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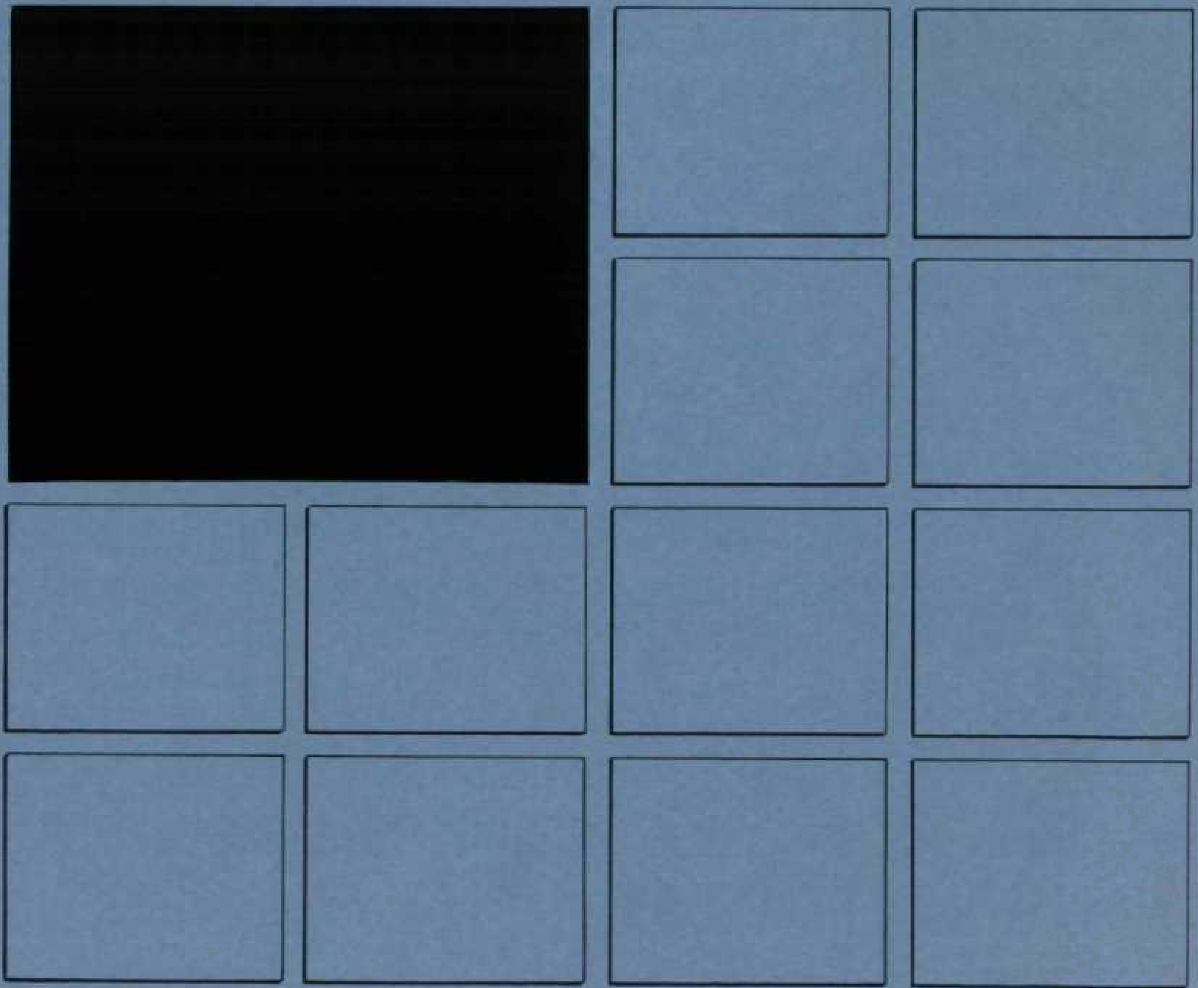

