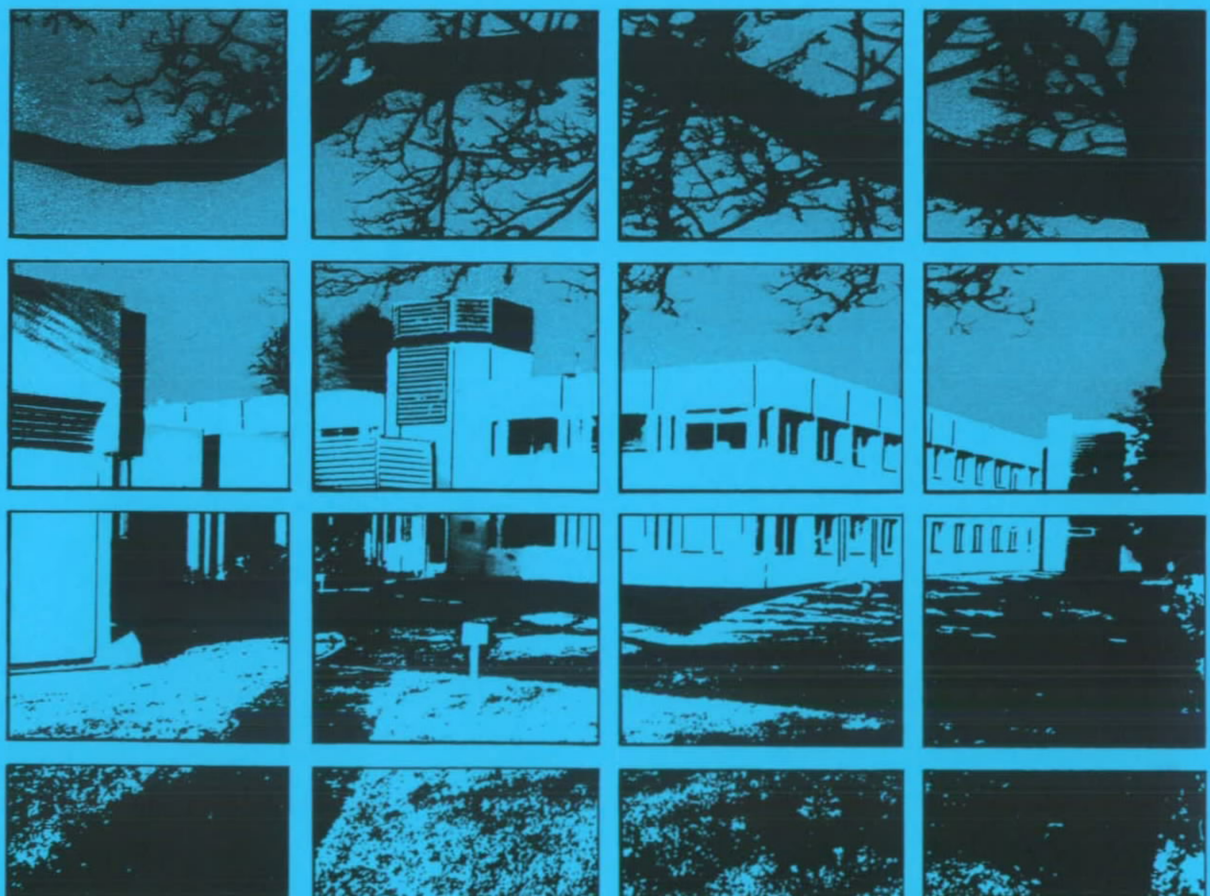
INSTITUTE of HYDROLOGY

Low flow estimation in Scotland



Report No 101

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Low flow estimation in Scotland

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Abstract

This report describes the results of a low flow study of Scotland commissioned by the Scottish Development Department and carried out by the Institute of Hydrology. The main objective of the study was to improve techniques for low flow estimation at the ungauged site. The study was based on mean daily discharge data for 232 stations held on the UK surface water archive. The authors would like to acknowledge the assistance of the River Purification Boards of Scotland not only for collecting and processing the data used in the study, but also for their contribution to the production of a Base Flow Index map of Scotland. This report is part of a series of Low Flow Study Reports the first of which was published by the Institute of Hydrology in 1980.

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Symbols and abbreviations

ADF	average flow in cumecs
AE	actual evaporation in mm
AREA	catchment area in km^2
BFI	base flow index
FALAKE	proportion of catchment covered by a lake or reservoir
PE	potential evaporation in mm
MAM(10)	mean annual 10 day minimum
Q95(10)	10 day average flow exceeded by 95% of 10 day average discharges
r	ratio between potential and actual evaporation
SAAR	standard period (1941-70) annual average rainfall

1. Background to the study

1.1 Introduction

Reports 2.1 and 2.2 of the 1980 Low Flow Studies Report (Institute of Hydrology 1980) present methods for calculating the flow duration and low flow frequency curves from flow data and at ungauged sites in the UK. The method used for ungauged sites is based on relating low flow statistics derived from recorded flow data to the geological and climate characteristics of their catchment areas. The Base Flow Index (BFI) was found to be a key variable in the estimation procedures and Report No.3 describes methods for estimating BFI at the ungauged site. This report presents revised equations for Scotland for estimating Q95(10) the 95 percentile discharge of 10 day flows and MAM(10) the mean annual 10 day minimum. These equations were derived from a data set of 155 stations - which included a further 10 years of mean daily flow data available for each station and 68 more stations than the original study. The revised equations enable the influence of lakes in a catchment to be incorporated in the estimation procedure. A further development has been the production of a river network map of BFI at a scale of 1:625 000 for Scotland, which considerably simplifies the task of estimating BFI at an ungauged site.

1.2 Summary of Report

The selection and grading of the 232 flow records which were used in the study is given in the next paragraph and this is followed by a summary of each of the low flow measures which were used to analyse the discharge data. Section 2 of this report describes the estimation of Q95(10) and MAM(10) at the ungauged site using the characteristics of the upstream catchment area. Section 3 outlines how a map of BFI for Scotland enables one of these characteristics to be estimated. The final section summarizes the revised recommendations to assist in the calculation of low flows.

1.3 Catchment selection

Mean daily discharge data for 232 gauging stations held on the UK Surface Water Archive were used in the study (Figure 1). The number and name of each station together with the period of record used are shown in Appendix 1. Following discussion with the relevant hydrometric organisation, each flow record was graded using the following criteria:-

Grade A
Accurate low flow measurement, natural catchments with net artificial influences less than approximately 5% of the average flow (155 stations).

Grade B
All other stations <u>except</u> those with poor accuracy of flow measurement and/or artificial influences on low flows greater than 10% of the average flow (25 stations).

Grade C
Stations with low accuracy of flow measurement and/or artificial influences greater than 10% of the average flow (52 stations).

