LOW FLOW STUDIES

Report No 3

Catchment characteristic estimation manual

PREFACE

This report describes the procedure for calculating catchment characteristics that are used in low flow estimation, particularly in 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 techniques. 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. The third report describes the techniques for calculating catchment characteristics. Report No four consists of a series of regional monographs which detail the relationships between the base flow index and catchment geology and enable the index to be estimated at an ungauged site.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADF	average flow in cumecs
AE	actual evaporation in mm
AREA	catchment area in km^2
BFI	base flow index
L	mainstream length in km on 1:25,000 map
FALAKE	proportion of catchment covered by a lake or reservoir
PE	potential evaporation in mm
SAAR	standard period (1941-1970) annual average rainfall in mm
STMFRQ	stream frequency in junctions per square kilometre from 1:25,000 map
V_A	volume of water beneath the recorded hydrograph
V_B	volume of water beneath the base flow line

Introduction

This manual describes the calculation of catchment characteristics used in the flow duration curve and flow frequency curve estimation manuals. Section 2 contains details of the extraction of topographic characteristics from 1:25000 scale maps and catchment rainfall and evaporation from larger scale Meteorological Office maps. The effect of catchment geology has been indexed by estimating the proportion of base flow which drains from a catchment. Section 3.1 describes how this index - the base flow index (BFI) - can be calculated from flow data and Section 3.2 describes how it can be estimated from catchment geology.

The manual refers to an example catchment, the River Pang at Pangbourne, for which all the calculations have been completed. This material is presented in normal type face, generally on the right hand page. In italic type face and generally on the left hand page are details of three other catchments which can be practised by the reader. Figure 1.1 shows the location of the catchments. Details of the catchments and the relevant geological and topographic maps are shown in Figures 1.2a - 1.2d.

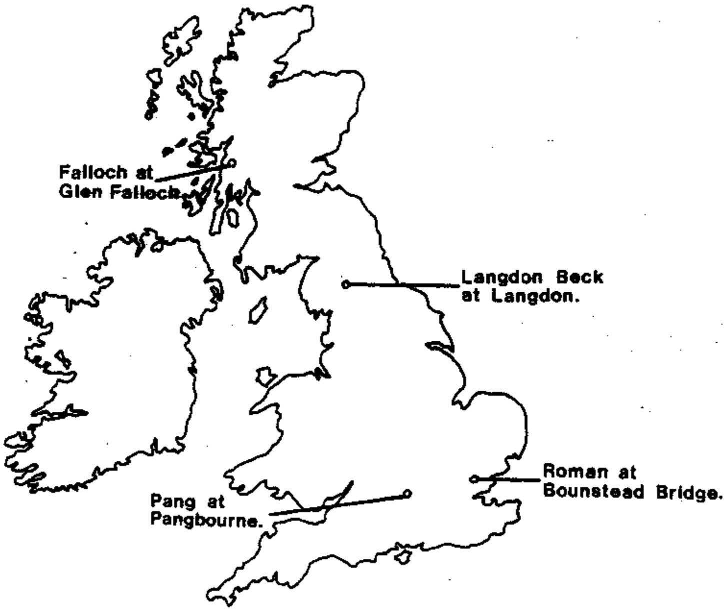


FIGURE 1.1 LOCATION OF ALL THE EXAMPLE CATCHMENTS

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 km^2 which includes the Dubh Eas catchment.*

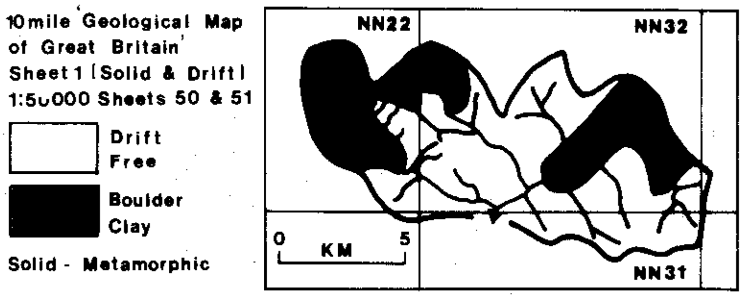


FIGURE 1.2b GEOLOGY AND KEY TO MAPS OF THE FALLOCH CATCHMENT

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 km^2.*

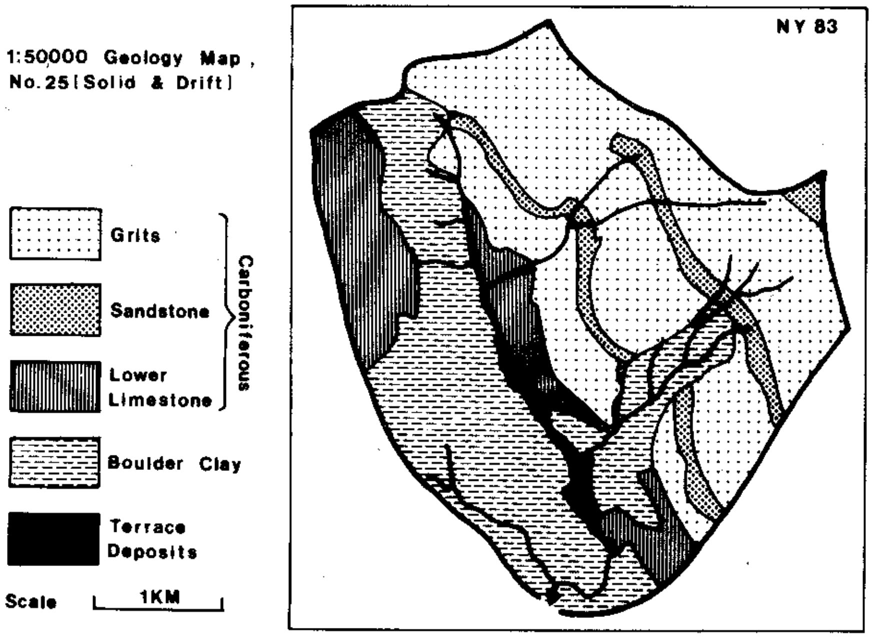


FIGURE 1.2c GEOLOGY AND KEY TO MAPS OF THE LANGDON CATCHMENT

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.

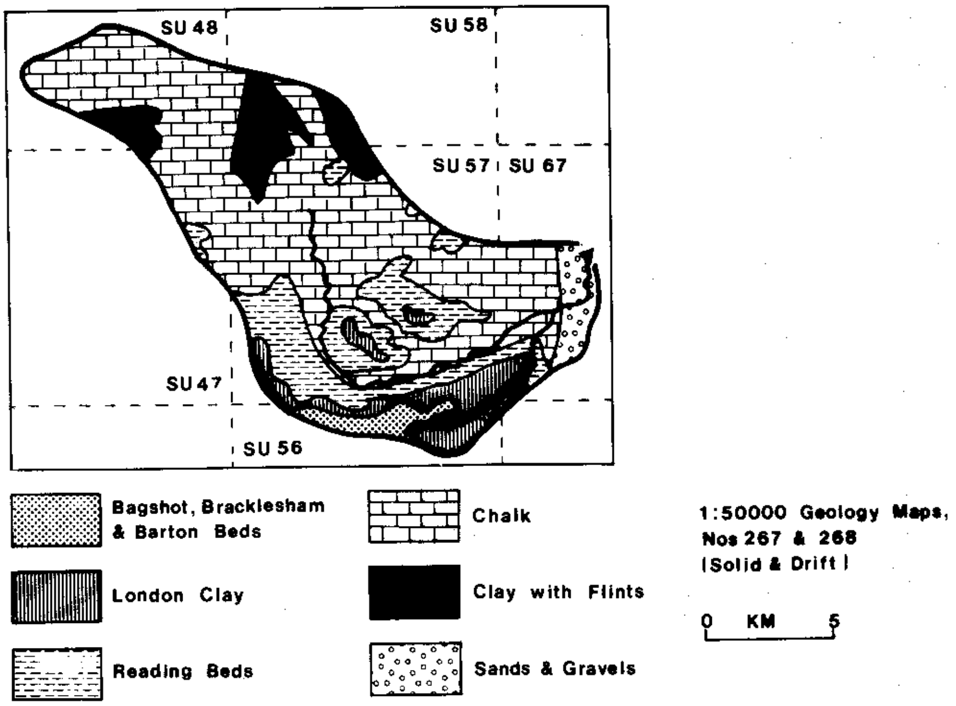
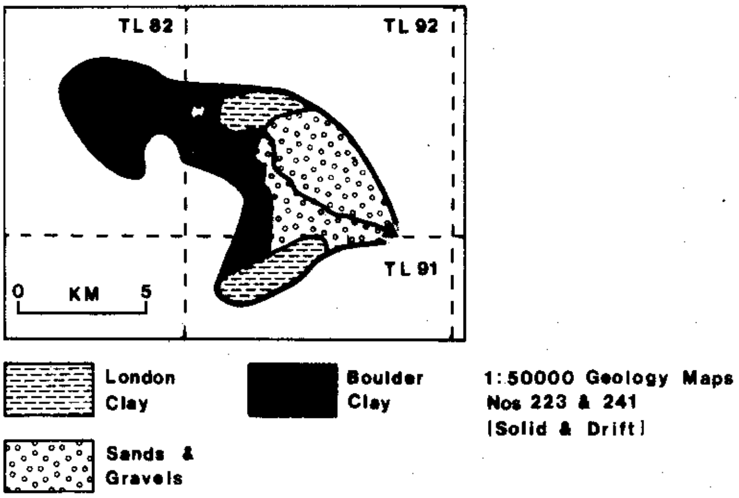