Low flow forecasting
to aid
regulation of the river Wye

D.W. Reed and D.W. Warne, December 1985

Report to Welsh Water South Eastern Division

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APPENDICES

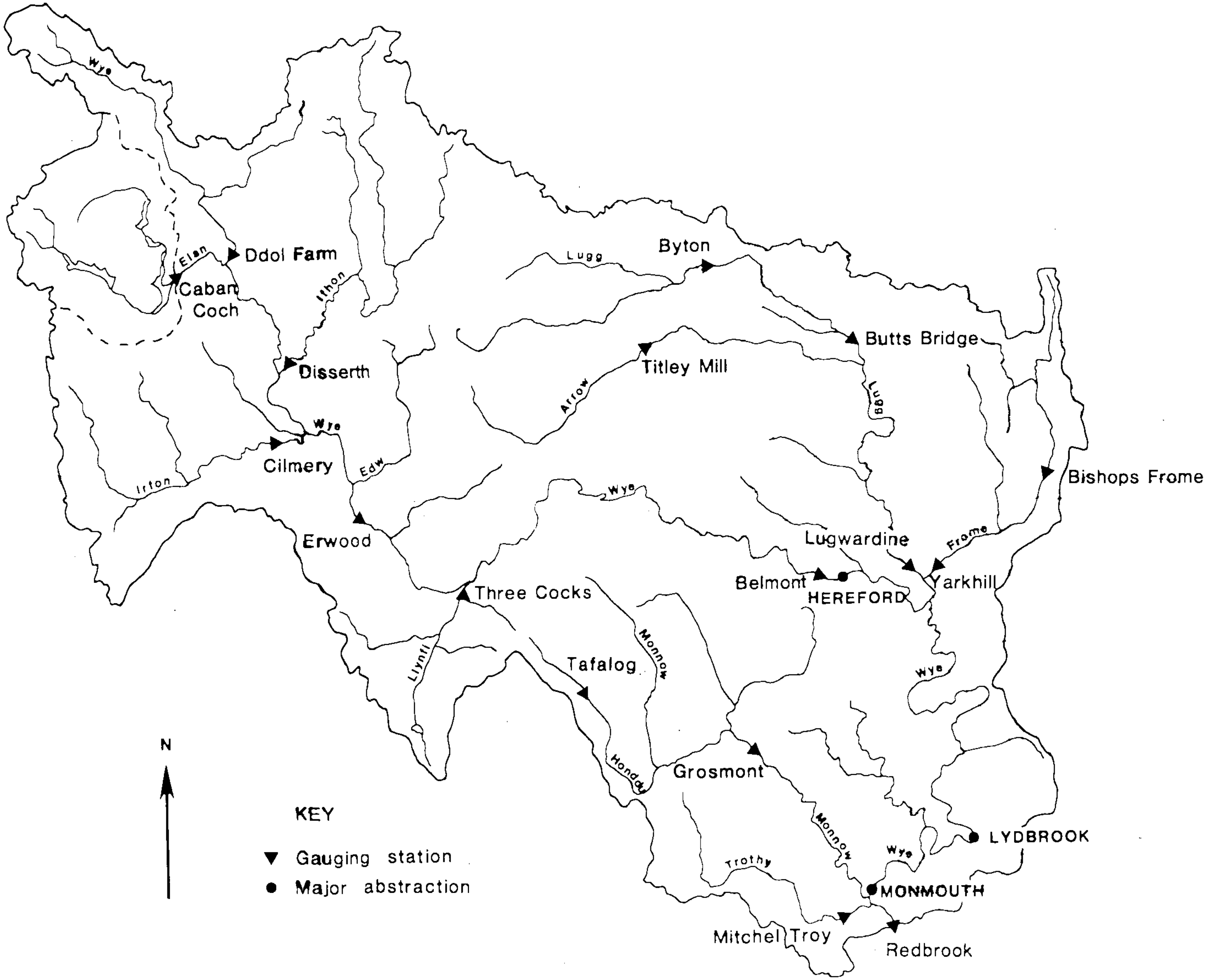

Fig 1. Plan of Wye catchment to Redbrook.

1. INTRODUCTION

Under a recent agreement with Severn-Trent WA (Ref.1), water will be released from Caban Coch reservoir (in the Elan Valley) to regulate low flows in the river Wye. The scheme supports increased abstractions from the river, notably Welsh Water's new abstraction at Monmouth.

For much of the time, water will be released from Caban Coch at a rate of 0.79 cumecs - the minimum release rate. However, in dry weather recession periods the release rate will be adjusted on a daily basis in order to maintain where possible a residual flow at Redbrook (see Fig.1) of 14.00 cumecs. Appendix 3 of Ref.1 specifies a maximum release rate of 2.68 cumecs, limited to 2.37 cumecs if the Elan Valley resource system is under stress.

Releases from Caban Coch take about 3 days to arrive at Redbrook. It is therefore necessary to forecast flows in the Wye system up to 3 days ahead so that resource wastage (through "over-releasing") or resource shortfall (through "under-releasing") can be minimized.

The brief for this project was to provide guidance in forecasting the recovery of Redbrook flows from observed flow "up-turns" at gauging stations in the middle and upper reaches of the Wye and its tributaries. However, the work carried out is relevant also to the more general problem of forecasting the release requirement, for which a method is given in Section 8 of the report.

2. DATA

2.1 Flows

Daily mean flow data are available for about 25 gauging stations in the Wye basin as part of the UK Surface Water Archive maintained at the Institute.

The period 1970-1984 was initially chosen for study: this period includes the severe drought years of 1976 and 1984. Unfortunately, processing and validation of the flow data are incomplete for recent years* and the study has therefore centred on analyses for the ten-year period 1970-1979.

During the study the Institute's holding of river level chart data was brought up to date by microfilm copying funded by the Surface Water Archive project. It has therefore been possible to make a preliminary test of how models developed on historical daily mean flow data might be translated for operational forecasting using instantaneous (rather than daily) data.

2.2 Releases

Past releases from Caban Coch have mainly taken the form of compensation water. Prior to September 1975 the basic rate was 1.58 cumecs, thereafter 1.42 cumecs. From time to time, freshets have been released for fisheries or canoeing interests. These have typically been pulse releases of + 3.03 cumecs lasting for 48 hours. Some specific experimental releases have also been made to monitor the propagation of low flow releases down the Wye. (See Ref.2).

Daily release (and overspill) data for Caban Coch were received during the project and extended the record already held on the Surface Water Archive up to December 1984.

2.3 Abstractions

Excluding the Elan valley supply, the main abstractions from the Wye are at Hereford, Lydbrook and (from 1985) Monmouth. The licenced quantities are 0.35, 0.53 and 1.58 cumecs respectively. The abstraction at Hereford is for public water supply locally and there is a corresponding effluent return to the Wye. (The abstraction and discharge points are downstream of the Belmont gauging station). However, the abstraction at Lydbrook is exported from the Wye basin. Monthly abstraction data for Lydbrook show a progressive increase in utilization from 1973 (0.0 cumecs) to 1977 (mean of 0.2 cumecs). Thereafter, the abstraction has been fairly steady in the range 0.3 to 0.4 cumecs (mean of 0.36 cumecs).

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* Problems with the more recent data include the downgrading of some stations (eg. Lugwardine and Tafolog) and uncertain rating curves due to weed-growth (eg. Redbrook).

2.4 Flow naturalization

In order to assess the natural behaviour of the Wye, the flows at Erwood, Belmont and Redbrook gauging stations were naturalized as follows. First, that part of the Wye catchment draining to the Elan valley reservoirs (184 km^2) has been excluded by subtracting all releases and overspill at Caban Coch from the gauged flows at Erwood, Belmont and Redbrook. (A total naturalization - attempting to estimate the river flows that would have occurred if the reservoirs hadn't been built - is practicable only for monthly or weekly data and would be of interest more for planning studies than for operational studies of existing arrangements.) The naturalization was carried out assuming a 1-day travel time to Erwood, two days to Belmont and three days to Redbrook. (See Section 4.)