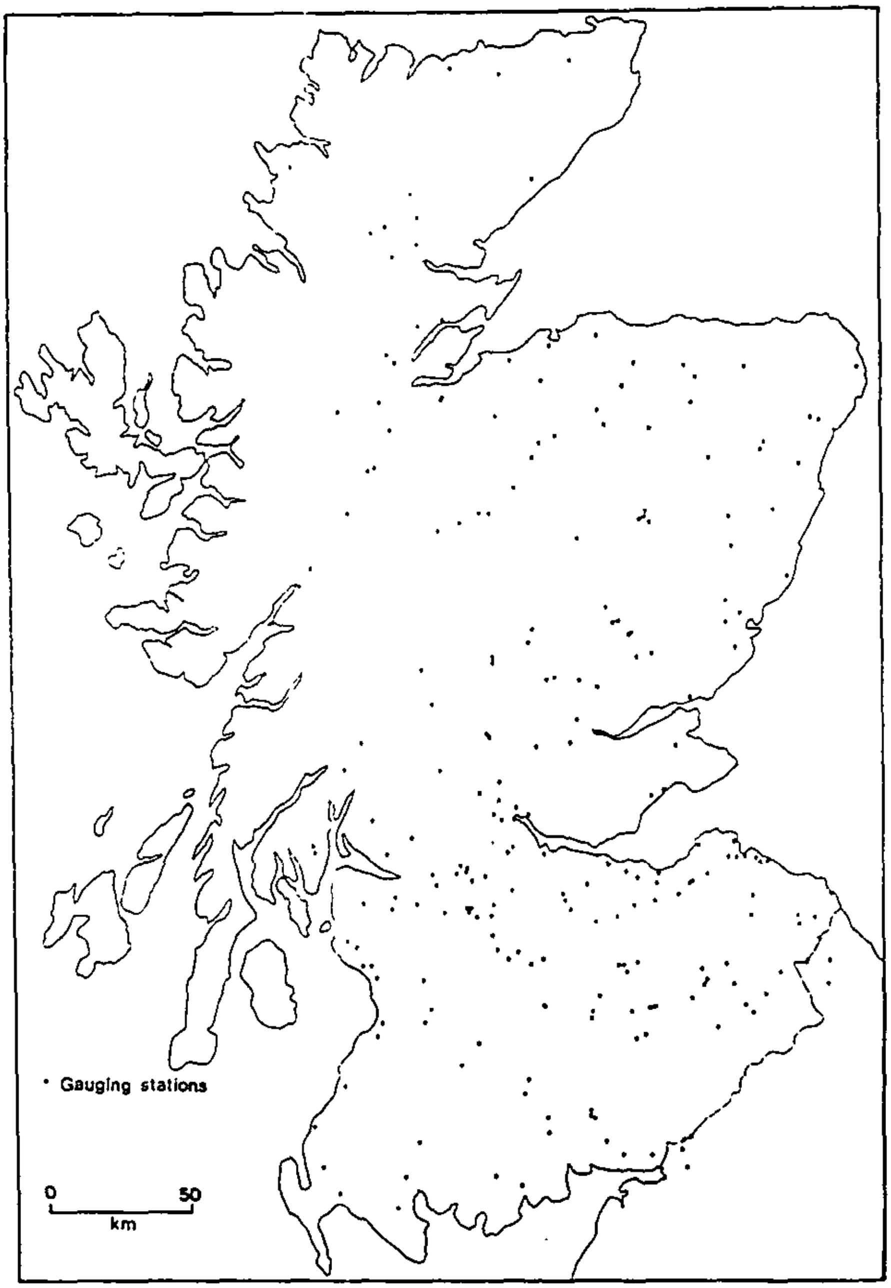


Figure 1 Location of the stations used in the study

Figure 2 shows the length of record for stations in each grade. Grade A stations were used for relating low flow statistics to the Base Flow Index. Both grade A and B stations were used for developing a method for estimating BFI at the ungauged site. Grade C stations were excluded from the analysis although their BFI is shown with an asterisk on the BFI map. Although they are influenced by artificial controls or are of poor accuracy, they may provide useful information on the flow regime for a number of rivers in Scotland.

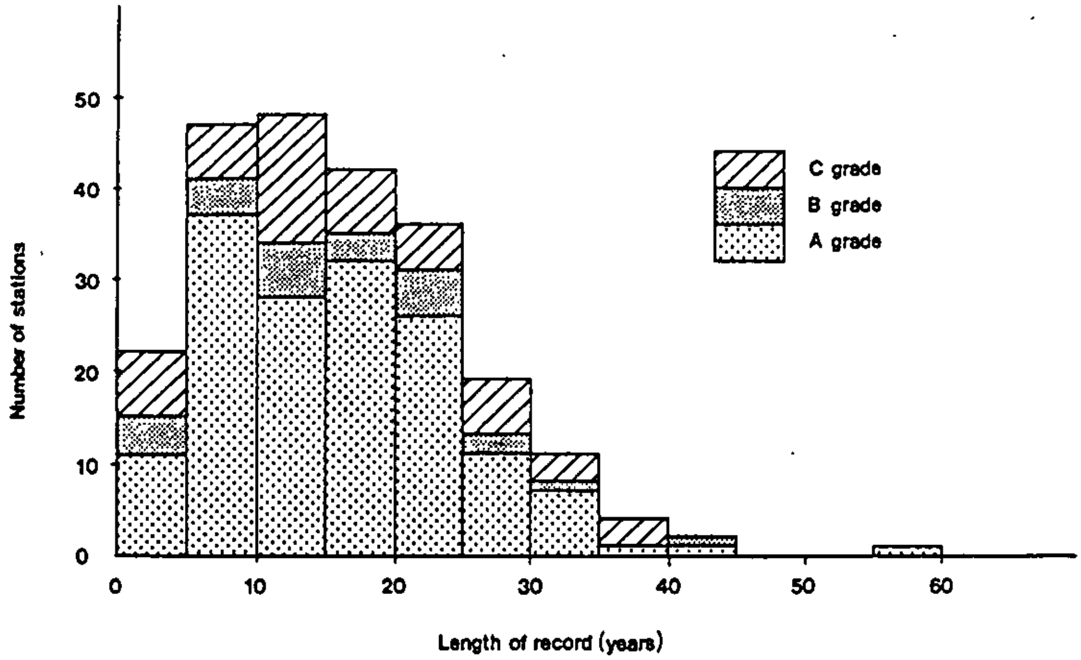


Figure 2 Histogram of length of record for each grade of station

1.4 Analysis of Flow Data

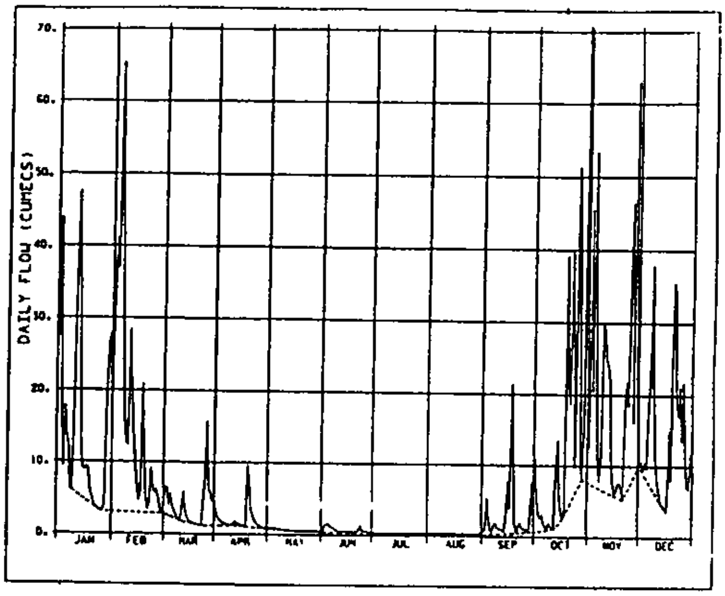
Figure 3 illustrates each low flow measure used in the study for the Endrick Water from which three summary statistics were calculated. All 232 flow records were analysed in this way and the results are summarised in Appendix 1. The following Low Flow Study Reports (LFSR) describe in detail the calculation of each low flow measure from mean daily discharge data and how single number indices can be calculated for each diagram:-

* Q95(10) - the 95 percentile 10 day discharge: Report 2.1 Flow duration curve estimation manual.

* MAM(10) - the mean annual 10 day minimum: Report 2.2 Flow frequency curve estimation manual.

* BFI - the Base Flow Index: Report 3 Catchment characteristic estimation manual.

There are no major revisions to the published procedures for estimating these low flow measures although Appendix 2 summarises a number of important aspects concerning the Base Flow Index.

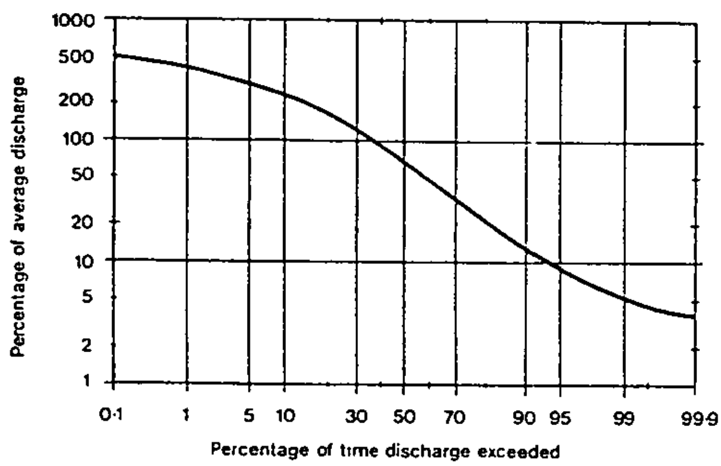


——— Recorded Hydrograph

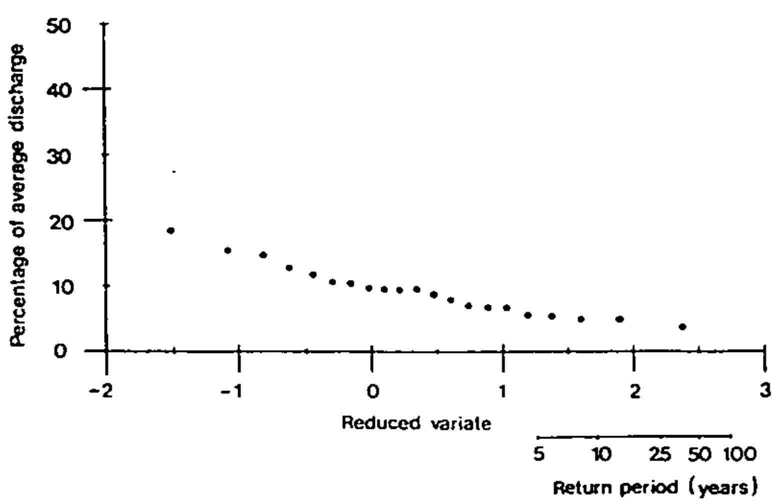
- - - - - - Base Flow Line

Base Flow Index = 0·33

(a) Base Flow Separation 1984



(b) Ten Day Flow Duration Curve
1964 – 1984
Q95(10) = 9·38% ADF



(c) Ten Day Flow Frequency Curve
1964 – 1984
MAM(10) = 9·10% ADF

Figure 3 Low flow measures for Endrick Water

2. Flow estimation at the ungauged site

In the LFSR the British Isles were divided into five regions of which Scotland occupied the whole of one region and part of another. Regression equations were derived for each of these regions for estimating Q95(10) and MAM(10) from the Base Flow Index (BFI) and Standard Annual Average Rainfall (SAAR). These variables and the methods that should be employed to compute them are described in detail in LFSR 3, Catchment characteristic estimation manual. The most suitable transformation for the data prior to deriving the regression equations, was found to be the square root transform, both the dependent and independent variables were transformed in this way.