FIGURE 1.2a GEOLOGY AND KEY TO MAPS OF THE PANG CATCHMENT



1:50000 Geology Maps
Nos 223 & 241
(Solid & Drift)

2.1 AREA (AREA) AND STREAM FREQUENCY (STMFRQ)

Falloch	*AREA*	80·3	*km²*
	No. of junctions	273	
	STMFRQ	3·4	*jun/km²*
Langdon	*AREA*	13·0	*km²*
	No. of junctions	38	
	STMFRQ	2·92	*jun/km²*
Roman	*AREA*	52·6	*km²*
	No. of junctions	32	
	STMFRQ	0·61	*jun/km²*

2.2 STREAM LENGTH (L)

	Falloch	*Langdon*	*Roman*
Number of steps to head of mainstream N =	124	50	157
Length of 50 steps in calibration trial L_c* =	200	209	196
Main stream length $L = 0.1 \times N \times L_c/200$ =	12·40	5·23	15·39

**Because of the difficulty of accurately setting dividers to 4 mm they can be calibrated by stepping off 50 steps along the edge of the map and recording the total length.*

2 Topographic and climate characteristics

2.1 AREA (AREA) AND STREAM FREQUENCY (STMFRQ)

The topographic area is used except for those cases where the groundwater divide is known to deviate from the topographic divide. Sources of such differences (which affect mostly limestone and chalk catchments) are Water Authority Annual, Section 14 and 24 Reports and Institute of Geological Sciences publications. Three significant figures accuracy is appropriate so square counting or planimetering will suffice. Site inspection may be necessary to fix the boundary of small or of flat catchments.

Stream frequency is not used directly in estimation equations, but because it is controlled primarily by geology it is a useful characteristic for judging the comparability between catchments.

The number of natural stream junctions (N) is counted upstream on the 1:25,000 map including the starting point as a junction. It is best to work progressively up each tributary noting the running total at each major junction. Where natural channels exist, but are not shown on the map, for instance in urban areas, or where junctions occur in a lake or reservoir, the missing junctions are counted.

N = 30 junctions

AREA = 171 km^2

STMFRQ = N/AREA = 0·18 junctions/km^2

NOTE: Ignore artificial drainage in flat lands.

2.2 STREAM LENGTH (L)

'Length' is measured on the main channel which is defined to be the longest stream. In cases of difficulty, work upstream on the 1:25,000 map and at every junction follow the stream draining the largest area. Set the dividers to 4 mm and step up the main channel starting from the point of interest and going upstream until the farthest upstream point of the channel is reached. It helps to mark off every 5th step. This definition of L is used in the Low Flow Study work so it is wrong to adopt other procedures, eg including all meanders.

Number of steps N = 269

Therefore L = .1 x N = 26·9 km.

2.3 LAKE AREA (FALAKE)

	Falloch	*Langdon*	*Roman*
Surface area of lake	....	....	....
Falake	....	....	....

2.4 CALCULATION OF ANNUAL AVERAGE RAINFALL (SAAR)

From Figures 2b, c and d

Class interval	*Effective value*		*No. of squares*		*Weighted rainfall*
......	......	X	......	=	......
......	......	X	......	=	......
......	......	X	......	=	......
......	......	X	......	=	......
......	......	X			
		N =		*W* =	

SAAR = W/N = ... (F) ...... (L) ...... (R)

FIGURE 2.1b

STANDARD ANNUAL AVERAGE RAINFALL, SAAR, FOR FALLOCH (mm x 10^2)

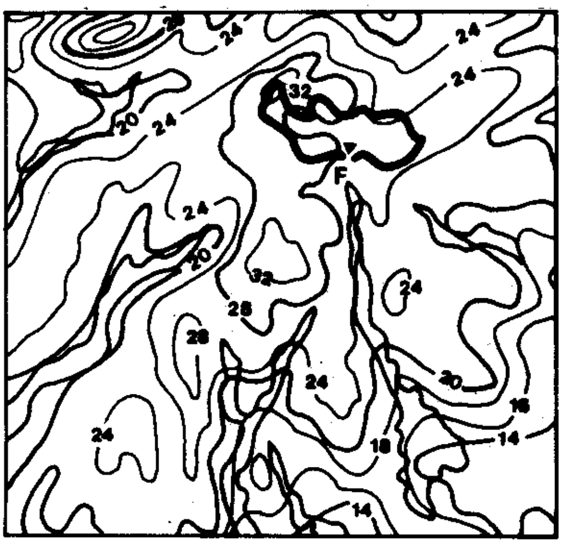
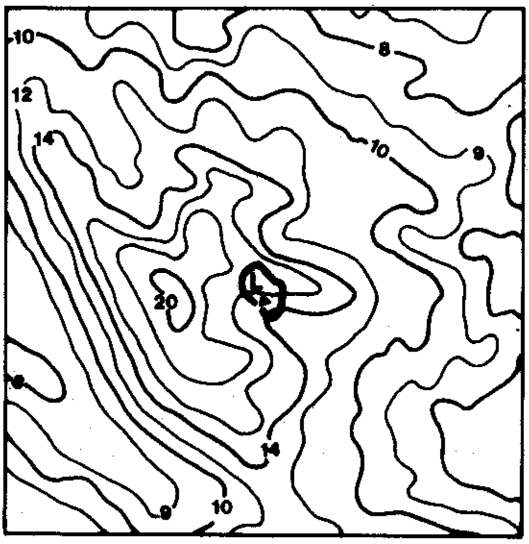


FIGURE 2.1c

STANDARD ANNUAL AVERAGE RAINFALL, SAAR, FOR LANGDON (mm x 10^2)



2.3 LAKE AREA (FALAKE)

Lakes and reservoirs smooth the hydrograph, lowering peaks and raising troughs. The index **FALAKE** is the proportion of the catchment marked as a lake or reservoir on an appropriate scale map. Counting squares provides sufficient accuracy.

Lake area = 0·008 km^2

FALAKE = 0·008 /171 = 0·00005

NOTE: For large scale studies an exhaustive survey (The Distribution of Freshwaters in Great Britain, *in press*) of all lakes visible on 1:250,000 scale maps has been undertaken by the Institute of Terrestrial Ecology, 78 Craighall Road, Edinburgh.

2.4 CALCULATION OF ANNUAL AVERAGE RAINFALL (SAAR)

The annual average rainfall in the 1941-1970 standard period was used in the Low Flow Study. Maps at 1:625,000 scale covering the UK are now available from the Meterological Office. Figure 2.1a below shows an extract from the map covering the Pang area. The weighted area technique, or alternatively the average of 20 equally spaced points, may be used. For the former procedure 1/10" graph paper and square counting is suitable.