The Redbrook flows were further naturalized by the addition of the Lydbrook abstraction.

3. LOW FLOW BEHAVIOUR

Before developing forecasting methods it is helpful to appraise the low flow behaviour of the Wye and its tributaries. Since a storm occurring over only a single subcatchment could result in a flow recovery at Redbrook, flows throughout the Wye basin are of interest. Hence daily mean flow data were examined for 15 gauging stations. (See Table 1 and Figure 1). Stations assessed to be more than 3 days low flow travel time from Redbrook (eg. Wye at Pant Mawr) or of little consequence (eg. Yazor at Three Elms) were not analysed.

Standard programs were used to plot and tabulate the daily mean flow data. Most of the data appeared to be reliable but some anomalies were noted and attributed to abrupt changes in rating curves, faulty instrumentation, or a very occasional rogue value. However, few of these anomalies affected the period 1970-1979 and this was the main reason for choosing to standardize the analyses to this period of record.

Table 1. Low flow characteristics for Wye subcatchments

(1) Sub-basin	(2) Station	(3) Area km^2	(4) ADF (70/79) cumecs	(5) AARO (70/79) mm	(6) Q90/ADF –	(7) Q90 (70/79) cumecs	(8) h90 days	(9) BFI –
Upper Wye	Ddol Farm	174	6.48	1175	0.113	0.74	11	0.38
	Cilmery	244	8.97^{e}	1160^{e}	0.100	0.90^{e}	12½	0.39
	Disserth	358	7.00^{e}	617^{e}	0.068	0.46^{e}	13½	0.42
	Ungauged*	322	7.85^{e}	769^{e}				
	Erwood*	1098	30.3	871	0.115	3.47	13½	0.43
Middle Wye	Erwood*	1098	30.3	871	0.115	3.47	13½	0.43
	Three Cocks	132	1.98^{e}	473^{e}	0.111	0.22^{e}	31^{e}	0.60
	Ungauged	666	5.22^{e}	247^{e}				
	Belmont*	1896	37.5	624	0.139	5.23	16½	0.46
Lugg	Byton	203	3.67	570	0.221	0.81	46	0.69
	Ungauged	168	1.85^{e}	347^{e}				
	Butts Bridge	371	5.52	469	0.202	1.11	37	0.68
	Titley Mill	126	2.23	558	0.170	0.38	36	0.62
	Ungauged	389	3.14^{e}	255^{e}				
	Lugwardine	886	10.89	388	0.206	2.24	37½	0.64
Frome	Bishops Frome	78	0.70^{e}	283^{e}	0.174	0.12^{e}	24^{e}	0.54
	Ungauged	66	0.47^{e}	225^{e}				
	Yarkhill	144	1.17^{e}	256^{e}	0.174	0.20^{e}	25^{e}	0.55
Monnow	Tafolog	25	0.70^{e}	880^{e}	0.194	0.14^{e}	24	0.54
	Ungauged	329	4.93^{e}	473^{e}				
	Grosmont	354	5.63^{e}	502^{e}	0.134	0.75^{e}	32	0.54
Lower Wye	Belmont*	1896	37.5	624	0.139	5.23	16½	0.46
	Lugwardine	886	10.89	388	0.206	2.24	37½	0.64
	Yarkhill	144	1.17^{e}	256^{e}	0.174	0.20^{e}	25^{e}	0.55
	Grosmont	354	5.63^{e}	502^{e}	0.134	0.75^{e}	32	0.54
	Ungauged	546	7.11^{e}	411^{e}				
	Redbrook*	3826	62.3	514	0.201	12.5	21½	0.57

Footnotes: * excludes Elan valley reservoired catchment, see Section 2.4.

e = estimated

3.1 Average daily flow

Nine of the stations have complete records for the period. For the remaining six stations, the gauged average daily flow (ADF) was adjusted to the standard period (1970-1979) by reference to neighbouring gauges with complete records. The ADF's are given in column 4 of Table 1, which summarizes the low flow characteristics of the various subcatchments. Column 5 shows the equivalent average annual runoff (AARO) in millimetres.

3.2 Flow duration analysis

A standard program was used to calculate (and plot) flow duration curves. The 90 percentile flow (Q90) - the daily mean flow exceeded 90% of the time - was chosen as a reference low flow in this study. Generally the Q90 values shown in column 7 of Table 1 have been taken directly from the flow duration analysis. However, for the six stations with incomplete records, the ratio Q90/ADF (column 6) was applied to the adjusted ADF (see Section 3.1) to arrive at an estimate of Q90 for the standard period 1970-1979.

3.3 Master recession curve

Figure 2 shows the Redbrook naturalized daily mean flows for 1981. (The period July to September 1981 was chosen to provide an independent test of the forecasting methods derived, to which Section 8.3 refers.) The logarithmic scale used in Fig.2 accentuates low flow periods and highlights "dry weather" recessions.

A manual technique (Ref.3) was used to assemble a master recession curve for each of the more important stations. The curves for Erwood, Redbrook and Byton are shown in Fig.3. Although fiddly and highly subjective to derive, these master recession curves characterize low flow behaviour in a manner especially helpful to forecasting the earliest time at which a critical low flow may be reached.