The LFSR analysis as outlined above was followed in this study using the 155 grade A stations. Table 1 shows the correlation matrix between the square roots of the variables.

Table 1 Correlation matrix for square root transformation applied to all variables (155 stations)

	Q95(10)	MAM(10)	BFI	SAAR	FALAKE
Q95(10)	1.000	0.954	0.805	-0.420	-0.140
MAM(10)	0.954	1.000	0.859	-0.556	-0.201
BFI	0.805	0.859	1.000	-0.578	-0.041
SAAR	-0.420	-0.556	-0.578	1.000	0.369
FALAKE	-0.140	-0.201	-0.041	0.369	1.000

After exploring a number of combinations of independent variables the following equations were derived for estimating Q95(10) and MAM(10) from BFI and other catchment characteristics.

$$\sqrt{Q95(10)} = 8.81\sqrt{BFI} + 0.0248\sqrt{SAAR} - 2.40\sqrt{FALAKE} - 2.66$$

$$R^2 = 0.665 \quad se = 0.57$$

$$\sqrt{MAM(10)} = 9.44\sqrt{BFI} - 2.80\sqrt{FALAKE} - 2.27$$

$$R^2 = 0.761 \quad se = 0.54$$

All variables were significant at the 99% confidence level in both equations. An examination of the residuals (difference between the observed and predicted dependent variable) indicated that there was no tendency for positive or negative residuals to cluster in particular areas of Scotland. It was therefore decided to use one equation for the whole of Scotland.

The main revision to the LFSR equations is the addition of the variable FALAKE, the proportion of the catchment which is covered by a lake or reservoir (Figure 4). This was not a significant variable in the original LFSR but the enhanced data set has now made it possible to incorporate the effects of lakes on low flows. The negative regression coefficient of FALAKE does not imply that catchments with lakes have lower low flows than those without. This apparent paradox is resolved by recalling that the attenuating effect of a lake on the downstream hydrograph will greatly increase the BFI. This results in higher BFIs in laked catchments for a given Q95(10) than in lake free catchments and so this increased BFI is compensated in the equation by a negative coefficient of FALAKE. This same phenomenon occurs in the MAM(10) equation. The other feature of the equations is that SAAR is a useful explanatory variable for Q95(10) but not for MAM(10). This confirms the LFSR results which consistently showed that Q95(10) was higher in wet than in dry areas having the same BFI but that MAM(10) was independent of rainfall in most regions.

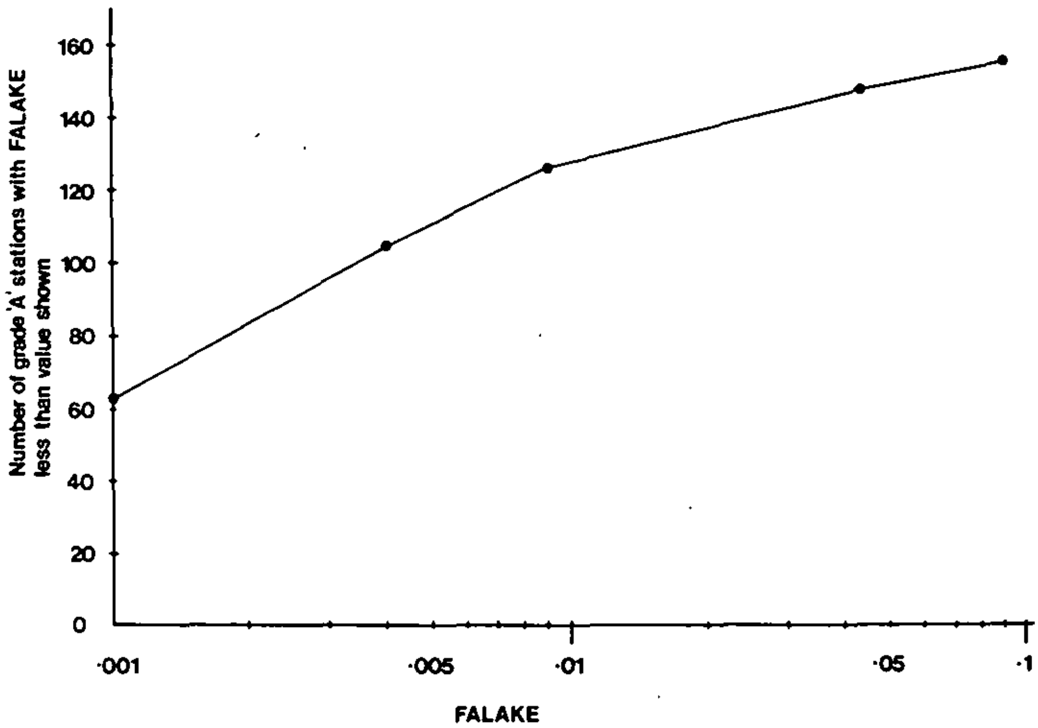


Figure 4 Number of grade A stations having a given fraction of their catchment area covered by lake

Examination of the revised equations indicates that they predict 10 and 30 percent lower than the LFSR region 1 equation for catchments with a BFI of 0.7 and 0.3 respectively. This is due to the increased number of stations used in the current study and to the reduction in magnitude of flow statistics by about 10 percent with the extension of the older records which now include some notable droughts in the period 1974 to 1984. This lowering of Q95(10) and MAM(10) compares with a reduction of less than 2% for the mean BFI value.

A revision of the full duration and frequency relationship of Reports 2.1 and 2.2 was beyond the scope of this study. It is recommended that the revised equations for Q95(10) and MAM(10) are used and that the LFSR is followed if flow statistics of different durations or frequencies are required.

The final stage in the estimation procedure is to calculate the average discharge (ADF) at the ungauged site in order to convert low flows expressed as a %ADF to absolute values in cumecs. The recommendations given in LFSR 3 were reviewed in this study by carrying out a water balance of 43 catchments using concurrent flow and rainfall data. The results from this investigation supported the LFSR procedure which should be used for calculating ADF.

3. Base Flow Index estimation

3.1 Introduction

The LFSR illustrated how relationships could be developed between the Base Flow Index and catchment geology using data from gauged catchments, and how these relationships can be used to estimate BFI at ungauged sites. One of the main objectives of this study was to improve the ease with which BFI estimates could be made by producing a river network map of BFI for Scotland. The map was based on an analysis of 232 gauged values of BFI.

To develop links between observed values of BFI and the factors thought to control the availability of storage in the catchment, the mainland of Scotland was divided into the following regions:-

The Scottish Highlands - delineated to the south by the Highland Boundary Fault. This is an area of rugged hills including the Cairngorm Mountains, rising to Ben Nevis at 1343m. Metamorphic rocks outcrop over much of the region, with Devonian sandstone sediments around the Moray Firth and Torridonian sandstone and grit in the west. Igneous rocks of various ages are found throughout the area.

The Midland Valley of Scotland - bounded by the Highland Boundary Fault in the north and the Southern Upland Fault in the south. The area is a fault guided valley stretching from the Firths of Forth and Tay to the Firth of Clyde. The floor of the valley consists of a complex of Palaeozoic sediments with Devonian sandstones and Carboniferous grits, limestones and coal measures predominating. There are also extensive volcanic outcrops. It is a broad undulating lowland, with the higher parts reaching altitudes of over 600m in the Lennox and Ochill hills.

The Southern Uplands - between the Southern Upland Fault and the English Borders. This is an undulating dissected plateau with the greater part of the region being occupied by highly folded Silurian and Ordovician rocks. Intrusions in the form of dykes and sills abound and large granite masses occur to the west.