For Pang catchment SAAR = 722 mm

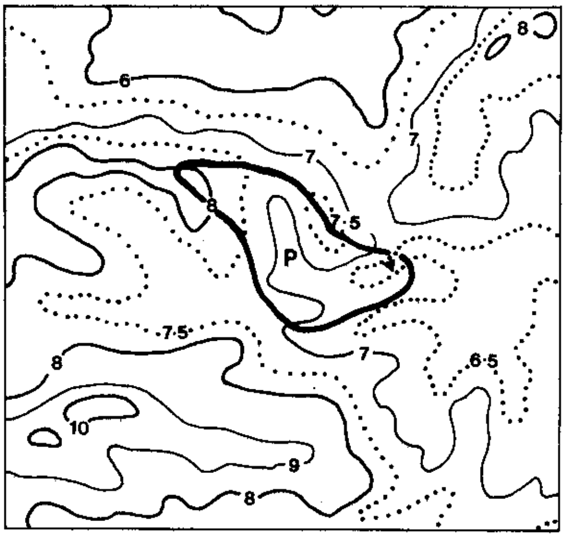


FIGURE 2.1a

STANDARD ANNUAL AVERAGE RAINFALL, SAAR, FOR PANG (mm X 10^2)

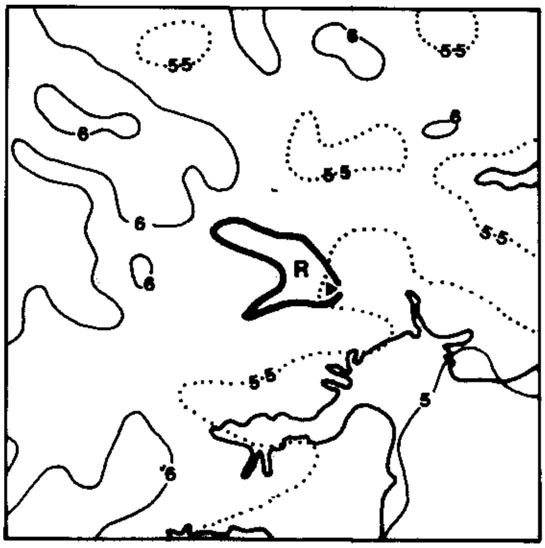


FIGURE 2.1d

STANDARD ANNUAL AVERAGE RAINFALL, SAAR, FOR ROMAN (mm x 10^2)

Standard annual average rainfall (mm x *10^2)* . . . . . *(Falloch)* . . . . . *(Langdon)* . . . . . *(Roman)*

2.5 CALCULATION OF POTENTIAL EVAPOTRANSPIRATION (PE) AND AVERAGE DISCHARGE (ADF)

From Figures 2.2b to 2.2d

Class interval	*Effective value*		*No. of squares*		*Weighted PE*
. . . . .	. . . . .	x	. . . . .	=	. . . . .
. . . . .	. . . . .	x	. . . . .	=	. . . . .
. . . . .	. . . . .	x	. . . . .	=	. . . . .
. . . . .	. . . . .	x	. . . . .	=	. . . . .
. . . . .	. . . . .	x	. . . . .	=	. . . . .
	TOTALS	*N* =		*W* =	

P.E. = W/N = ... *(F)* . . . . . *(L)* . . . . . *(R)*

Adjustment, r = ...

∴ *AE* = ... *mm*

∴ *ADF* = *SAAR–AE* = ... *mm*

Conversion to cumecs = ...

∴ *ADF* = ... *cumecs*

2.5 CALCULATION OF POTENTIAL EVAPOTRANSPIRATION (PE) AND AVERAGE DISCHARGE (ADF)

The potential evapotranspiration is used in the calculation of average discharge. Most estimated low flows are standardised by ADF so have to be rescaled in order to obtain the answer in cumecs.

(a) In the absence of any gauged data obtain PE by the weighted area method from the Meteorological Office 1:2,000,000 map of annual average potential evaporation. (Figure 2.2a shows an extract for the Pang catchment).

PE = 540 mm

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

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

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

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

The conversion from mm to cumecs is made by multiplying the mm figure by .00003171 x AREA = 0·00542 , ∴ ADF = 0·00542 x 225 = 1.22 cumecs.

(b) Where a nearby long period analog station is available use the simultaneous average rainfall P_L and discharge Q_L to estimate AE = $P_L - Q_L$ and apply this figure to the SAAR value for the study catchment. If a short record is also available for the study catchment then the short period average should be multiplied by an adjustment factor $\frac{Q_S}{Q_L}$ where Q_S and Q_L are the short and long period discharge at the station.

Potential evaporation for example catchments (in mm).

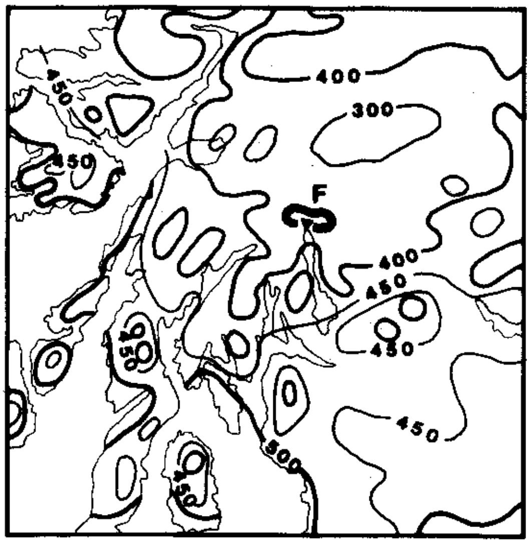


FIGURE 2.2b PE FALLOCH

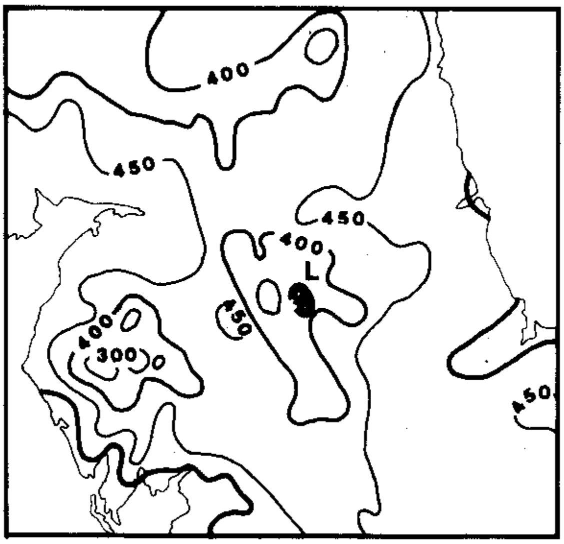


FIGURE 2.2c PE LANGDON

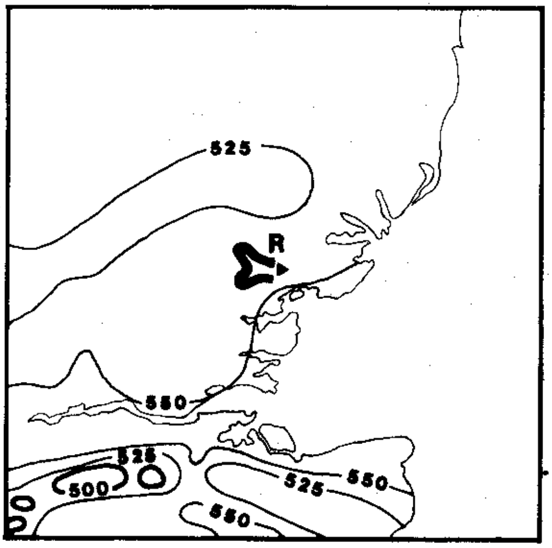


FIGURE 2.2d PE ROMAN

Potential evaporation in mm . . . . . (Falloch) . . . . . (Langdon) . . . . . (Roman)

(c) A check on the value is obtained for larger rivers using the Water Data Unit map of estimated runoff or from tabulated information produced for the River Pollution Survey of England & Wales.

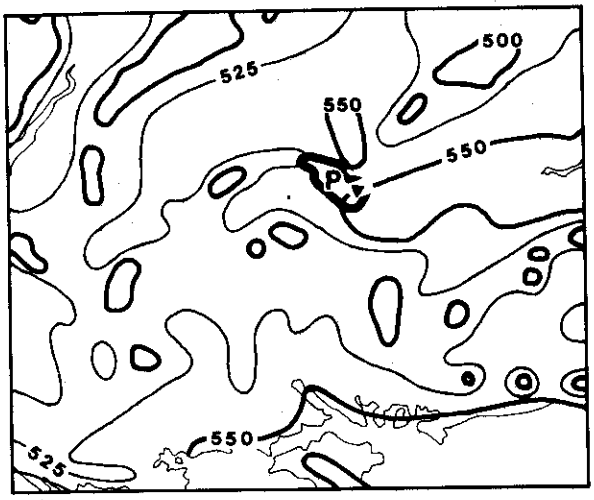


FIGURE 2.2a

POTENTIAL EVAPORATION FOR PANG (mm)

3.1 CALCULATING THE BASE FLOW INDEX FROM DATA

The daily data for the example catchments will be found in Tables 3.1b - 3.1d. Use only the first eight months from the year's data provided. Normally, a full year's data is recommended.

