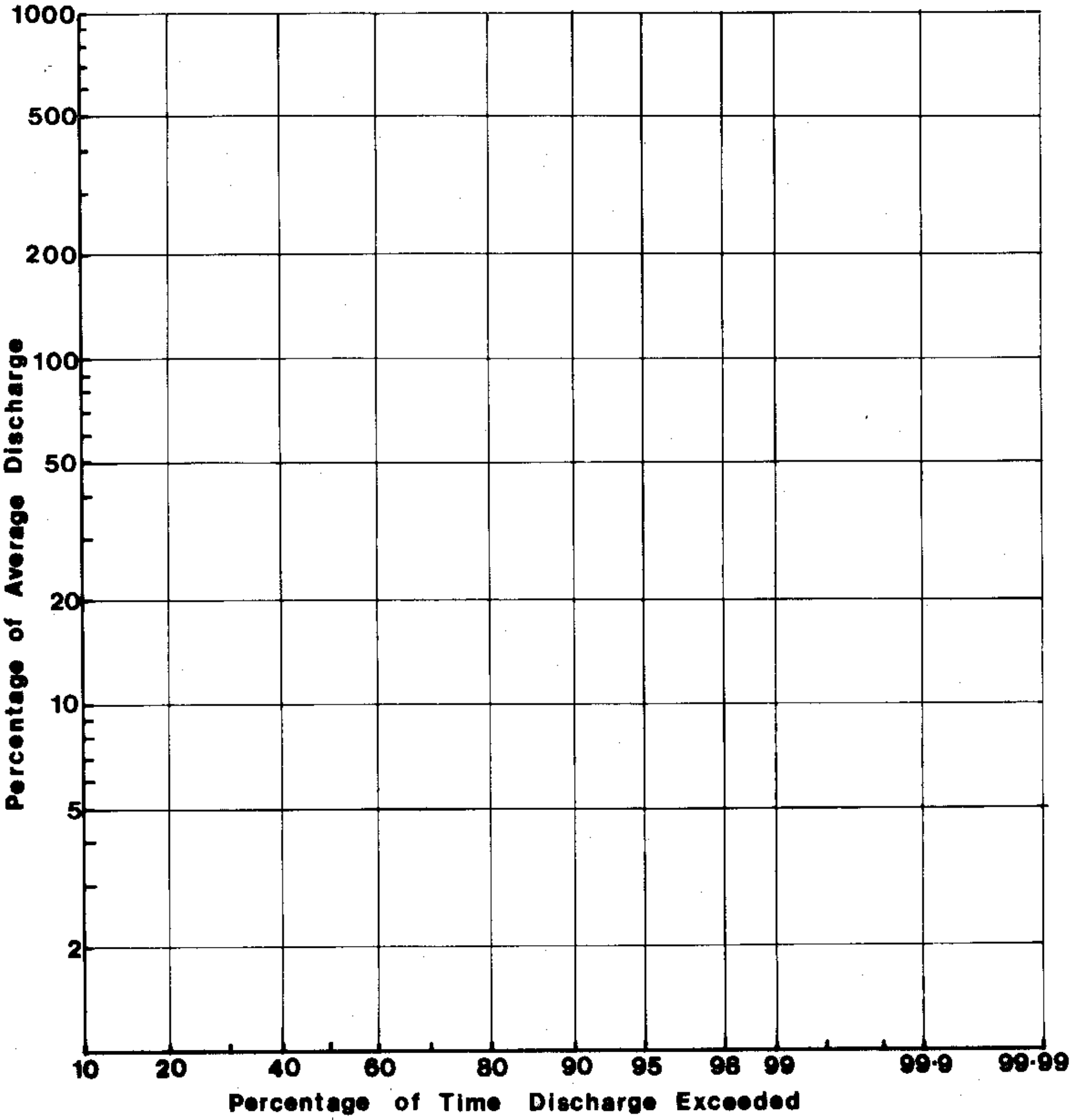


FIGURE 3.3 TYPE CURVES AND FREQUENCY RELATIONSHIP FOR FLOW DURATION CURVE



<u>FIGURE 3.4b</u> FLOW DURATION CURVE FOR FALLOCH, LANGDON, ROMAN

3.5 CONVERTING TO ABSOLUTE UNITS

Using Report No. 3, calculate the average flow (ADF) from rainfall and evaporation data.