The solid geology of each region is overlain by considerable thicknesses of superficial deposits which significantly influence the importance of the underlying geology on the catchment response. Drift deposits range from impermeable boulder clays to fluvio-glacial sands and gravel which sustain base flows in dry weather. Much of the upland areas are covered by very variable thicknesses of peat deposits. The thickness of superficial deposits ranges from a few metres to more than 30 metres. (A full description of the solid and drift geology of Scotland can be found in the British Regional Geology series published by the Natural Environment Research Council).

3.2 Relationship with soil and geology

Catchment boundaries were drawn for the 232 catchments on a 1:250 000 scale topographic map and transferred to a 1:625 000 map. This scale was chosen for the convenience of map size and also because it permitted easy comparison with reference maps which could be related to the Base Flow Index. The topography, geology and soils of each catchment were evaluated using the following maps at 1:625 000:-

1. Physical Map of Great Britain, Sheet 1. OS 1957.
2. Geological Map of United Kingdom, North. Solid. 3rd Edition, OS 1979.
3. Quaternary Map of the United Kingdom, North. 1st Edition, OS 1977.
4. Winter Rain Acceptance Potential NERC. FSR supplement No.7. Apl 1978.

For each catchment the solid and drift geology and the proportion of the five Flood Studies soil classes (NERC 1975, Farquharson et al 1978) were calculated. Regression equations were derived using gauged values of BFI to estimate the BFI from catchment geology and soil class. The solid geology was generally of less significance than the superficial geology or soil indices although the equations provided some useful guidance on the BFI of particular lithologies, for example the relatively low values of BFI on the Ordovician rocks of the Southern Uplands and the igneous rocks of the Midland valley. The analysis using the five class WRAP (Winter Rain Acceptance Potential) map indicated relatively high BFI values from WRAP classes 1 and 2 and low values from class 5. Regressions carried out between BFI and soil class resulted in different coefficients in each of the three regions (Table 2). Classes 1 and 2 were combined in the Highland region but were not included in the other regions because of the very small proportion of these classes in gauged catchments. Within each region some inconsistencies between BFI and WRAP class were apparent - for example a very wide range of BFI from 0.2 to 0.6 on WRAP class 5 soils in the Highland region. However the soil class does provide a useful variable for estimating BFI at ungauged sites in Scotland.

Table 2 Estimated BFI for 100% coverage of given WRAP class

	Class 1/2	Class 3	Class 4	Class 5
Highlands	.66	.50	.35	.40
Midland Valley	†	.60	.38	.30
Southern Uplands	†	.53	.44	.30

† insufficient class 1 & 2 soils

Inspection of BFIs from small headwater catchments indicated that BFIs were approximately 0.05 lower in first and second order streams than at points lower down the catchment. Examination of the BFI below lochs showed the effect of increased storage raising the BFI to approximately 0.6 downstream of large lochs in excess of 5 km^2 and to 0.4 downstream of small lochs.

The analysis of BFI on gauged catchments provided a basis for estimating BFI at ungauged sites in each of the three mainland regions and in the Scottish Islands and also provided guidance on transferring local gauged BFIs to adjacent ungauged rivers.

3.3 BFI map

A Base Flow Index map of Scotland (Gustard et al, 1986) at a scale of 1:625 000 depicts BFI along river stretches. The network displayed is that shown on the O.S. Physical Map of Great Britain Sheet 1, augmented to show additional rivers on which there are gauging stations. The BFIs on the map lie between 0.18 (85003) and 0.81 (85001), and each river stretch is shown in one of twelve classes (Table 3).

Table 3 Base Flow Index along river stretches

Class 1	0.00 - 0.24
2	0.25 - 0.29
3	0.30 - 0.34
4	0.35 - 0.39
5	0.40 - 0.44
6	0.45 - 0.49
7	0.50 - 0.54
8	0.55 - 0.59
9	0.60 - 0.64
10	0.65 - 0.69
11	0.70 - 0.74
12	≥0.75

The river network was divided into river links between confluences or further subdivided where necessary into stretches typically four kilometres in length. A BFI was assigned according to data availability by using one or more of the following procedures (listed in order of reducing accuracy and preference).

1. Assigning BFI calculated from a grade A, B or C station.

2. Interpolation between gauged BFIs or extrapolation of values upstream or downstream.

3. Transference of gauged BFIs from nearby catchments with similar geology, soils and topography.

4. Estimation of BFI from regional regression equations based on flow records from grade A and B stations.

5. Estimation of BFI downstream of lochs and in small headwater streams.

A draft map with the BFI marked against each river stretch was sent to each River Purification Board and their suggestions, based on more detailed local knowledge, were incorporated.

3.4 Using the BFI map

The BFI value at an ungauged site on a river shown on the map can be easily read using the colour coded river network. The following recommendations may be helpful when using the map:-

- Approximately one third of the rivers shown at a scale of 1:250 000 are marked on the 1:625 000 map. In estimating BFI for a minor stream not shown on the map, comparisons should be made with adjacent catchments on the BFI map having similar geology, soils and topography.

- Values of BFI have been adjusted to allow for upstream lochs shown only on the 1:625 000 map. Where inspection of the 1:50 000 map reveals a significant number of small lochs, it may be appropriate to substitute a BFI value two classes higher than that shown on the published map.

- The mid point of each class interval should be used in the regression equations. For the lowest and highest intervals it is suggested that in the absence of additional information that values of 0.2 and 0.8 are used.

- The rivers are classified as though the BFI is based on a natural flow regime, except downstream of gauged sites known to be artificially influenced. Low flow estimates should be based on the mapped BFI and adjustments made for artificial influences upstream of the site.

- It is recommended that the calculated values of Q95(10) or MAM(10) shown in Appendix 1 be used immediately up or downstream of gauging stations. Inspection of the BFI map will provide information to assess how far from the gauging station, estimates can be transferred with confidence. For stations influenced by artificial controls (marked with an asterisk on the map) the flow statistics tabulated in Appendix 1 will include the artificial influences.

- Where durations and frequencies other than Q95(10) or MAM(10) are required for locations near gauged records, it is recommended that a full analysis of the mean daily flow data is carried out. (LFSR 2.1 and 2.2).

4. Summary of Q95(10) and MAM(10) estimation procedure

The following left hand pages in italic type are available for carrying out the estimation procedure.

4.1 Catchment characteristics

Catchment area (AREA)

Select a practice catchment and follow the steps illustrated on the page opposite. This catchment may be the Falloch at Glen Falloch in which case a description will be found in LFSR 3, p2.

Practice catchment _

Grid Reference of point of interest _

AREA of catchment = _ _ _ _ _ _ _ *sq km*

Lake area (FALAKE)

Surface area of lake = _ _ _ _ _ _ _ _ _ _ _ _ _ *sq km*

FALAKE = $\frac{\text{\_ \_ \_ \_ sq km}}{\text{sq km}}$ = _ _ _ _ _ _ _ _ _

4. Summary of Q95(10) and MAM(10) estimation procedure

The user is referred to LFSR 2.1, p11 for recommendations on the most appropriate method to use to calculate Q95(10) for a given length of record and to p35 of the same report for information on incorporating local data. Similarly, LFSR 2.2, p11 suggests guidelines for calculating MAM(10), instructions on the use of local data will be found on p33. LFSR 3.0 contains the methodology in detail for calculating the catchment characteristics below.

The following summary of Q95(10) and MAM(10) estimation at an ungauged site should only be followed when there are no local data available. Section 4 of LFSR 2.1 and 2.2 describe methods of incorporating local data into the estimation procedure.

To help summarise the calculation steps a worked example for the Endrick Water at Gaidrew, Hydrometric area 85, grid ref NS 485866, is given on the right hand pages. The left hand page is provided for practice and is set in italic type.

4.1 Catchment characteristics

Catchment area (AREA) in sq km

Calculate topographic catchment area in sq km from 1:50 000 or 1:25 000 scale O.S. maps.

For the Endrick Water at Gaidrew the topographical catchment AREA was found from 1:25 000 scale maps to be 219.9 sq km.

Lake area (FALAKE)

Determine the sum total area of any lake(s) or reservoir(s) within the catchment in sq km. FALAKE is the fraction obtained by dividing the area covered by lake, by the topographic catchment area.