Stations	*Period to be used*	*Total runoff* (V_A) *cumec days*
Falloch	*1 Jan-31 Aug 1971*	*748.873*
Langdon	*1 Jan-31 Aug 1971*	*61.415*
Roman	*1 Jan-31 Aug 1971*	*51.199*

The procedure described opposite is followed and the values obtained are recorded in Table 3.2b

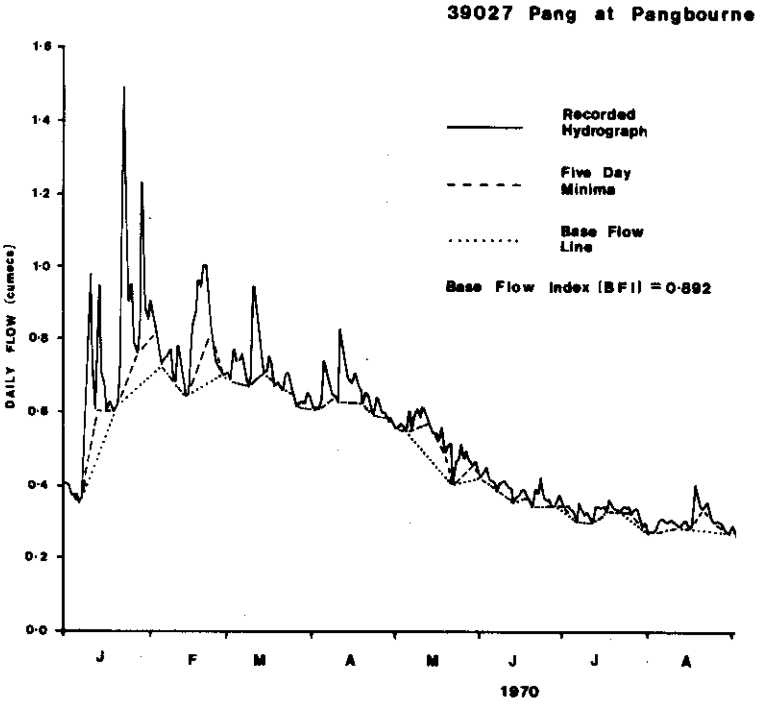


FIGURE 3.1 HYDROGRAPH FOR THE PANG (Jan-Aug 1970)

3 Geological characteristics

Catchment geology is indexed using a variable termed the base flow index (BFI) and from its construction, can be thought of as measuring the proportion of the river runoff that derives from stored sources. The index can be calculated from flow data (Section 3.1) or estimated from catchment geology (Section 3.2).

3.1 CALCULATING THE BASE FLOW INDEX FROM DATA

The data are presented in the form of consecutive average daily flows.

It will be preferable to calculate BFI from data rather than from geological maps when more than a single year of record is available. For demonstration purposes, eight months of data for the Pang at Pangbourne (January-August 1970) are used. This is shown on Table 3.1a and drawn on Figure 3.1.

The procedure is as follows:

1. Divide the data into non-overlapping blocks of 5 days, commencing January 1st, by a series of horizontal lines as shown on Table 3.1a.

2. Ring the minima of each of these blocks, and let them be called Q_1, Q_2, Q_3... Q_n, etc. (Table 3.1a, Figure 3.1).

3. Consider in turn (Q_1, Q_2, Q_3), (Q_2, Q_3, Q_4), ... (Q_{n-1}, Q_{n+1}) etc. In each case if 0.9 x central value < outer values, then the central value is a turning point for the base flow line and should be marked as such. Continue this procedure until all the data have been analysed. In the Pang example quoted above, of the first six "five day minima" only the second, fourth and fifth are turning points; these are shown ticked on Table 3.1a.

4. Let the dates at the turning points be x_1, x_2, etc (column 1 of Table 3.2a) and the discharges be q_1, q_2, etc (column 2). Column 3 is the time span between turning points, $x_2 - x_1$, $x_3 - x_2$, etc. The average discharge $(q_1 + q_2)/2$, $(q_2 + q_3)/2$, etc is entered into column 4.

5. The volume beneath the base flow line (V_B) between the first and last turning points inclusive, is calculated by summing the individual trapezium areas, i.e. by multiplying the time between baseflow line turning points by the average discharge and summing the results as set out on Table 3.1b.

6. It is also necessary to establish the volume of water beneath the recorded hydrograph (V_A), which can easily be done by summing the average daily flow values between the first and last turning points inclusive, to give a figure in cumec days.

7. The BFI is then V_B/V_A.

TABLE 3.1b **Flow data for Falloch**

```
                              INSTITUTE OF HYDROLOGY DAILY FLOW LISTING

     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      .827    16.631     3.171     1.208      .573     2.243     3.121     5.867     9.575     1.860     7.093     1.056
         3      .900     6.465     2.039      .982      .491     1.783     2.711     2.063     3.498     1.179    20.051    16.939
         4      .447     2.730     1.482      .901      .425     1.476     8.262     2.603     3.263      .897     9.466     6.059
         5      .389     1.708     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     1.135     2.548     5.002     1.005     9.883     5.338     1.169
         7    20.491     1.730     1.951      .763     6.055     1.019     1.385     4.221      .787     7.270    19.247     1.073
         8    11.116     1.849     1.435      .678     3.753      .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     1.304      .581     2.896      .859      .927     1.679      .423    60.302     2.424     2.777

        11     1.949    11.562    13.382      .549     2.004      .993     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     1.405      .465     3.143      .978      .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     3.120
        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      .784     4.386     3.301      .829      .672      .363     1.147    11.888     1.842    24.959
        19    17.318     9.664      .739     2.433     2.553      .787      .872      .315     1.494    17.033     1.288    20.524
        20     7.278    18.016      .693     1.362     2.296      .769      .736      .281     1.816    10.569     1.458    49.229

        21     7.506     5.244      .610     1.124     1.807     6.382     1.736      .261     2.528    88.025     1.329    10.630
        22     4.806     2.596      .539      .929     1.529     3.261     1.774      .246     1.447    20.263     1.595     4.547
        23     9.278    12.616     3.235    24.445     7.220     2.424     3.409      .304     1.684     7.383     2.759    14.974
        24    22.228     5.053    12.195     3.987     4.728     8.844     6.176      .337      .942     6.161     6.002     5.337
        25    13.200     3.247     5.693     1.553     2.865    10.823    11.107      .313      .685     2.318     6.904     5.786

        26     4.517     2.114     4.248     1.072     6.293    17.571     5.655     3.283     3.148     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     2.081     9.884      .696     4.721     4.841     2.593     8.473     1.407     1.099     2.475     1.253
        29     2.241               8.268      .823     3.960     3.212     1.861     3.235     5.329     1.109     6.203      .913
        30     1.530               2.481      .896    16.655     2.715     1.432    12.120     4.268     4.484     2.854      .661

        31     1.179               1.788               4.298               10.547    14.832               4.483                .573

DAYS WITH DATA 31         28        31        30        31        30        31        31        30        31        30        31
MEAN           8.384     6.821     3.826     2.105     3.849     3.189     2.833     3.063     2.211    11.531     6.108     7.795
MIN FLOW        .389     1.201      .539      .448      .372      .769      .672      .246      .331      .897     1.288      .573
MAX FLOW      51.426    43.923    18.529    24.445    16.655    17.571    11.107    14.832    12.784    88.025    20.448    49.229
```