A straight line plot on Fig.2 or Fig.3 would correspond to the linear exponential recession:

$$Q_t = Q_0 e^{-\alpha t} \qquad (1)$$

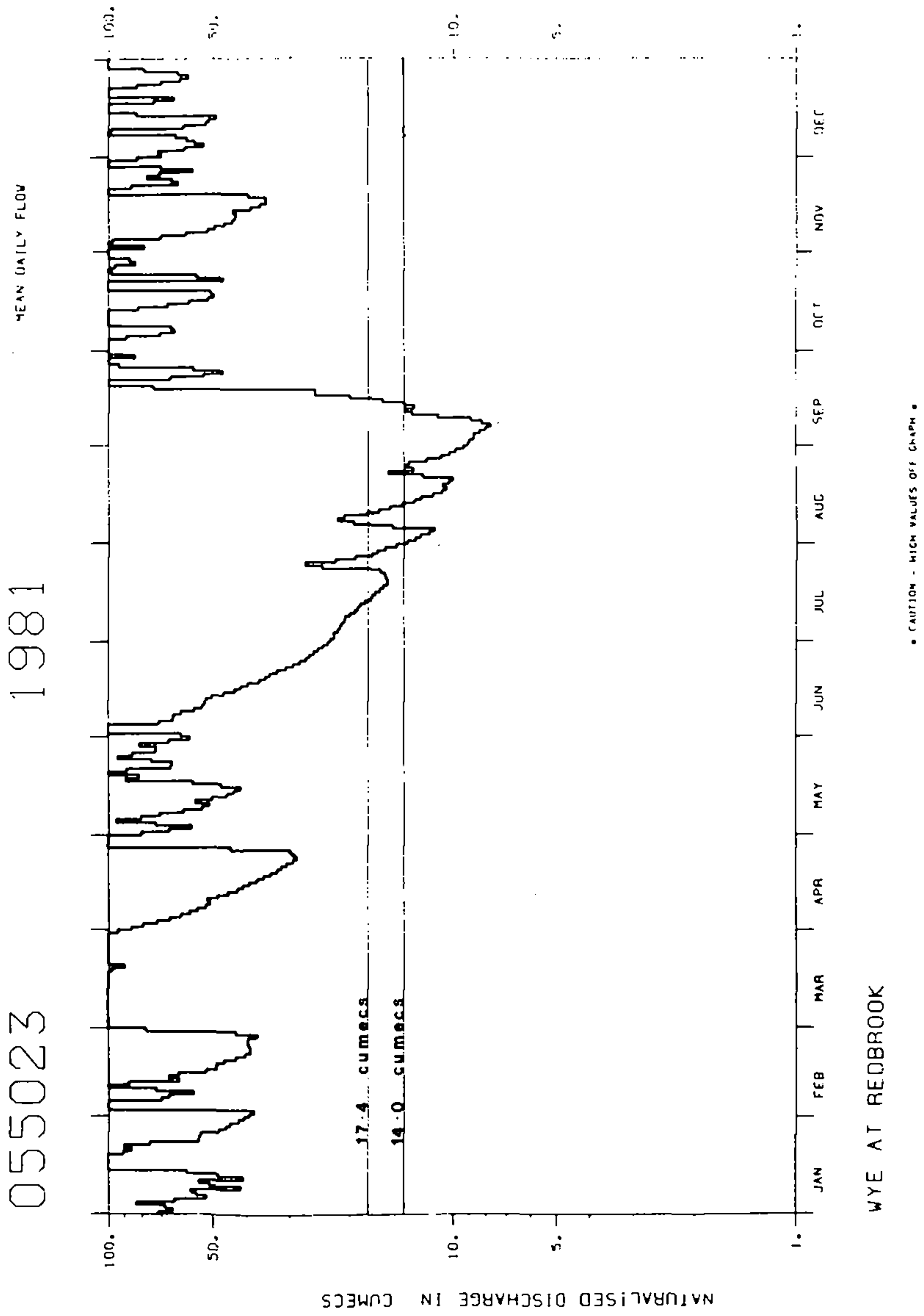


Fig 2. Redbrook naturalized daily mean flows for 1981.

where Q is flow, Q_0 initial flow and t is time. The recession parameter α has the dimensions of $[\text{time}^{-1}]$; the gradient of the ℓnQ v. t plot is $-\alpha$.

To aid interpretation it is convenient to speak of the recession half-life, h, which is the time taken for Q to decay to half its initial value. Substituting:

$$\alpha = \frac{\ell n2}{h} \qquad -(2)$$

yields: $$Q_t = Q_o\left(\frac{1}{2}\right)^{t/h} \qquad -(3)$$

which is entirely equivalent to Eqn.1. For a linear exponential recession, specification of h(or α) completely determines the recession behaviour.

In practice, master recessions often plot as a curve on ℓnQ v. t, the recession decaying ever more slowly. Recessions for Titley Mill, Byton and Lugwardine were the most curved; those for Cilmery, Disserth, Belmont and Redbrook were almost straight.

Various non-linear recession formulations are possible, eg.

$$(4)- \quad Q_t = Q_o\, e^{-at^b} \quad \text{or} \quad Q_t = Q_o\, e^{-(at+b\sqrt{t})} \quad -(5)$$

However, whereas interpretation of h in Equation 3 is relatively straightforward, it is all too easy to become confused with the parameter interactions in non-linear models.

Instead a compromise approach was adopted in this study. The recession behaviour has been characterized by the gradient of the master recession curve at the reference low flow, Q90. (See Fig.3.) The corresponding recession half-life, h90, is given in column 8 of Table 1. It is seen that Ddol Farm has the fastest dry weather recession (h90 = 11 days) and Byton the slowest (h90 = 46 days).