Lake area = 1.98 sq km.

$$\text{FALAKE} = \frac{1.98 \text{ sq km}}{219.9 \text{ sq km}} = 0.009$$

Standard annual average rainfall (SAAR)

From 1941 - 1970 Standard Annual Average Rainfall map

SAAR = _ _ _ _ mm

Potential and actual evaporation (PE & AE)

SAAR = _ _ _ _ mm

From the table opposite, r = _ _ _

From The Met Office PE map, PE = _ _ _ mm

AE = _ _ _ _ mm

Base Flow Index

From BFI map, BFI class = _ _ _ _ _

BFI (midpoint of class) = _ _ _ _

Standard Annual average rainfall (SAAR)

Calculate SAAR from the 1941-1970, 1:625 000 Meteorological Office map of annual average rainfall.
For the Endrick Water SAAR = 1478mm

Potential and actual evaporation (PE & AE)

Potential evaporation may be estimated from the 1:2 000 000 Meteorological Office map of annual average potential evaporation.

PE for the Endrick Water is 450 mm

Actual evaporation is calculated by multiplying potential evaporation by a factor which is dependent upon SAAR.

AE = PE x r where r derives from the following table;

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

For the Endrick Water r = 1.0 (SAAR=1478)

AE = PE x 1.0 = 450 mm

Base flow index

The BFI class interval is read from the BFI map and the mid point of this interval used in the regression equation. For the lowest and highest class interval it is suggested that in the absence of additional information, values of 0.20 and 0.80 are used. (In Scotland, the lowest observed BFI is 0.18 and the highest 0.81).

BFI class = 0.30 - 0.34

mid point BFI = 0.32

Note that there is a flow record at this site but the data are not being used in this demonstration example. For short records with one or two years of data, BFI calculated from the flow record should be used; for longer records, values of Q95(10) and MAM(10) are preferred (Appendix 1). If the point of interest is sited on a river which does not appear on the map, interpolate a value using data from nearby rivers having a similar soil type, geology and topography.

4.2 Estimating low flow measures

Flow duration curve

$$\sqrt{Q95(10)} = 8.81\sqrt{BFI} + 0.0248\sqrt{SAAR} - 2.40\sqrt{FALAKE} - 2.66$$

$\sqrt{Q95(10)}$ = ...

$Q95(10)$ = ... %ADF

Flow frequency curve

$$\sqrt{\mathrm{MAM(10)}} = 9.44\ \sqrt{\mathrm{BFI}} - 2.80\ \sqrt{\mathrm{FALAKE}} - 2.27$$

$\sqrt{\mathrm{MAM(10)}}$ = ...

$MAM(10)$ = ... %ADF

4.2 Estimating low flow measures

Flow duration curve

$$\sqrt{Q95(10)} = 8.81\sqrt{BFI} + 0.0248\sqrt{SAAR} - 2.40\sqrt{FALAKE} - 2.66$$

Substituting the values of the independent variables determined above;

$$\sqrt{Q95(10)} = 8.81\sqrt{0.32} + 0.0248\sqrt{1478} - 2.40\sqrt{0.009} - 2.66$$

$\therefore$ Q95(10) = 9.24%ADF

This equation supercedes that shown in LFSR 2.1, Table 3.1, Eqn 1 & Eqn 2 (within Scotland).

Having determined Q95(10), percentiles of other durations and frequencies e.g. Q95(1) or Q80(10) etc. may be established using methods described in LFSR 2.1 pp29-33.

Flow frequency curve

$$\sqrt{MAM(10)} = 9.44\sqrt{BFI} - 2.80\sqrt{FALAKE} - 2.27$$

$$\sqrt{MAM(10)} = 9.44\sqrt{0.32} - 2.80\sqrt{0.009} - 2.27$$

$\therefore$ MAM(10) = 7.84%ADF

This equation supercedes that shown in LFSR 2.2, Table 3.1, Eqn 1 & Eqn 2 (within Scotland).

Having determined MAM(10), annual minima of different durations and return periods e.g. MAM(1) or AMP(10) etc. may be established using methods described in LFSR 2.2, pp27-31.

4.3 Converting to absolute units

Annual runoff = SAAR - AE = _ _ _ mm

ADF = 0.00003171 x *AREA* x *Annual Runoff*

= _ _ _ _ _ _ *cumecs*

Thus

$$Q95(10) = \frac{\rule{2em}{0.4pt}}{100.0} \%ADF \times \_\_\_\_\_\_ \; cumecs = \_\_\_\_ \; cumecs$$

$$MAM(10) = \frac{\rule{2em}{0.4pt}}{100.0} \%ADF \times \_\_\_\_\_\_ \; cumecs = \_\_\_\_ \; cumecs$$

4.3 Converting to absolute units

The equations above result in estimates for Q95(10) and MAM(10) expressed in %ADF terms. To convert these figures to cumecs, first compute the annual runoff expressed in mm from rainfall and actual evaporation, over the catchment area.

Annual runoff = SAAR - AE = 1478 - 450 = 1028 mm

The conversion from mm to cumecs is made by multiplying the mm figure by 0.00003171 x AREA.

For the Endrick, ADF = 0.00003171 x AREA x Annual runoff

= 0.00003171 x 219.9 x 1028

= 7.168 cumecs

Thus Q95(10) = 9.24 %ADF x 7.168 = 0.662 cumecs

MAM(10) = 7.84 %ADF x 7.168 = 0.562 cumecs

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Appendix 1 Flow data used in study

GRADE	NO	STATION NAME	PERIOD OF RECORD	BFI	Q95(10) %ADF	MAM(10) %ADF
A	2001	HELMSDALE AT KILPHEDIR	1975-1984	0.48	24.04	21.50
A	3001	SHIN AT LAIRG	1954-1957	0.59	14.46	13.62
C	3002	CARRON AT SGODACHAIL	1974-1984	0.31*	11.33	9.41
A	3003	OYKEL AT EASTER TURNAIG	1977-1984	0.25	7.31	6.55
C	3004	CASSLEY AT ROSEHALL	1979-1984	0.22*	8.96	5.91
C	3005	SHIN AT INVERAN	1982-1984	0.54*	36.23	33.87
A	3803	TIRRY AT RHIAN BRIDGE	1949-1956	0.27	11.80	9.74
C	4001	CONON AT MOY BRIDGE	1976-1984	0.68*	24.83	26.17
C	4002	GLASS AT REDBURN	1953-1962	0.42*	39.30	33.75
B	4003	ALNESS AT ALNESS	1974-1984	0.45	11.82	10.33
C	4004	BLACKWATER AT CONTIN	1982-1984	0.41*	23.79	25.47
C	5001	BEAULY AT ERCHLESS	1953-1962	0.50*	39.30	33.75
A	5802	FARRAR AT LOCH BEANNACHRAN	1952-1957	0.33	17.16	13.23
C	6001	NESS AT NESS CASTLE FARM	1935-1963	0.54*	17.70	21.64
A	6003	MORISTON AT INVERMORISTON	1929-1945	0.28	11.00	7.15
A	6004	GARRY AT INVERGARRY	1936-1944	0.41	11.25	5.08
A	6006	ALLT BHLARAIDH INVERMORISTON	1954-1962	0.29	8.19	6.87
C	6007	NESS AT NESS SIDE	1973-1984	0.60*	23.20	20.84
A	6008	ENRICK AT MILL OF TORE	1979-1984	0.38	1.58	1.54
A	7001	FINDHORN AT SHENACHIE	1960-1984	0.37	18.70	16.30
A	7002	FINDHORN AT FORRES	1958-1983	0.41	19.36	17.97
A	7004	NAIRN AT FIRHALL	1979-1984	0.45	13.64	12.98
A	7005	DIVIE AT DUNPHAIL	1983-1984	0.47	18.48	16.52
A	7003	LOSSIE AT SHERIFFMILLS	1963-1984	0.52	28.55	28.54
A	8001	SPEY AT ABERLOUR	1938-1974	0.58	31.78	30.62
A	8002	SPEY AT KINRARA	1951-1984	0.57	30.05	27.37
C	8003	SPEY AT RUTHVEN BRIDGE	1951-1973	0.50*	31.62	27.55
A	8004	AVON AT DALNASHAUGH	1952-1984	0.55	29.35	29.60
B	8005	SPEY AT BOAT OF GARTEN	1951-1984	0.61	34.01	33.52
A	8006	SPEY AT BOAT OF BRIG	1952-1984	0.60	31.17	30.68
C	8007	SPEY AT INVERTRUIM	1952-1984	0.53*	29.45	27.46
C	8008	TROMIE AT TROMIE BRIDGE	1952-1984	0.64*	50.83	48.02
A	8009	DULNAIN AT BALNAAN BRIDGE	1952-1984	0.47	20.74	21.99
A	8010	SPEY AT GRANTOWN	1953-1984	0.60	31.11	29.62
B	8011	LIVET AT MINMORE	1981-1984	0.63	X	
C	8807	SPEY AT LAGGAN BRIDGE	1938-1974	0.58*	31.80	30.62
A	9001	DEVERON AT AVOCHIE	1959-1984	0.59	27.49	28.84
A	9002	DEVERON AT MUIRESK	1960-1984	0.58	23.28	24.94
A	9003	ISLA AT GRANGE	1969-1984	0.54	22.94	23.86
A	9004	BOGIE AT REDCRAIG	1980-1984	0.70	32.05	29.32
A	9801	ALLT DEVERON AT KINGSFORD BR.	1949-1981	0.50	31.00	32.14
A	10001	YTHAN AT ARDLETHEN	1965-1983	0.71	24.53	31.65
A	10002	UGIE AT INVERUGIE	1971-1984	0.61	22.48	25.19
B	10003	YTHAN AT ELLON	1983-1984	0.68	17.43	9.74
A	11001	DON AT PARKHILL	1969-1984	0.68	27.11	32.24
A	11002	DON AT HAUGHTON	1969-1984	0.67	29.58	31.53
A	11003	DON AT BRIDGE OF ALFORD	1973-1984	0.68	30.96	31.23
A	11801	URIE AT URIESIDE	1969-1981	0.72	21.77	31.87
A	12001	DEE AT WOODEND	1929-1984	0.53	25.41	23.61