TABLE 3.1a Derivation of hydrograph baseflow line turning points

39027 PANG AT PANGBOURNE

YEAR 1970

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
1	.422	.883	.733	.665	.596	.466	.390	.310
2	.426	.941	.737	.633	.577 ✓	.439 ✓	.357	.278 ✓
3	.421	.879	.711 ✓	.637	.580	.449	.358	.286
4	.398	.851	.810	.630 ✓	.592	.468	.359	.281 ✓
5	.389	.797	.765	.657	.580	.440	.347	.290
6	.395	.756 ✓	.768	.777	.568 ✓	.431	.341	.317
7	.364 ✓	.776	.790	.724	.628	.426	.312 ✓	.323
8	.379	.781	.759	.699	.572	.404 ✓	.371	.313
9	.593	.805	.708	.675	.619	.424	.347	.310
10	.775	.729	.698 ✓	.669 ✓	.634	.428	.332	.319
11	1.020	.706 ✓	.978	.653 ✓	.608	.431	.335	.315
12	.740	.813	.997	.863	.641	.414	.316	.305
13	.630	.749	.859	.806	.624	.407	.308 ✓	.298 ✓
14	.988	.708	.798	.748	.593	.367 ✓	.359	.299
15	.740	.667 ✓	.734 ✓	.715	.596	.387	.354	.320
16	.708	.673	.741	.706	.563	.389	.352	.313
17	.628 ✓	.879	.785	.735	.564	.403	.359	.291 ✓
18	.657	.907	.759	.710	.545	.408	.340 ✓	.301
19	.633	1.000	.697	.689	.581	.382 ✓	.379	.427
20	.628	.975	.708	.649 ✓	.506	.378	.355	.384
21	.645 ✓	1.040	.694 ✓	.682	.526	.355 ✓	.347	.359
22	.784	1.040	.686	.672	.536	.411	.348	.349
23	1.550	.962	.732	.644	.418 ✓	.391	.340 ✓	.368
24	1.180	.850	.734	.615 ✓	.487	.443	.357	.340
25	.937	.806	.692	.669	.488	.379	.352	.320
26	.990	.761	.676 ✓	.647	.538	.373	.358	.310
27	.820	.748	.638 ✓	.622	.491	.378	.333	.315
28	.786	.731 ✓	.648	.622	.517	.359	.349	.311
29	.856		.658	.605 ✓	.486	.358 ✓	.348	.306
30	1.280		.649	.607	.475	.370	.328	.293
31	.916		.679		.485		.291	.280

(i) Ringed values are 5 day minima

(ii) Ticked 5 day minima are baseflow line turning points

TABLE 3.1c   Flow data for Langdon

```
                    INSTITUTE OF HYDROLOGY DAILY FLOW LISTING

     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

DAYS WITH DATA 31           28        31        30        31        30        31        31        30        31        30        31
MEAN            .747      .458      .500      .219      .051      .251      .067      .562      .055      .380      .481      .208
MIN FLOW        .098      .075      .100      .034      .030      .030      .024      .035      .029      .027      .065      .080
MAX FLOW       6.252     4.061     2.331     2.456      .148      .928      .376     4.703      .204     3.435     2.559     1.367
```

TABLE 3.1d Flow data for Roman

```
                              INSTITUTE OF HYDROLOGY DAILY FLOW LISTING

   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      .221      .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

   DAYS WITH DATA 31        28        31        30        31        30        31        31        30        31        30        31
   MEAN         .643      .355      .268      .181      .141      .162      .098      .107      .091      .105      .159      .150
   MIN FLOW     .091      .234      .206      .152      .114      .073      .067      .090      .082      .077      .095      .119
   MAX FLOW    1.879      .678      .371      .275      .225      .467      .117      .159      .149      .220      .491      .249
```

TABLE 3.2b **BFI from data for Falloch, Langdon, Roman**

1 *Date of turning point*	2 *Discharge (cumecs)*	3 *Time span between turning points (days)*	4 *Average discharge (cumecs)*	5 *Increment of baseflow (cumec-days)* *col 3 x col 4*

$V_B = \Sigma$ *col 5* =

Total volume beneath baseflow hydrograph from .... to .... $= V_B =$

Total volume beneath recorded hydrograph from .... to .... $= V_A =$

Base flow index $= V_B/V_A =$

TABLE 3.2a BFI from data for Pang

1 Date of turning point	2 Discharge (cumecs)	3 Time span between turning points (days)	4 Average discharge (cumecs)	5 Increment of Baseflow (cumec-days) Col 3 x Col 4
7/1	·364	10	·496	4·96
17/1	·628	4	·637	2·55
21/1	·645	16	·701	11·21
6/2	·756	5	·731	3·66
11/2	·706	4	·687	2·75
15/2	·667	13	·699	9·09
28/2	·731	3	·721	2·16
3/3	·711	7	·705	4·93
10/3	·698	5	·716	3·58
15/3	·734	6	·714	4·28
21/3	·694	5	·685	3·43
26/3	·676	1	·657	0·66
27/3	·638	8	·634	5·07
4/4	·630	6	·650	3·90
10/4	·669	1	·661	0·66
11/4	·653	9	·651	5·86
20/4	·649	4	·632	2·53
24/4	·615	5	·610	3·05
29/4	·605	3	·591	1·77
2/5	·577	4	·573	2·29
6/5	·568	17	·493	8·38
23/5	·418	10	·429	4·29
2/6	·439	6	·422	2·53
8/6	·404	6	·386	2·31
14/6	·367	5	·375	1·87
19/6	·382	2	·369	0·74
21/6	·355	8	·366	2·85
29/6	·358	8	·335	2·68
7/7	·312	6	·310	1·86
13/7	·308	5	·324	1·62
18/7	·340	5	·340	1·70
23/7	·340	10	·309	3·09
2/8	·278	2	·280	0·56
4/8	·281	9	·290	2·61
13/8	·298	4	·295	1·18
17/8	·291			

$V_B = \Sigma$ col 5 = 116.660

Total volume beneath baseflow hydrograph from 7/1 to 17/8 = V_B = 116.660

Total volume beneath recorded hydrograph from 7/1 to 17/8 = V_A = 130.797

Base flow index = V_B/V_A = .892

3.2 ESTIMATING THE BASE FLOW INDEX FROM CATCHMENT GEOLOGY

The supplied data for estimating BFI for the example catchments consists of regional maps showing salient geolgoical features (Figures 3.1b to d) and supplemented by generalised values for major rock types and locally applicable revisions (Figures 3.3 and 3.4). Note that the BFI values for the example catchments have been omitted (deliberately) from the regional geology maps.