Label Fig 3.4b in cumec units.

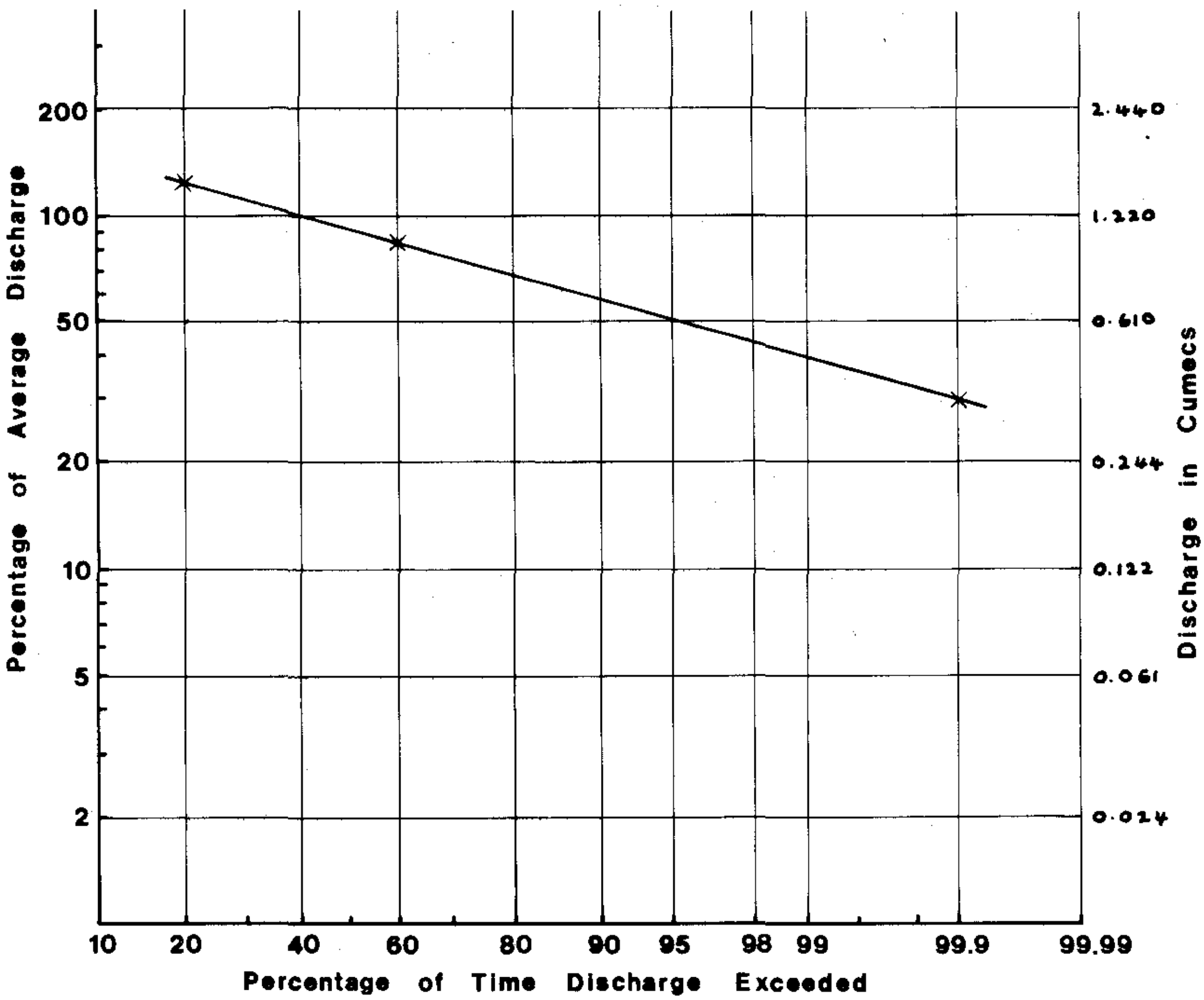


FIGURE 3.4a FLOW DURATION CURVE FOR PANG CATCHMENT

3.5 CONVERTING TO ABSOLUTE UNITS

Each step of the estimation procedure expresses discharge in terms of the % ADF. The final stage in the estimation procedure requires the estimation of the average discharge to the site of interest. A number of different techniques for doing this are described in report No. 3; they are based on one of two approaches. The first uses rainfall and evaporation data, the second is based on recorded flow data at or near the site of interest.

From report No. 3 the average flow for the Pang estimated from catchment characteristics is 1.220 cumecs. The scale of Fig. 3.4a is then calibrated in curves where 100% ADF = 1.220 cumecs. 10% ADF = 0.122 cumecs etc.

4.1 USING RELATIONSHIPS BETWEEN FLOW FREQUENCY CURVE AND FLOW DURATION CURVE

Suppose that data at the site had yielded a value for the mean annual 1 day minimum MAM(1) of:

____________ *(F)* ____________ *(L)* ____________ *(R)* *% ADF*

(Calculate values of MAM(1) from Section 2.1 of Report 2.2)

The first step is to convert these to MAM(10) values.

$log_{10}(GRADMAM)$ =

GRADMAM =

MAM(10) = _________/ {1 − 9 x _____} = *% ADF*