GRADE	NO	STATION NAME	PERIOD OF RECORD	BFI	Q95(10) %ADF	MAM(10) %ADF
A	12002	DEE AT PARK	1972-1984	0.54	19.47	17.67
A	12003	DEE AT POLHOLLICK	1975-1984	0.52	20.96	18.95
A	12004	GIRNOCK AT LITTLEMILL	1970-1984	0.40	9.66	7.65
A	12005	MUICK AT INVERMUICK	1976-1984	0.53	18.17	18.84
A	12006	GAIRN AT INVERGAIRN	1978-1984	0.57	20.15	19.40
A	12007	DEE AT MAR BRIDGE	1983-1984	0.49	11.67	Z
A	12801	GLEN DYE AT BRIDGE OF DYE	1969-1981	0.42	20.43	17.32
A	13001	BERVIE AT INVERBERVIE	1979-1984	0.54	16.06	18.03
A	13002	LUTHER WATER AT LUTHER BRIDGE	1982-1983	0.57	16.92	14.95
A	13003	SOUTH ESK AT STANNOCHY BR	1979-1983	0.53	17.82	16.72
A	13005	LUNAN WATER AT KIRKTON MILL	1981-1983	0.52	12.20	11.07
A	13007	NORTH ESK AT LOGIE MILL	1976-1983	0.52	17.45	16.30
A	14001	EDEN AT KEMBACK	1967-1983	0.61	25.76	27.64
A	14002	DIGHTY WATER AT BALMOSSIE MILL	1969-1983	0.59	17.15	17.88
A	15001	ISLA AT FORTER	1953-1968	0.56	30.50	30.54
A	15002	NEWTON BURN AT NEWTON	1959-1968	0.58	30.77	26.27
C	15003	TAY AT CAPUTH	1947-1983	0.62*	28.87	26.84
A	15004	INZION AT LOCH OF LINTRATHEN	1927-1968	0.62	24.91	23.68
C	15005	MELGAM AT LOCH OF LINTRATHEN	1927-1968	0.56*	23.61	21.27
C	15006	TAY AT BALLATHIE	1952-1983	0.64*	29.07	27.01
C	15007	TAY AT PITNACREE	1957-1983	0.64*	26.53	24.37
C	15008	DEAN WATER AT COOKSTON	1958-1983	0.58*	25.25	25.08
B	15010	ISLA AT WESTER CARDEAN	1972-1983	0.54	21.67	19.76
C	15011	LYON AT COMRIE BRIDGE	1972-1983	0.46*	28.01	23.91
C	15012	TUMMEL AT PORT-NA-CRAIG	1978-1983	0.65*	25.91	25.62
A	15013	ALMOND AT ALMONDBANK	1972-1983	0.44	14.13	12.01
C	15016	TAY AT KENMORE	1974-1983	0.66*	13.31	13.35
A	15017	BRAAN AT BALLINLOAN	1975-1980	0.39	7.41	5.73
C	15018	LYON AT MOAR	1953-1958	0.23*	10.05	7.26
A	15023	BRAAN AT HERMITAGE	1983-1983	0.49	6.01	5.73
A	15024	DOCHART AT KILLIN	1982-1983	0.31	4.81	3.37
B	15809	MUCKLE BURN AT EASTMILL	1949-1956	0.53	22.35	26.25
B	16001	EARN AT KINKELL BRIDGE	1947-1958	0.48	16.74	15.35
C	16002	EARN AT ABERUCHILL	1955-1977	0.46*	14.35	13.60
A	16003	RUCHILL AT CULTYBRAGGAN	1971-1983	0.31	7.81	6.36
C	16004	EARN AT FORTEVIOT BRIDGE	1972-1983	0.50*	15.30	13.72
C	17001	CARRON AT HEADSWOOD	1969-1984	0.36*	19.00	16.71
C	17002	LEVEN AT LEVEN	1969-1984	0.66*	18.20	16.84
C	17003	BONNY WATER AT BONNYBRIDGE	1971-1984	0.45*	22.56	20.22
A	17004	ORE AT BALFOUR MAINS	1972-1984	0.54	10.78	18.32
B	17005	AVON AT POLMONTHILL	1971-1984	0.41	17.37	15.76
A	18001	ALLAN WATER AT KINBUCK	1957-1984	0.45	17.64	17.41
C	18002	DEVON AT GLENOCHIL	1959-1983	0.53*	24.70	24.12
A	18003	TEITH AT BRIDGE OF TEITH	1963-1984	0.44	19.24	18.24
A	18005	ALLAN WATER AT BR OF ALLAN	1971-1984	0.46	14.32	13.41
A	18008	LENY AT ANIE	1973-1984	0.39	6.06	4.57
A	18011	FORTH AT CRAIGFORTH	1981-1982	0.40	11.53	Z
C	19001	ALMOND AT CRAIGIEHALL	1957-1984	0.38*	17.51	15.62
A	19002	ALMOND AT ALMOND WEIR	1962-1984	0.34	18.53	16.65
A	19003	BREICH WATER AT BREICH WEIR	1972-1978	0.30	13.06	12.34
A	19004	NORTH ESK AT DALMORE WEIR	1960-1984	0.53	25.18	24.85
C	19005	ALMOND AT ALMONDELL	1962-1984	0.35*	15.10	14.19
B	19006	WATER OF LEITH AT MURRAYFIELD	1963-1984	0.46	26.58	25.11
B	19007	ESK AT MUSSELBURGH	1962-1984	0.51	26.09	25.15
B	19008	SOUTH ESK AT PRESTONHOLM	1964-1984	0.53	26.61	30.70
C	19009	BOG BURN AT COBBINSHAW	1963-1984	0.63*	17.03	14.18