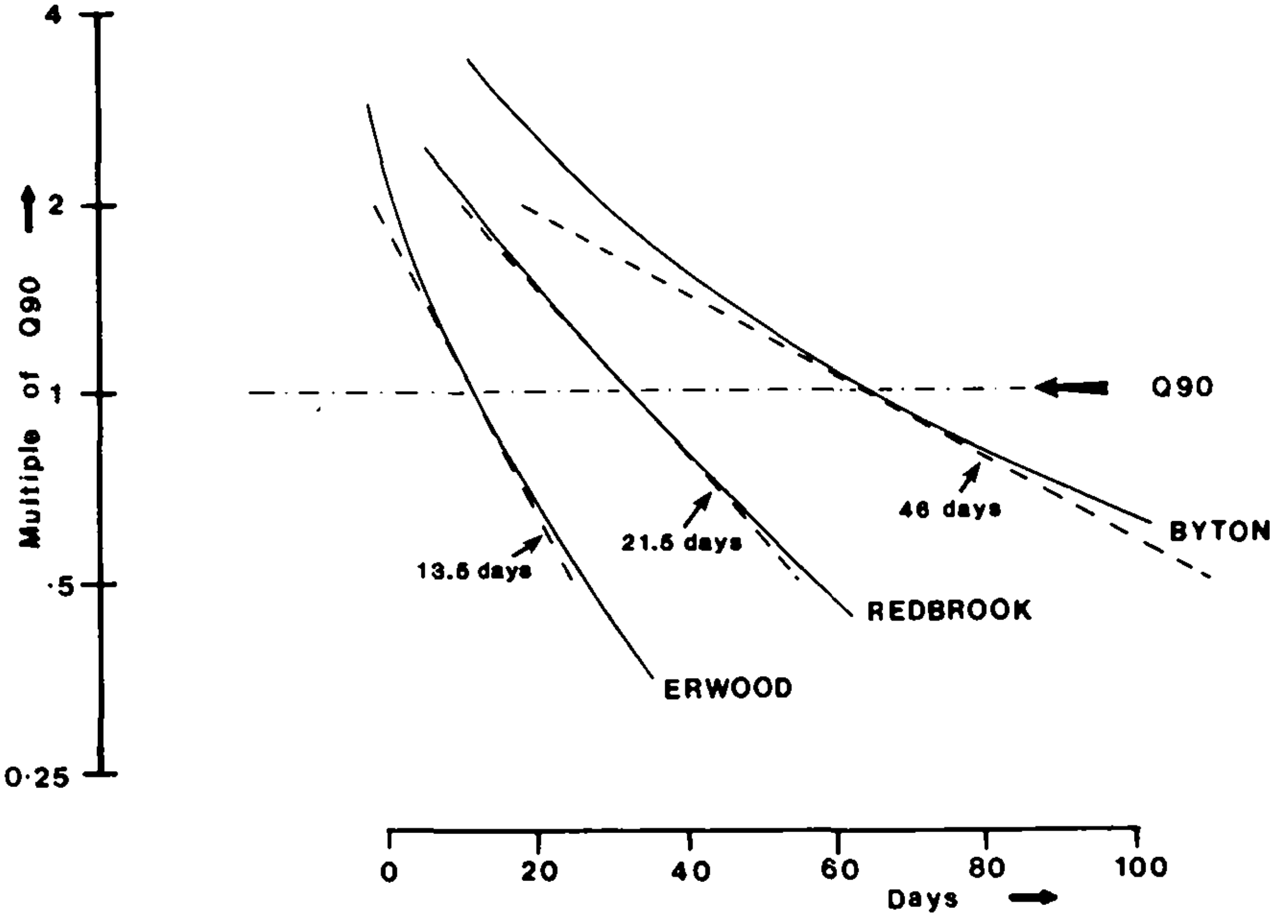


Fig 3. Master recession curves for Erwood, Redbrook and Byton. Attached numbers denote recession half-life.

3.4 Baseflow index (BFI)

Partly to overcome the labour and subjectivity of recession curve analysis, the UK Low Flow Study (Ref. 4) developed the baseflow index, BFI. Calculated from daily mean flow data by a simple algorithm, the index ranges between 0 and 1. Higher values (eg. 0.7) are derived for stations where groundwater-fed baseflow represents a large part of the annual runoff; lower values (eg. 0.3) are derived on less permeable catchments where baseflow constitutes a much smaller proportion of annual runoff.

The BFI values derived for the Wye stations are given in column 9 of Table 1. The values confirm the distinct behaviour of different parts of the Wye basin.

Table 2. Catchment subdivision by geology and low flow characteristics

Region	Solid geology	BFI	h90 (days)
Lugg	Relatively permeable sandstones (especially marls)	0.62 to 0.69	36 to 46
Other middle and lower Wye tributaries	Less permeable sandstones	0.54 to 0.60	24 to 32
Upper Wye (to Erwood)	Relatively impermeable Ordovician and Silurian sediments	0.38 to 0.43	11 to 14

3.5 Discussion

Low flow behaviour is generally controlled by geological factors. From an outline map of the Wye basin geology (map 2 of Ref.5) it is possible to distinguish three regions of differing solid geology. (See Table 2.) The basin is generally drift-free but there are notable glacial sands and gravels in the Lugg valley south of Leominster and the Wye Valley west of Hereford. Re-arranging the BFI and h90 values from Table 1 into these three regions it is seen that the observed low flow behaviour is consistent with this subdivision. There is therefore some support for estimating BFI or h90 for ungauged areas on the basis of geology.