The second step is the linking relationship between the flow duration and flow frequency curves.

$\sqrt{Q95(10)} = 0.935\sqrt{\quad} + 0.0299\sqrt{\quad} - 0.693$

= *% ADF*

As a check on the results, Fig. 4.1 may be used. This is an overall average and omits the effect of climate. The value obtained from Fig. 4.1 is ___________ *% ADF*

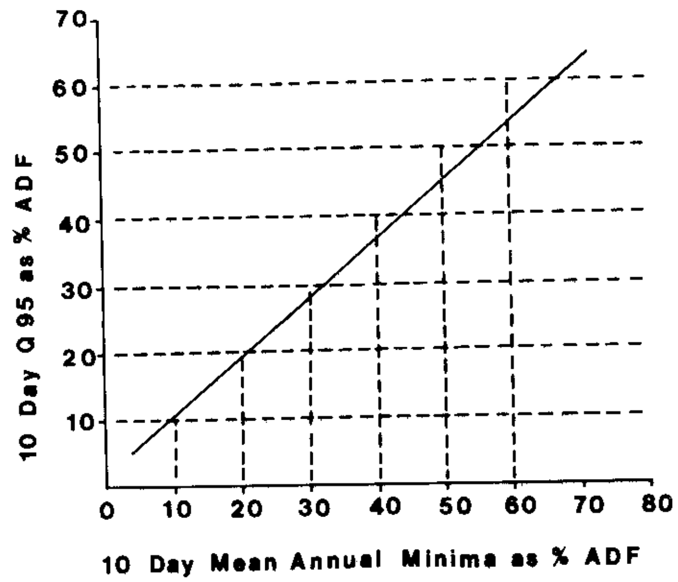


FIGURE 4.1

APPROXIMATE FLOW DURATION : FLOW FREQUENCY RELATION

4 Use of local data

In this chapter a number of methods of incorporating short or discontinuous data sources are demonstrated.

4.1 USING RELATIONSHIPS BETWEEN FLOW FREQUENCY CURVE AND FLOW DURATION CURVE

If a record of the lowest 1 day flows experienced in each year for, say 5 years is available, the mean annual minimum obtained from that data enables another estimate to be made of Q95. As the relationship between the flow duration and flow frequency curve has been developed for the 10 day duration statistics, it is necessary to convert from the 1 day to 10 day mean annual minimum. Using principles from Estimation Manual 2.2, Section 3.3, the following relationships are used:

$$MAM(10) = MAM(1)/\{1-9 \times GRADMAM\}$$

$$\text{where } \log_{10}(GRADMAM) = 0.00842\sqrt{SAAR} - 0.148\sqrt{MAM(1)} - 1.61$$

which is sufficiently accurate for present purposes.