GRADE	NO	STATION NAME	PERIOD OF RECORD	BFI	Q95(10) %ADF	MAM(10) %ADF
A	19010	BRAID BURN AT LIBERTON	1969-1984	0.62	25.58	23.08
A	19011	N ESK AT DALKEITH PALACE	1976-1984	0.53	27.76	25.29
A	19805	SPITTAL BURN AT NINEMILEBURN	1966-1975	0.68	22.22	21.05
A	20001	TYNE AT EAST LINTON	1961-1984	0.52	20.25	22.67
C	20002	W PEFFER BURN AT LUFFNESS	1966-1984	0.47*	7.03	11.91
A	20003	TYNE AT SPILMERSFORD	1965-1984	0.49	20.56	25.06
C	20004	E PEFFER BURN AT LOCHHOUSES	1967-1984	0.37*	6.44	10.40
A	20005	BIRNSWATER AT SALTOUN HALL	1976-1984	0.46	19.06	18.58
A	20006	BIEL WATER AT BELTON HOUSE	1976-1984	0.61	31.78	30.37
A	20007	GIFFORD WATER AT LENNOXLOVE	1976-1984	0.57	23.34	23.79
A	20008	BROX BURN AT BROXMOUTH	1967-1975	0.50	11.66	14.26
A	20804	THORNTON BURN AT THORNTON MILL	1967-1975	0.64	20.00	35.71
B	20806	HEDDERWICK BURN AT N BELTON	1969-1973	0.26	Y	
A	20807	WOODHALL BURN AT WOODHALL	1969-1975	0.68	16.22	32.00
B	20808	COGTAIL BURN AT ATHELSTANEFORD	1966-1975	0.50	Y	
B	20809	SALTERS BURN AT CRICHTON DENE	1967-1975	0.32	Y	
A	21001	FRUID WATER AT FRUID	1959-1968	0.31	19.40	18.25
A	21002	WHITE ADDER W AT HUNGRY SNOUT	1959-1968	0.50	14.86	16.16
A	21003	TWEED AT PEEBLES	1959-1982	0.55	23.25	23.37
C	21004	WATCH WATER AT WATCHWATER RES	1965-1968	0.40*	19.57	68.62
A	21005	TWEED AT LYNE FORD	1961-1982	0.56	25.11	24.18
A	21006	TWEED AT BOLESIDE	1961-1982	0.50	20.71	18.27
A	21007	ETTRICK WATER AT LINDEAN	1961-1982	0.39	12.93	10.69
A	21008	TEVIOT AT ORMISTON MILL	1960-1982	0.45	16.81	16.67
A	21009	TWEED AT NORHAM	1962-1984	0.52	19.36	18.56
A	21010	TWEED AT DRYBURGH	1963-1980	0.51	20.25	18.76
A	21011	YARROW WATER AT PHILIPHAUGH	1963-1982	0.44	14.77	11.93
A	21012	TEVIOT AT HAWICK	1963-1982	0.43	14.44	13.33
A	21013	GALA WATER AT GALASHIELS	1964-1981	0.52	16.63	16.75
B	21014	TWEED AT KINGLEDORES	1961-1982	0.44	25.75	23.26
A	21015	LEADER WATER AT EARLSTON	1966-1981	0.48	14.02	14.17
A	21016	EYE WATER AT EYEMOUTH MILL	1967-1981	0.44	10.70	14.05
A	21017	ETTRICK WATER AT BROCKHOPERIG	1965-1982	0.34	13.15	10.56
A	21018	LYNE WATER AT LYNE STATION	1968-1982	0.59	25.09	24.52
A	21019	MANOR WATER AT CADEMUIR	1968-1982	0.59	21.74	20.37
A	21020	YARROW WATER AT GORDON ARMS	1967-1982	0.44	13.57	11.02
A	21021	TWEED AT SPROUSTON	1969-1982	0.50	18.27	16.66
A	21022	WHITEADDER WATER HUTTON CASTLE	1969-1982	0.53	19.45	20.26
A	21023	LEET WATER AT COLDSTREAM	1970-1982	0.33	2.94	3.94
A	21024	JED WATER AT JEDBURGH	1971-1981	0.43	19.50	19.70
A	21025	ALE WATER AT ANCRUM	1972-1981	0.44	10.46	9.72
A	21026	TIMA WATER AT DEEPHOPE	1973-1981	0.26	7.47	5.20
A	21027	BLACKADDER WATER MOUTH BRIDGE	1973-1981	0.50	16.79	17.53
A	21028	MENZION BURN AT MENZION FARM	1948-1952	0.43	16.43	15.34
A	21030	MEGGET WATER AT HENDERLAND	1968-1982	0.39	14.61	12.42
B	21031	TILL AT ETAL (NWA)	1956-1980	0.57	18.90	22.53
B	21032	GLEN AT KIRKNEWTON (NWA)	1966-1980	0.50	16.04	16.13
C	21033	BADDINGSGILL BURN AT INTAKE	1963-1975	0.66*	45.94	54.42
C	21034	YARROW WATER AT CRAIG DOUGLAS	1975-1982	0.42*	11.57	9.37
A	21805	WHITE ADDER AT BLANERNE	1960-1975	0.48	16.42	18.26
A	77001	ESK AT NETHERBY (NWWA)	1963-1978	0.36	15.36	13.08
A	77002	ESK AT CANONBIE	1962-1983	0.38	14.49	12.40
A	77003	LIDDEL WATER AT ROWANBURNFOOT	1973-1983	0.33	11.78	9.77
A	77004	KIRTLE WATER AT MOSSKNOWE	1979-1983	0.28	8.50	6.73
A	77005	LYNE AT CLIFF BRIDGE (NWWA)	1977-1983	0.27	9.43	7.09
B	78001	ANNAN AT ST MUNGOS MANSE	1956-1961	0.42	14.75	14.08

GRADE	NO	STATION NAME	PERIOD OF RECORD	BFI	Q95(10) %ADF	MAM(10) %ADF
B	78002	WATER OF AE AT ELSHIESHIELDS	1963-1965	0.34	27.65	21.84
A	78003	ANNAN AT BRYDEKIRK	1967-1983	0.43	13.92	11.67
A	78004	KINNEL WATER AT REDHALL	1963-1983	0.27	6.11	4.71
A	78005	KINNEL WATER AT BRIDGEMUIR	1979-1984	0.35	9.95	7.94
C	79001	AFTON WATER AT AFTON RES	1969-1981	0.10*	4.00	6.80
A	79002	NITH AT FRIARS CARSE	1957-1984	0.38	11.21	10.71
B	79003	NITH AT HALL BRIDGE	1959-1984	0.27	7.32	6.67
A	79004	SCAR WATER AT CAPENOCH	1963-1983	0.31	7.32	6.20
A	79005	CLUDEN WATER AT FIDDLERS FORD	1963-1983	0.37	7.57	7.38
A	79006	NITH AT DRUMLANRIG	1967-1984	0.34	9.75	8.27
A	80001	URR AT DALBEATTIE	1963-1984	0.35	5.21	4.73
C	80002	DEE AT GLENLOCHAR	1977-1984	0.40*	7.96	8.07
A	80303	WHITE LAGGAN BURN AT LOCH DEE	1980-1984	0.19	5.59	2.93
C	81001	PENWHIRN BURN AT PENWHIRN RES	1965-1968	0.22*	18.24	14.34
A	81002	CREE AT NEWTON STEWART	1963-1984	0.28	8.63	6.03
A	81003	LUCE AT AIRYHEMMING	1967-1983	0.23	5.85	4.66
A	81004	BLADNOCH AT LOW MALZIE	1977-1984	0.33	4.40	3.02
A	82001	GIRVAN AT ROBSTONE	1963-1984	0.34	9.10	8.68
C	82002	DOON AT AUCHENDRANE	1974-1984	0.60*	39.05	40.25
A	82003	STINCHAR AT BALNOWLART	1973-1984	0.30	4.22	3.38
C	83001	CAAF WATER AT KNOCKENDON RES	1971-1981	0.43*	23.30	10.85
B	83002	GARNOCK AT DALTRY	1963-1977	0.22	6.98	5.35
A	83003	AYR AT CATRINE	1970-1984	0.27	9.87	10.21
A	83004	LUGAR AT LANGHOLM	1972-1984	0.24	5.78	4.80
A	83005	IRVINE AT SHEWALTON	1972-1984	0.27	7.20	5.08
A	83006	AYR AT MAINHOLM	1976-1981	0.30	11.62	9.71
A	83007	LUGTON WATER AT EGLINTON	1980-1981	0.25	6.49	Z
A	83009	GARNOCK AT KILWINNING	1978-1981	0.24	2.75	4.26
A	83010	IRVINE AT NEWMILNS	1979-1981	0.25	8.16	Z
C	84001	KELVIN AT KILLERMONT	1948-1984	0.43*	22.73	19.53
C	84002	CALDER AT MUIRSHIEL	1952-1976	0.42*	2.75	6.10
A	84003	CLYDE AT HAZELBANK	1956-1984	0.50	22.12	20.71
A	84004	CLYDE AT SILLS	1957-1984	0.51	21.00	20.13
A	84005	CLYDE AT BLAIRSTON	1954-1984	0.44	21.57	19.87
A	84006	KELVIN AT BRIDGEND	1963-1983	0.44	17.69	17.28
C	84007	SOUTH CALDER WATER AT FORGEWOOD	1966-1984	0.61*	40.17	43.00
B	84008	ROTTEN CALDER WATER AT REDLEES	1966-1984	0.32	12.52	10.66
A	84009	NETHAN AT KIRKMUIRHILL	1966-1983	0.34	11.89	9.94
A	84011	GRYFE AT CRAIGEND	1963-1984	0.29	8.25	7.82
A	84012	WHITE CART WATER AT HAWKHEAD	1963-1984	0.36	15.83	14.80
B	84013	CLYDE AT DALDOWIE	1963-1984	0.45	23.28	21.14
A	84014	AVON WATER AT FAIRHOLM	1964-1984	0.26	7.07	6.39
A	84015	KELVIN AT DRYFIELD	1960-1984	0.43	19.44	18.44
A	84016	LUGGIE WATER AT CONDORRAT	1966-1984	0.33	11.11	9.27
C	84017	BLACK CART WATER MILLIKEN PARK	1967-1984	0.38*	9.33	8.56
A	84018	CLYDE AT TULLIFORD MILL	1969-1984	0.51	16.30	15.16
C	84019	NORTH CALDER WATER CALDERPARK	1963-1984	0.47*	26.63	26.13
A	84020	GLAZERT WATER MILTON CAMPSIE	1968-1984	0.31	9.56	8.69
C	84021	WHITE CART WATER AT NETHERLEE	1969-1972	0.51*	32.84	22.34
A	84022	DUNEATON AT MAIDENCOTS	1966-1984	0.44	15.75	13.33
A	84023	BOTHLIN BURN AT AUCHENGEICH	1973-1984	0.39	13.13	12.50
C	84024	NORTH CALDER WATER HILLEND	1972-1984	0.68*	39.55	39.33
A	84025	LUGGIE WATER AT OXGENG	1975-1984	0.42	14.23	12.72
A	84026	ALLANDER WATER AT MILNGAVIE	1974-1981	0.35	8.08	8.13
C	84027	N CALDER WATER AT CALDERBANK	1973-1974	0.57*	23.80	Z
A	84029	CANDER WATER AT CANDERMILL	1975-1981	0.25	7.65	6.49