The close relationship between these low flow indices is revealed by a plot of h90 against BFI. This is shown in Fig.4 together with the empirical relation:

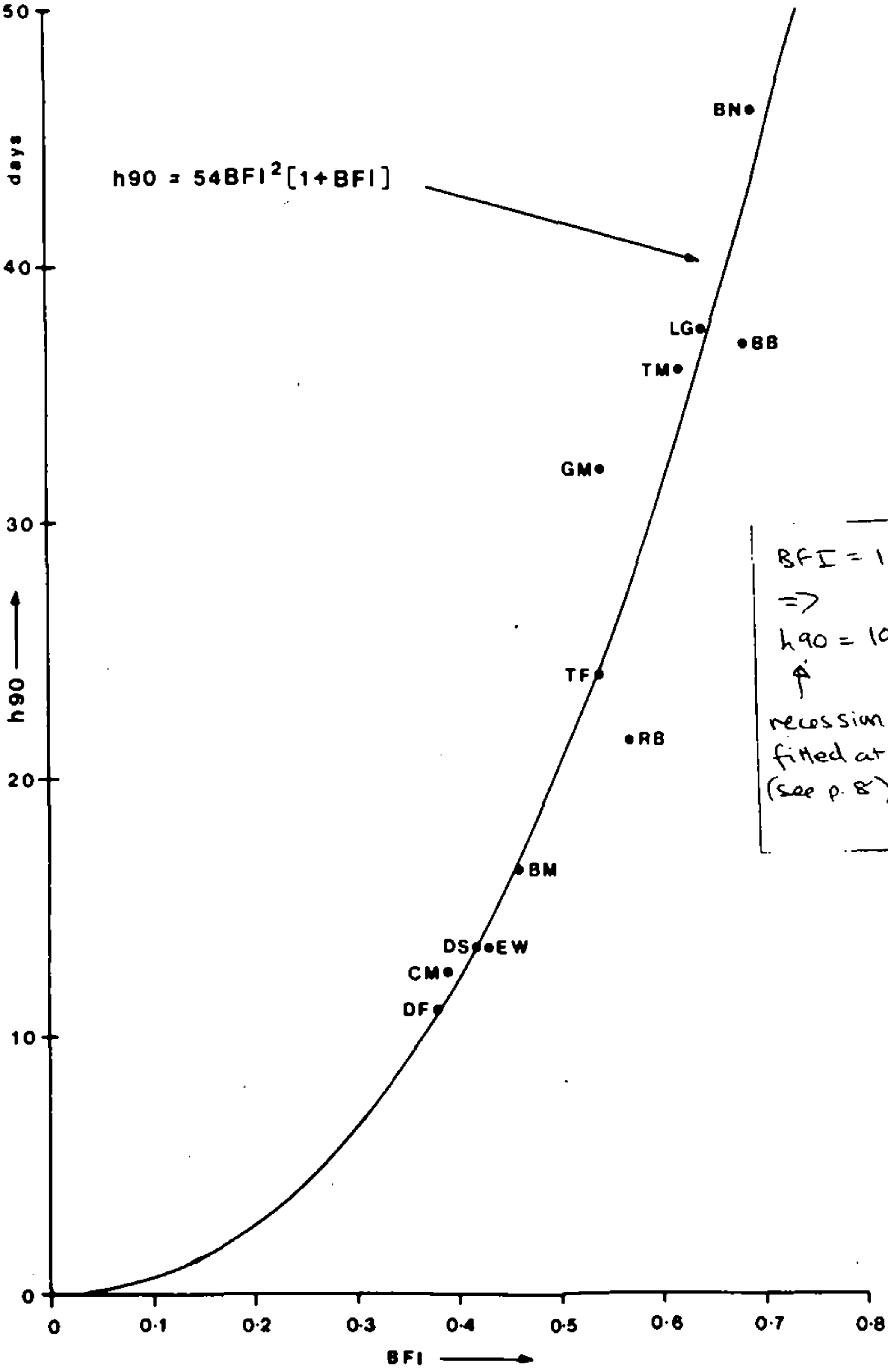
$$h90 = 54\ BFI^2\ (1 + BFI) \qquad -(6)$$

fitted to the data. This equation has been used to estimate h90 for three catchments for which a master recession analysis was not attempted (namely: Three Cocks, Bishops Frome and Yarkhill); deriving master recession curves is time-consuming!

While there is consistency in much of Table 1, there are one or two derived values that warrant further comment. The low value of Q90/ADF for Disserth indicates that groundwater is particularly limited on the Ithon. This feature was noted in the Wye R.A. Section 14 Survey (Ref.5) and the suggestion made that this might be true also for much of the ungauged area to Erwood (notably the Edw).

The relatively high value of Q90/ADF for Redbrook indicates that low flows are particularly well maintained on the lower Wye. This probably arises out of the sheer diverseness of the catchments upstream: low flows on the upper Wye not always coinciding with low flows on the Lugg.

The Q90/ADF values for Tafolog and Grosmont appear to be inconsistent. It is difficult to explain why low flows at Tafolog should be much better sustained than at Grosmont. One notion is that low flows in the Honddu may benefit from groundwater contributions from the sandstone - which slopes from the Wye just downstream of Erwood towards the Honddu and adjacent tributaries. (Comparison of ADF's and flow duration curves for Erwood, Three Cocks and Belmont suggests that the Wye may be effluent to groundwater in the Erwood/Belmont reach for normal and high flows, but influent at low flows. Perhaps the same aquifer feeds the Honddu at low flows too.) A no less likely explanation is that low flow measurement at Tafolog or Grosmont may simply be inaccurate. The poor correspondence between Tafolog and Grosmont low flows is discussed further in Section 6.6.



BFI = 1
=>
h90 = 108 days
↑
recession half-life fitted at Q90
(see p. 8)

Fig 4. Relationship between recession half-life (at Q90) and BFI.

4. TRAVEL TIMES

A prerequisite to constructing a method for forecasting flow recovery at Redbrook is an appreciation of travel times in the Wye system.

Flood wave travel times between Erwood and Redbrook were examined in the Flood Studies Report (Ref.6) and the range of values to be expected is reported in the Wye Area flood warning procedures (Ref.7). Travel times of flow "rises" in low flow conditions are, of course, rather longer.

Some specific information was available from a study of experimental regulation releases in June and July 1975 (Ref.2). This was augmented in the present study by extracting river level data for three freshet releases (see Section 2.2) which took place in low flow conditions. Travel times of flow "rises" deduced from these data are summarized in Table 3.