For the Pang:

$$\log_{10}(GRADMAM) = 0.00842\sqrt{722} - 0.148\sqrt{37.53} - 1.61$$

$$\therefore GRADMAM = 0.005124$$

MAM(1) = 37.53 from Report 2.2, table 2.3,

$$\therefore MAM(10) = 37.53 \;/\{1 - 9 \times 0.00512\} = 39.34 \text{ \% ADF}$$

The linking relationship between the flow duration and flow frequency curve is:

$$\sqrt{Q95(10)} = 0.935\sqrt{MAM(10)} + .0299\sqrt{SAAR} - 0.693$$

$$\sqrt{Q95(10)} = 0.935\sqrt{39.34} + .0299\sqrt{722} - 0.693$$

$$Q95(10) = 35.70 \text{ \% ADF}$$

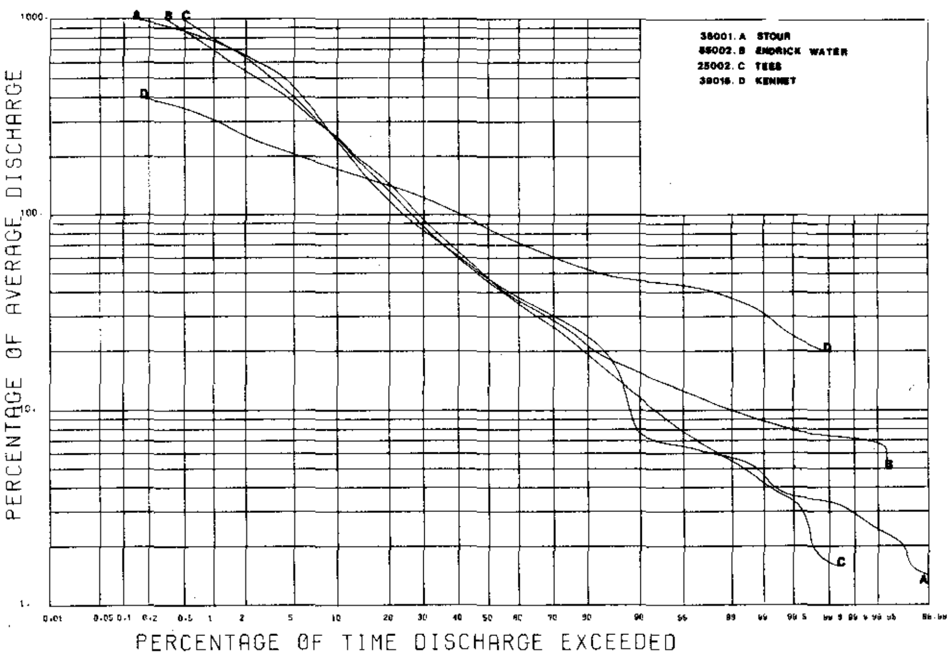
4.2 USING CURRENT METERINGS

Draw up the flow duration curve on Fig. 2.1b using the following current metering Q_A *and same day discharges* Q_B *at the analogue site.*

For the Falloch use the Endrick Water as an analogue station (ADF = 6.098)
For the Langdon use the Tees as an analogue station (ADF = 7.600)
For the Roman use the Stour as an analogue station (ADF = 2.776)

The 1-day duration curves for the analogue station are shown in Figure 4.2 and are used to estimate P_B *from* Q_B.

FIGURE 4.2 ANALOG FLOW DURATION CURVES FOR PANG, FALLOCH, LANGDON, ROMAN



4.2 USING CURRENT METERINGS

A programme of current meterings carried out at the site of interest can enable a reasonable alternative answer to the synthetic procedure to be found. The meterings, at least 10, should be reasonably distributed over a period of a season, not all crowded into a few days, should cover as much of the flow range as possible and should be carried out or adjusted with due regard for diurnal variations. The method is described below and is particularly valuable for small catchments as it overcomes the doubts about ADF and BFI assessment.