GRADE	NO	STATION NAME	PERIOD OF RECORD	BFI	Q95(10) %ADF	MAM(10) %ADF
C	85001	LEVEN AT LINNBRANE	1963-1972	0.81*	33.33	33.64
A	85002	ENDRICK WATER AT GAIDREW	1963-1984	0.31	9.36	9.10
A	85003	FALLOCH AT GLEN FALLOCH	1970-1984	0.18	5.17	3.17
A	85004	LUSS WATER AT LUSS	1977-1981	0.27	6.74	5.30
C	86001	LITTLE EACHAIG AT DALINLONGART	1968-1984	0.22*	5.67	4.27
A	86002	EACHAIG AT ECKFORD	1968-1980	0.35	8.47	7.91
A	87801	ALLT UAINE AT INTAKE	1950-1975	0.15	9.62	6.15
B	90003	NEVIS AT CLAGGAN	1983-1984	0.30	10.92	5.55
C	91002	LOCHY AT CAMISKY	1981-1984	0.42*	8.69	6.82
A	93001	CARRON AT NEW KELSO	1979-1984	0.27	10.30	6.47
A	94001	EWE AT POOLEWE	1970-1984	0.66	21.21	16.37
A	95001	INVER AT LITTLE ASSYNT	1977-1984	0.62	25.04	19.35
A	96001	HALLADALE AT HALLADALE	1963-1984	0.26	4.77	5.07
A	96002	NAVER AT APIGILL	1977-1984	0.41	6.29	7.16
B	97002	THURSO AT HALKIRK	1972-1984	0.46	5.65	7.17

* MAP SHOWS THESE STATIONS WHERE ARTIFICIAL INFLUENCE MAY AFFECT BFI
X BFI SUPPLIED BY RPB
Y RIVER DRIES UP
Z MAM(10) NOT AVAILABLE BECAUSE RECORD IS SHORT

A STATIONS USED IN REGRESSION ANALYSIS
B STATIONS WHERE ARTIFICIAL INFLUENCE IS SMALL
C STATIONS WHERE ARTIFICIAL INFLUENCE OR POOR HYDROMETRY MAY AFFECT LOW FLOW INDICES

Appendix 2 The Base Flow Index

Base Flow separation procedure

The Base Flow Index (BFI) can be thought of as measuring the proportion of the river's runoff that derives from stored sources. The computer program applies smoothing and separation rules to the recorded flow hydrographs from which the index is calculated as the ratio of the flow under the separated hydrograph to the flow under the total hydrograph (Figure 3). The program calculates the minima of five day non-overlapping periods and subsequently searches for turning points in this sequence of minima. The turning points are then connected to obtain the separated hydrograph. The published separation procedure (LFSR 3.0 Jan 1980, pp 13-19) can result in the baseflow line crossing and being higher than the recorded hydrograph. This rarely occurs for more than one percent of the days in the record, although for some overseas catchments it has led to calculated BFIs in excess of 1.0. The BFI program was modified to remedy this problem by constraining the base flow line to the observed hydrograph ordinate on any day when the separated hydrograph exceeds the observed.

Baseflow line start and finish points

Baseflow separation cannot start on the first day of the data record and similarly will not finish on the last day of record. It is important therefore to recognise that when the dates of the beginning and end of the baseflow line have been established, then these same dates must be used in calculating the total volume of flow beneath the hydrograph as well as in calculating the volume of flow beneath the baseflow line.

Calculation of annual BFI

There are two alternative methods for calculating annual BFIs. The first is to compute the separation for the entire record and then estimate BFI for each year. The second is to run the separation program on year 1 and then on year 2 etc., starting each year as an entirely new record. In the latter case a few days in early January and late December will be eliminated from the calculation for every year of record. The two approaches differ slightly and for calculating annual values the first procedure is preferred.

Calculation of period of record BFI

A mean value of BFI can be calculated from a series of annual BFIs but this will be different from a single value calculated from the period of record. The LFSR defines BFI as the ratio V_b/V_a where V_b represents the average flow beneath the baseflow separation line and V_a represents the average flow beneath the hydrograph.

Ten years of record will provide ten annual values of BFI. However, the average of these ten values will not in general equate to the single value obtained from the entire ten years of record. This can easily be seen by the following example, showing three years of artificial data in which one of the years is of a very different character.

	Year 1	Year 2	Year 3	Total
V_b	9.0	40.0	40.0	89.0
V_a	10.0	100.0	100.0	210.0
BFI = V_b/V_a	0.9	0.4	0.4	0.424

Here the average of the three annual BFI values is 0.567 while the overall value is 0.424. The recommended procedure is to calculate one value of BFI based on a separation of the entire record.

BFI variability

Earlier studies of BFI variability found that annual values of BFI were more stable than other low flow variables. For example the coefficient of variation of annual Base Flow Index values was found to be one-third of that for Q95(10) values. Furthermore, there was no evidence that, for example, years with high runoff experienced BFI values higher or lower than the average. This finding that values estimated from short records could be used with confidence supported the use of BFI as a key variable in the estimation procedure. A more detailed study of BFI variability in Scotland was carried out on 135 of the grade A and B stations which had more than 9 years of record.

The annual BFIs were calculated using the procedure described in this Appendix. The coefficient of variation (Figure 5) and the standard deviation

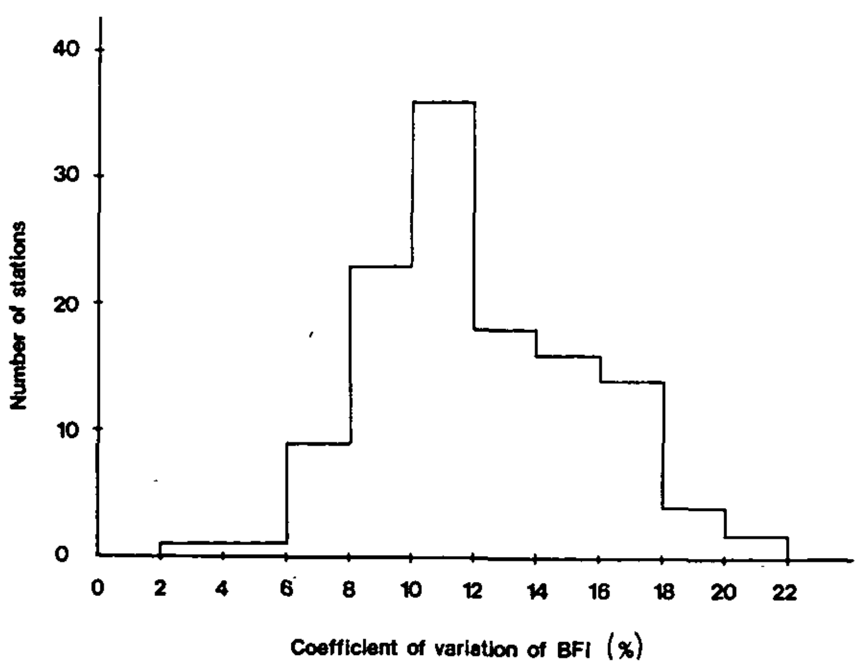

Figure 5 Coefficient of variation of annual BFI values

(s.d.) of annual BFIs were calculated for each of the 135 stations and the mean s.d. found to be 0.054. Variation in s.d. across Scotland was generally low although some stations in the Tweed and Forth areas showed a high annual variability while those in Solway were generally lower.

A linear regression was performed for each station between annual BFI and annual runoff to test whether wet or dry years had a tendency to give rise to low or high BFI values. Over 100 of the 135 records had values of explained variance less than 30% indicating a weak relationship between annual BFI and annual runoff. Only twenty stations had explained variances in excess of 50% and these were located mainly in the Forth and Tweed areas. Further investigation revealed that 75% of stations in the Tweed RPB area had their highest annual BFI in the drought years of 1973 and 1976. These results suggest that although extreme years may produce higher than average BFIs, most annual BFIs are close to the long term value. Provided extreme years are avoided BFI can be estimated with confidence from a short record with an error of 0.05 being typical for estimates derived from a single year of mean daily flow data.