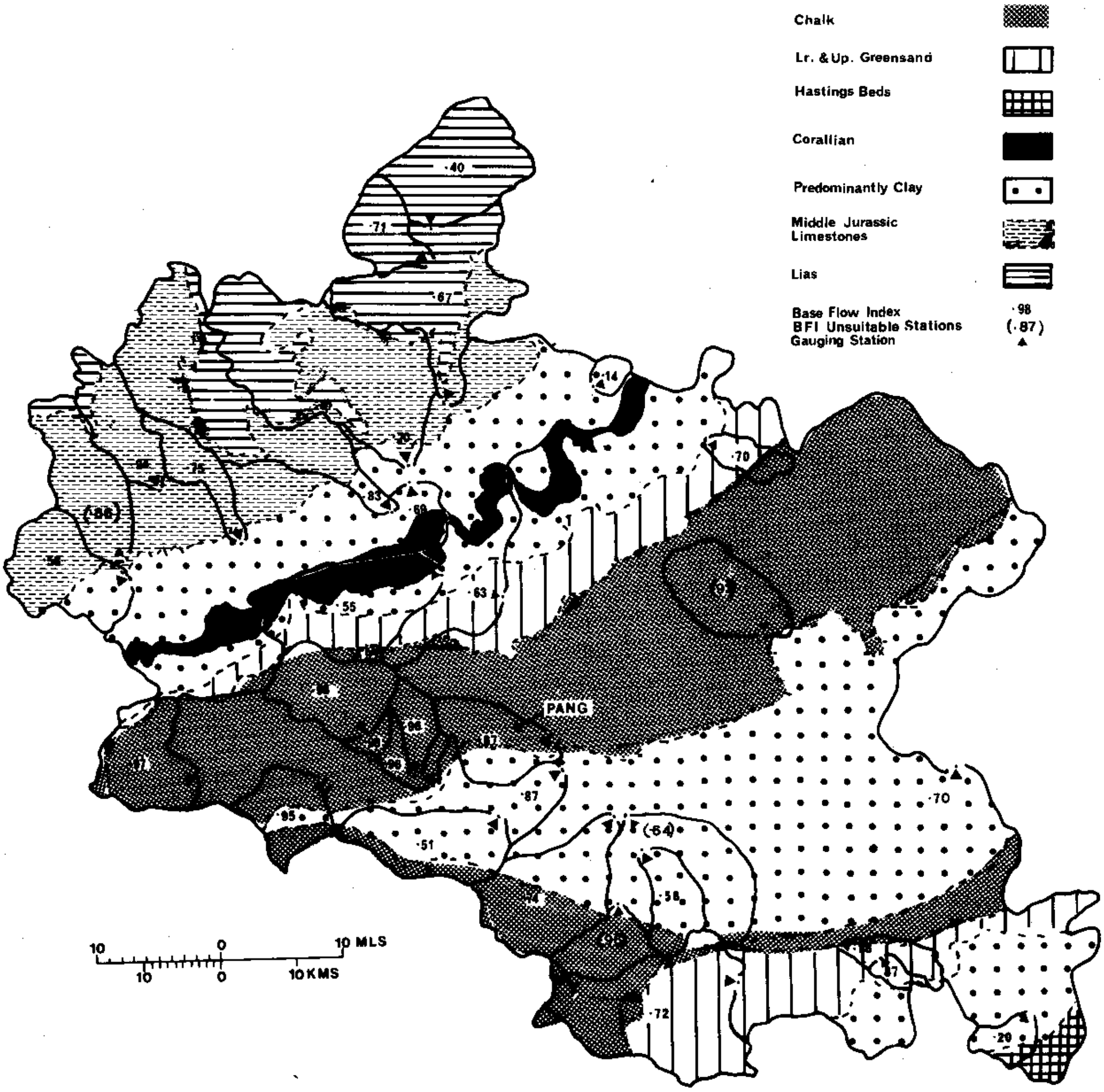


FIGURE 3.1a BFI AND GEOLOGY FOR RIVER THAMES AREA INCLUDING RIVER PANG

3.2 ESTIMATING THE BASE FLOW INDEX FROM CATCHMENT GEOLOGY

Rules for BFI calculation in the ungauged case cannot be given entirely objectively, the procedure falling under the general heading 'comparison with analog catchments'.

The basic steps in its estimation are:

(a) Assemble the BFI values for all catchments in the basin of the site of interest and in neighbouring basins and enter them, together with their catchment boundaries, on to a 1:625,000 scale overlay. Note any special features of the catchments that may modify the values from the expected ones, eg lakes and artificial influences. Give less weight to BFI values from stations not used in the Low Flow Study on the grounds of unsuitability of data.

(b) Mark the major geological strata on to the overlay, add details of surface deposits, in particular, drift types that may differ from, or mask the effect of, the solid rock, especially deposits such as boulder clay overlying chalk and sand or gravel on clay. Figure 3.1a shows the Thames area BFI values and geology. The hydrogeological characteristics of the rock on the catchment scale are more important than the detailed stratigraphy. Sources are:

(i) the Ordnance Survey 10 mile solid and drift geology map of Great Britain;

(ii) 1" and 1:50,000 solid and drift maps (partial cover only);

(iii) the hydrogeology map of England & Wales and regional hydrogeology maps published by IGS;

(iv) Water Authority surveys.

These can be supplemented by the Flood Studies winter rain acceptance potential map where a low soil type can be equated with a high BFI.

(c) Refer to published information on local geology and hydrogeology: IGS Regional Geology guides, Water Authority and CWPU reports for example - note particularly details of the thickness and permeability of the strata and whether there is a possibility that the river bed is incised into underlying rock units. The position of aquifer storage in relation to the base level of spring discharge determines whether the river is spring-fed. Note fault lines in relation to the drainage network.

(d) Having assembled the geological and flow information, the BFIs from gauged catchments must be compared with their geology and this comparison used to estimate the BFI from the solid and drift geology of the ungauged catchment. Catchments having similar hydrogeological characteristics in terms of permeability and storage should be compared and in areas with similar geology, variations in landscape are of importance. In this context the values of stream frequency and slope are an objective way of making comparisons.

The following situations merit further comment:

(i) When dealing with medium and large streams the grad ation in the BFI value when moving from upstream to downstream allows one to 'interpolate' a reasonable value; in well gauged basins the value is often obvious.

(ii) Isolated catchments can be assessed by analogy with gauged neighbours or by using the following table of rock types and typical BFI values.

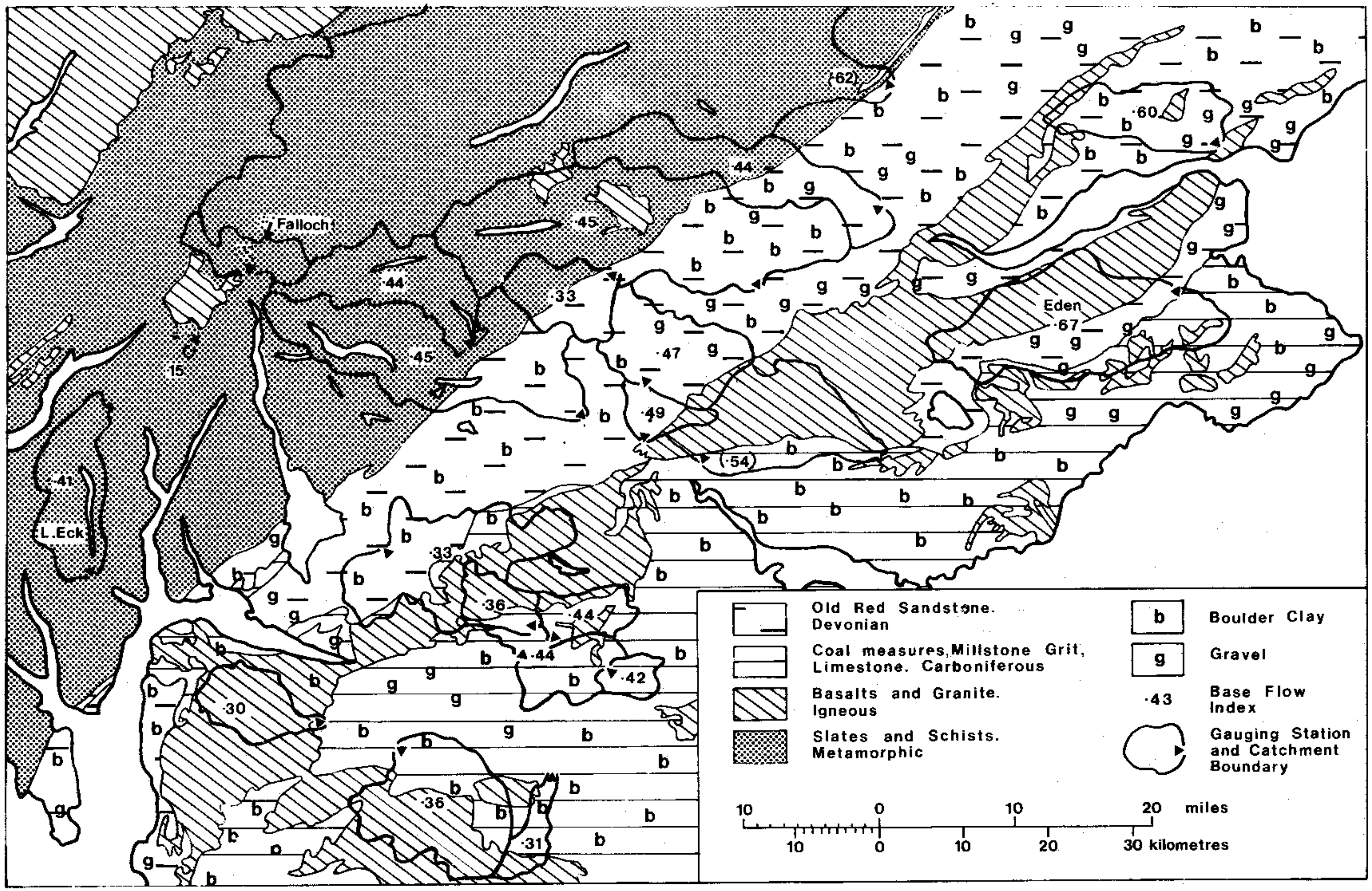


FIGURE 3.1b BFI AND GEOLOGY FOR CENTRAL SCOTLAND INCLUDING RIVER FALLOCH

TABLE 3.3 **Typical Base Flow Indices for various rock types**

Dominant Permeability Characteristics	Dominant Storage Characteristics	Example of rock type	Typical BFI range
Fissure	High storage	Chalk	.90 - .98
		Oolitic limestones	.85 - .95
	Low storage	Carboniferous limestone	.20 - .75
		Millstone Grit	.35 - .45
Intergranular	High storage	Permo-Triassic sandstones	.70 - .80
	Low storage	Coal measures	.40 - .55
		Hastings Beds	.35 - .50
Impermeable	Low storage at shallow depth	Lias	.40 - .70
		Old Red Sandstone	.45 - .55
		Silurian/Ordovician	.30 - .50
		Metamorphic-Igneous	.30 - .50
	No storage	Oxford Clay) Weald Clay) London Clay)	.15 - .45

(iii) The BFI value for catchments containing mixtures of rock type can be estimated using area proportions although, as is evident in Figure 3.2, there is a bias towards the value appropriate to the higher BFI rock type.