(i) choose a gauged analogue catchment (B) with well established 1-day flow duration curve and similar catchment geology - BFI comparisons are useful here;

(ii) at site of interest (A) measure discharge Q_A with current meter;

(iii) note percentile, P_B, (from flow duration curve Fig. 4.2) corresponding to flow Q_B at analogue catchment on the same day;

(iv) plot Q_A against P_B.

For the Pang catchment, the following current meterings, Q_A, were taken and same day discharge at station B, the Kennet at Theale, Q_B are shown below. The average flow for the Kennet at Theale = 9.442 cumecs and is used to convert to % ADF units for reading P_B from Fig. 4.2.

Date of current metering	Falloch (Endrick)				Langdon (Tees)				Roman (Stour)			
	Q_A (cumecs)	Q_B	Q_B %ADF	P_B	Q_A (cumecs)	Q_B	Q %ADF	P_B	Q_A (cumecs)	Q_B	Q_B %ADF	P_B
1/5	.71	1.327			.07	1.352			.17	3.587		
16/5	8.91	.925			.04	2.210			.20	1.831		
1/6	3.25	2.339			.04	2.295			.13	1.425		
16/6	.74	.780			.26	6.067			.10	3.356		
1/7	3.68	.932			.13	2.875			.13	1.080		
16/7	.77	.708			.02	3.115			.10	.820		
1/8	4.89	4.843			.13	4.397			.10	.936		
16/8	.47	1.577			.19	3.690			.09	.889		
1/9	12.13	4.230			.11	2.730			.09	.915		
16/9	.59	1.069			.04	2.787			.09	.804		
1/10	2.31	1.263			.03	2.609			.10	.868		
16/10	9.98	11.568			.41	6.596			.14	1.899		

The current metering Q_A is then plotted against percentile P_B on Fig. 2.1b.

4.3 USE OF A SHORT PERIOD OF CONTINUOUS DATA

One year of data or less

Calculate BFI using Section 3.1 of report 3 thus bypassing the need to estimate BFI from geology.

OR

Establish a graphical correlation between the discharge at site of interest Q_I and discharge at long term analogue station (Q_A).

$$Q_I = a + b\,Q_A$$

where a and b are estimated from the common record.

The flow axis Q_A of the flow duration curve can then be relabelled in terms of Q_I.

4.4 USE OF MONTHLY DATA

Use monthly flow duration curve estimate Q95(1 month) = Q95(30). Thereafter use internal duration and frequency relationship of Section 3.3 and 3.4.

Date of current metering	Current metering Q_A cumecs	Discharge on Kennet Q_B cumecs	Discharge on Kennet Q_B % ADF	Percentile on Kennet P_B
1.5	.63	11.100	117	34
16.5	.67	9.630	102	39
1.6	.52	7.360	78	56
16.6	.30	6.460	68	63
1.7	.43	6.060	64	68
16.7	.34	6.060	64	68
1.8	.33	5.440	58	72
16.8	.30	4.870	52	80
1.9	.27	4.590	49	84
16.9	.29	5.380	57	75
1.10	.24	4.420	47	88
16.10	.27	4.220	45	93

The current metering Q_A is plotted against percentile P_B on Figure 2.1a.

4.3 USE OF A SHORT PERIOD OF CONTINUOUS DATA

If a nearby analogue catchment with an established flow duration curve is available then the discharge at the site of interest can be correlated with the discharge at the long term station. The discharge axis of the long term flow duration curve can be relabelled with the discharge estimated from the short period correlation.

4.4 USE OF MONTHLY DATA

If only monthly flow data are available but daily based statistics are required, the result Q95(30) from daily data is equal to Q95(1 month) from monthly data can be used, to obtain an estimate of Q95(30).