TABLE 3. Observed travel times of recoveries from low flow

Start date	Release magnitude (cumecs)	Release duration (hr)	Rise travel times CC EW (hr)	EW BM (hr)	BM RB (hr)	Redbrook flow prior to release (cumecs)
21 Jul 70	+ 1.617	81.5	15	27	28	11.2
31 May 75	+ 3.033	48	12½	26	26½	18.8
8 Jul 75	+ 2.766	48	15	30	33	12.4
3 Jun 78	+ 3.033	48	13	24	25	25.0
7 Jun 80	+ 3.033	48	15	26	33	16.0
	Typical rise travel times:		15	27	30	

Key: CC-Caban Coch, EW-Erwood, BM-Belmont, RB-Redbrook

Similar travel times can be expected for natural flow rises passing these gauging stations*. Based on the Table 3 data, Table 4(a) gives estimated cumulative travel times to Redbrook for flow rises in low flow conditions. Travel times on the Lugg, Frome and Monnow have not been examined in detail but broad estimates are given in Table 4(b).

Table 4. Estimated cumulative travel times to Redbrook for flow rises (in low flow conditions).

	Station	Travel time to Redbrook (hr)	(nearest day)	Code (see Section 6)
	Caban Coch	72	3	
(a)	Ddol Farm	69	3	DF3
	Disserth	66	3	DS3
	Cilmery	63	2 or 3	CM2, CM3
	Erwood	57	2 or 3	EW2, EW3
	Three Cocks	51	2	TC2
	Belmont	30	1	BM1
(b)	Titley Mill	72	3	TM3
	Byton	72	3	BN3
	Butts Bridge	51	2	BB2
	Lugwardine	27	1	LG1
	Yarkhill	27	1	YH1
	Tafolog	15	1	TF1
	Grosmont	9	0 or 1	GM0, GM1

FOOTNOTE

* If anything, travel times may be slightly shorter because the runoff conditions responsible for the rise at the upstream station may also affect the ungauged area inflow between the upstream and downstream stations.

5. PROBLEMS IN FORECASTING FLOW RECOVERY AT REDBROOK

The brief of the study was to produce a method for forecasting natural flow recovery at Redbrook up to 3 days ahead - from telemetered river level rises elsewhere in the system - so that releases from Caban Coch can be curtailed. This section discusses some of the basic difficulties in achieving this.

5.1 The Trothy and Monnow

From examination of the travel times presented in Table 4, and the layout of the Wye catchment (Fig.1), it is apparent that flow rises on the Trothy and Monnow may cause the Redbrook flow to recover relatively rapidly.

The travel time from Mitchel Troy (on the Trothy) to Redbrook is no more than about 2 hours. The catchment to Mitchel Troy has been analysed in follow-up work to the Flood Studies Report and a recent IH report (Ref.8) tabulates results from a rainfall/runoff analysis of 8 events. Although these are all winter events, it is apparent that the natural response characteristics of the catchment are such that appreciable flow rises at Mitchel Troy (say, 1 cumec) can occur within about 4 hours of effective rainfall commencing. Only about 1mm of effective rainfall is needed. Developing a rainfall/runoff model to forecast Mitchel Troy flows from telemetered rainfall data might achieve warning lead times of 4+2=6 hours for consequent flow rises at Redbrook.

In the case of the Monnow, the travel time from Grosmont to Redbrook is no more than 9 hours. With appropriate telemetered rainfall data and a rainfall/runoff model, a total warning lead time of 6+9 = 15 hours might be realised for consequent flow rises at Redbrook. (The modelling task is demanding; an appreciable flow rise at Redbrook will be produced by as little as 0.5mm of effetive rainfall on the Monnow!)

These lead times are pitifully short in comparison with a release travel time of 3 days from Caban Coch to Redbrook. It must be acknowledged that if a period of dry weather recession (requiring regulation releases) is broken by heavy rainfall on the Trothy and Monnow catchments (whether this be local or widespread over the Wye basin) it is likely that at least 2 days' regulation releases will be "wasted".

In some instances there may be a sufficiently large soil moisture deficit (SMD) that no appreciable flow rise occurs. Monitoring SMD on a daily or weekly basis will provide some guidance but, when runoff from the Trothy or Monnow does occur, the very short lead time for flow recovery at Redbrook again applies.

Operational arrangements at present (Ref.1) are such that the release rate at Caban Coch is adjusted no more than once daily - generally at 14.00 hrs following a decision at about 12.00 hrs. If heavy rainfall affecting the Trothy and Monnow catchments were to commence between 12.00 and 24.00 hrs (a 50% chance), it is probable that the Redbrook flow will have risen appreciably before the next release adjustment is made. This would, of course, make forecasting the time of Redbrook flow recovery a nonsense.

While the Trothy and Monnow present a problem that is all too obvious, the other tributaries are less troublesome. The largest - the Lugg - is particularly slowly responding. The remaining tributaries in the lower and middle Wye are each fairly small and none is thought to be as quickly responding as the Trothy or Monnow.

5.2 Short-lived flow recoveries

In the event of a flow rise occurring as a result of one or more localised intense storms it is desirable that the forecasting method should recognize that the resultant flow recovery at Redbrook may be short-lived. The method presented in Section 8 seeks to achieve this.

6. FORECASTING MODELS DERIVED FROM DAILY MEAN FLOW ANALYSIS

6.1 Selection of data

Low flow "events" were selected from the period 1970-79 on the basis of the naturalized daily mean flow at Redbrook. The twin criteria were that the event should span successive days on which the flow was less than 17.4 cumecs (1500 Mℓ/day) and that, for at least one day within the period, the flow should fall below 14.0 cumecs (1210 Mℓ/day). The day on which the Redbrook natural flow finally rose above 17.4 cumecs was also included in each event. [The 17.4 cumecs is an arbitrary threshold; in a dry weather recession the Redbrook natural flow takes about 7 days to fall from 17.4 cumecs to 14.0 cumecs. Regulation support is generally required for natural flows below about 15.3 cumecs (1323 Mℓ/day), if the full licenced abstractions are to be taken.]