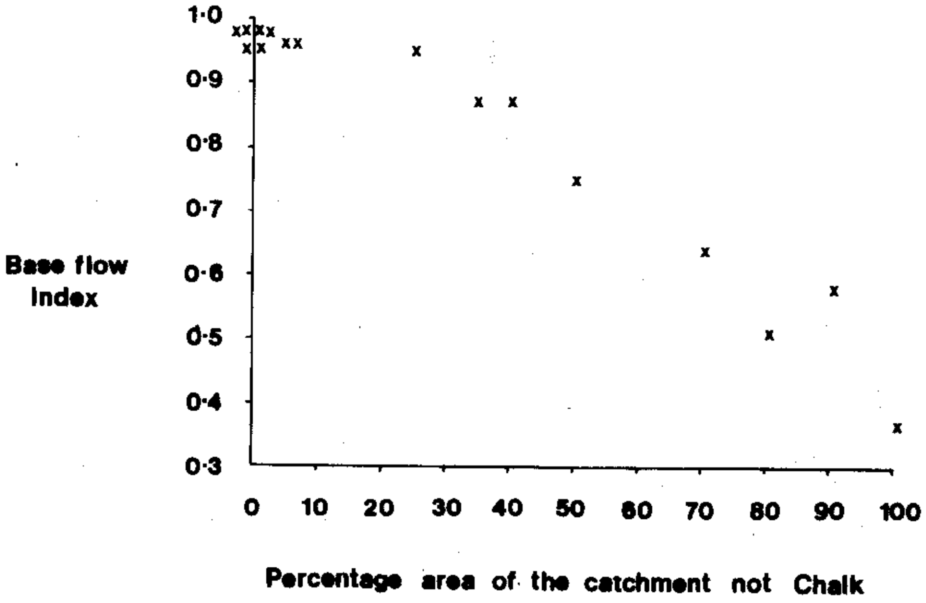


FIGURE 3.2 RELATIONSHIP BETWEEN BFI AND SOLID GEOLOGY FOR CHALK CATCHMENTS IN THE THAMES BASIN

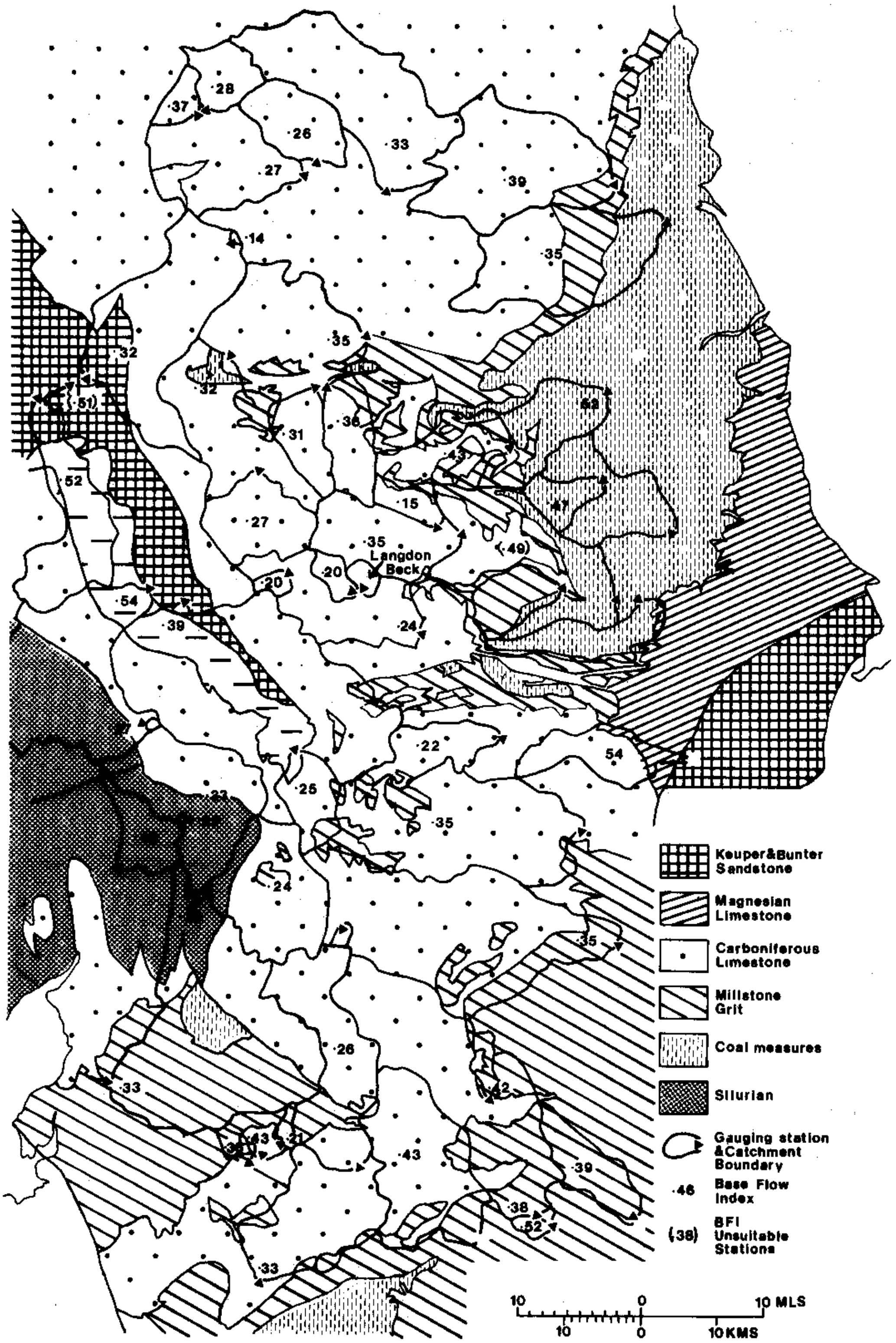


FIGURE 3.1c BFI AND GEOLOGY FOR CENTRAL NORTHERN ENGLAND INCLUDING RIVER LANGDON

(iv) Small catchments (< 10 km^2) present particular problems in that the presence or absence of springs can drastically affect the BFI value. A site inspection and local knowledge is indispensble in such cases.

(v) Although a lengthy record is unnecessary for BFI evaluation (the value is insensitive to wet or dry years) it is necessary to sample at least a complete year encompassing a summer and a winter period. Therefore a low flow station record will not suffice.

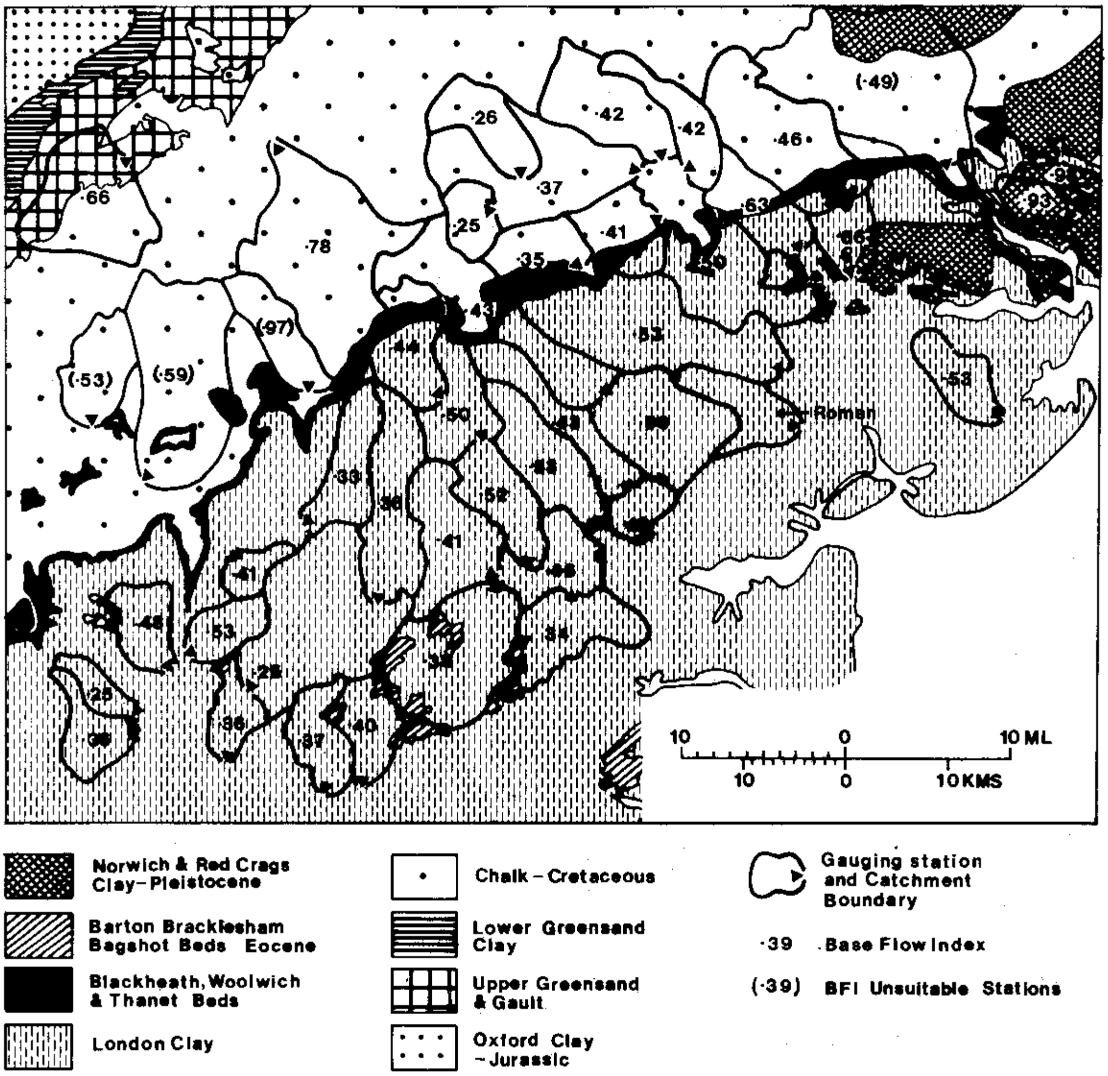


FIGURE 3.1d BFI AND GEOLOGY FOR ESSEX INCLUDING RIVER ROMAN

FALLOCH: *For the River Falloch, Figure 3.1b shows the locally available BFI values. Note that the presence of lakes within a catchment can substantially raise the BFI downstream.*

BFI in the light of geology is . . . . .

LANGDON: *For the River Langdon, Figure 3.1c shows the locally available BFI values. Figure 3.3 below gives additional guidance for carboniferous limestone catchments. Section 2.1 described how the stream frequency can be calculated from topographic maps: the value for this catchment is 2.92 J/km².*

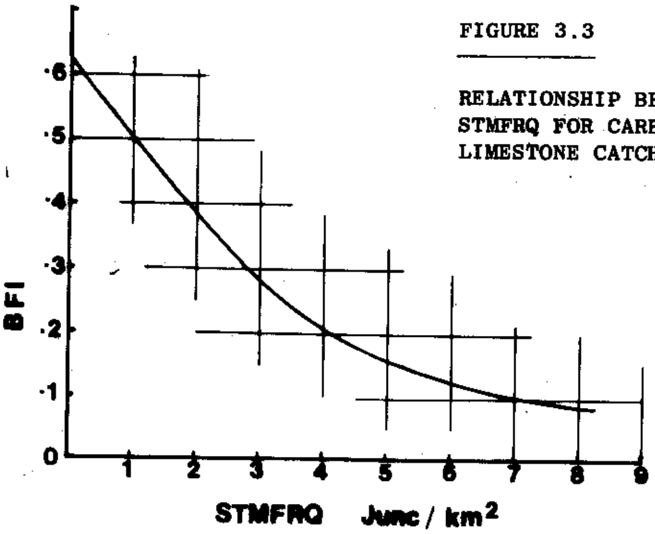


FIGURE 3.3

RELATIONSHIP BETWEEN BFI AND STMFRQ FOR CARBONIFEROUS LIMESTONE CATCHMENTS

BFI in the light of geology is . . . . .

ROMAN: *For the River Roman, Figure 3.1d shows the locally available BFI values. Figure 3.4 below gives guidance for London Clay catchments*

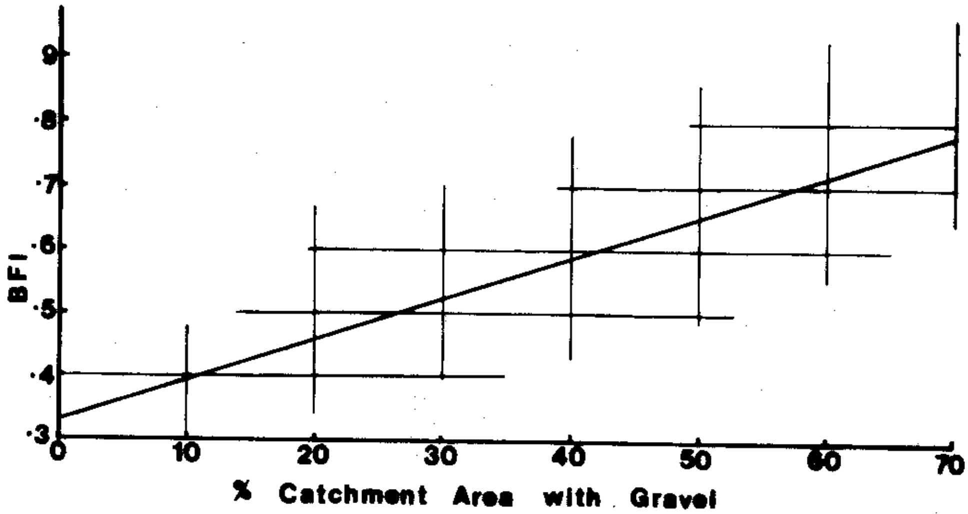


FIGURE 3.4 **RELATIONSHIP BETWEEN BFI AND PERCENTAGE AREA WITH GRAVEL COVER FOR LONDON CLAY CATCHMENTS**

BFI in the light of geology is . . . . .

The Base Flow Index for the Pang catchment can be estimated by considering the solid and drift geology:

1. SOLID GEOLOGY

(a) From Figure 1.2a it can be seen that excluding the drift deposits (clay with flints and sands and gravels) the percentage area of the solid geology which is chalk is about 70%. The remainder of the catchment consists of more impermeable Eocene beds, predominantly London Clay and Reading beds. Table 3.3 indicates that the BFI for these drift-free Chalk catchments is generally in the range 0.90 - 0.98. However, it might be expected that the index would be reduced by London Clay having an index of 0.14 - 0.45 (Table 3.3).

(b) A more accurate estimate can be obtained by referring to Figure 3.1a where the BFI for catchments surrounding the Pang but having similar mixtures of chalk and predominantly clay solid geology can be seen. This local data is of greater value than the national averages listed in Table 3.3 and an inspection of the purely chalk catchments indicates that their BFIs are between 0.96 and 0.98 but that the index is reduced for catchments with a smaller proportion of chalk. For these catchments the proportion of catchment which is not chalk has been plotted against the BFI and is shown on Figure 3.2. From Figure 1.2a the proportion of solid geology other than chalk can be estimated as 30% and using Figure 3.2 the BFI can be estimated for the Pang as 0.90. This compares with the long term value of 0.87 and a value of 0.89 calculated from eight months of flow data. Section 3.1 .

2. DRIFT GEOLOGY

Figure 1.2a also shows that 9% of the catchment is covered with clay with flints and a further 4% of the catchment is covered by sand and gravel. However, sands and gravels overlying chalk do not influence the BFI and furthermore, a study of 16 chalk catchments has shown that the BFI is not influenced by the % of clay with flints. Local results such as these are the subject of a series of regional monographs.