On this basis a total of 30 discrete events were identified, ranging from several 5-day events to a 123-day event commencing 26 May 1976. For the 675 days making up these events, daily mean flows were extracted from the Surface Water Archive for the stations listed in Table 4. In doing this, an appropriate 1, 2 or 3-day lag was allowed. Thus data for Belmont were taken one day earlier (than Redbrook) and labelled BM1. Similarly, data for Butts Bridge were taken two days earlier (than Redbrook) and labelled BB2. For stations such as Cilmery, data were extracted at two lag times (CM2 and CM3) because the low flow travel time was assessed to be about 2½ days (see Table 4).

Data for Kentchurch were used in lieu of Grosmont for dates prior to 1 May 1972. Five other stations considered in the analysis (Cilmery, Disserth, Three Cocks, Yarkhill and Tafolog) have incomplete records for 1970-79 and these missing values affected half of the 30 low flow events analysed. This meant that some of the 675 days had to be excluded at certain stages of the regression analysis. However, using the sophisticated weighting facilities available in GLIM (Ref.9) it was possible to make a minimum of exclusions while retaining even-handedness.

A step-by-step approach was adopted in the development of a flow forecasting method. First, a model was derived to forecast Redbrook 1 day ahead from tributary stations. Then models were sought for forecasting these tributary stations from stations further upstream.

6.2 1-day ahead forecast for Redbrook

Various model structures were considered. The best 3-variable additive model was:

$$RBO = 1.893 + 1.082\ BM1 + 1.056 LG1 + 8.133\ TF1$$
$$\left[r^2 = 85.6\%,\ \text{rmse} = 2.00\ \text{cumecs}\right] \qquad -(7)$$

Here r^2 denotes the percentage of variation in RBO explained by the regression, and rmse is the root mean square error. Additional variables were not significant.

The constant term in the regression is conceptually unappealing. Suppressing the constant yielded:

$$RBO = 1.114\ BM1 + 1.688\ LG1 + 8.494\ TF1\ \left[rmse = 2.10\ cumecs\right] \qquad -(8)$$

However, the residuals from these equations were unevenly distributed, higher flows tending to have larger forecast errors. A multiplicative model was therefore fitted by applying logarithmic transforms to the variables. This yielded:

$$RBO = 4.918\ BM1^{0.475}\ GM1^{0.305}\ LG1^{0.120}\quad \left[R^2 = 88.1\%,\ fse = 1.17\right] \qquad -(9)$$

Here R^2 denotes the percentage of variation in $\ell n(RBO)$ explained by the regression and fse is the factorial standard error in estimating RBO.

The relative merits of Eqns. 8 and 9 are difficult to assess either statistically or conceptually. An additive model is perhaps more obvious; the coefficients in Eqn.8 can be interpreted as weights for representing the ungauged area to Redbrook. It is natural to think of the flows at Belmont, Lugwardine and Tafolog - together with a representation of the ungauged flow- summing to the Redbrook flow (after appropriate time lags). However, where a low flow recovery occurs on one tributary in isolation, one might expect its effect at Redbrook to be attenuated somewhat. The form of Eqn. 8 cannot represent such interactions. In contrast, the multiplicative form of Eqn.9 gives greater emphasis to low flow recoveries that affect Belmont, Lugwardine and Grosmont in unison.

Forecasts made using either equation will be error-prone. For example, at times when the Redbrook natural flow is close to 14.0 cumecs, Eqn.9 has a standard error very similar to Eqn.8. Only two out of three forecasts will be within 2.1 cumecs of the correct value. This performance is, in itself, quite useless. However, the residual errors from Eqns. 8 and 9 exhibit considerable serial correlation and there is therefore potential for improving forecasts by some sort of real time correction procedure. (See Ref.10)

6.3 1-day ahead forecast for Belmont

Several models were developed for forecasting Belmont flows 1 day ahead. A multiplicative model was again preferred:

$$BM1 = 3.636\ EW2^{0.610}\ TAC2^{0.276} \quad [R^2 = 82.2\%,\ fse = 1.29] \qquad -(10)$$

A simpler equation, not requiring Three Cocks, is:

$$BM1 = 2.046\ EW2^{0.763} \quad [R^2 = 78.3\%,\ fse = 1.33] \qquad -(11)$$

The greater uncertainty in 1-day ahead forecasts for Belmont than for Redbrook (compare fse's for Equations 9 and 10) reflects the proportionally larger ungauged area to Belmont than to Redbrook. (Whereas Belmont, Lugwardine and Grosmont gauge 82% of the area to Redbrook, only 65% of the area to Belmont is gauged by Erwood and Three Cocks).

6.4 ½-day ahead forecast for Erwood

It was not practicable to develop a 1-day ahead model for Erwood: travel times from Cilmery and Disserth are only about 6 and 8 hours. However, by defining:

$$CM2.5 = \sqrt{CM2.\ CM3} \qquad \text{and} \qquad DS2.5 = \sqrt{DS2.\ DS3}$$

a model was derived for forecasting half a day ahead:

$$EW2 = 4.137\ (CM2.5)^{0.417}(DS2.5)^{0.330}(DF3)^{0.237} \qquad -(12)$$
$$[R^2 = 91.1\%,\ fse = 1.23]$$

6.5 2-day ahead forecast for Lugwardine

Several models were developed for forecasting Lugwardine flows. The preferred model:

$$LG1 = 4.238\ (TM3.\ BN3)^{0.615} \quad [R^2 = 78\%,\ fse = 1.25] \qquad -(13)$$

provides a 2-day ahead forecast.

6.6 ½ -day ahead forecast for Grosmont

The degree of correspondence between Tafolog and Grosmont low flows was relatively low, as discussed in Section 3.5. The model:

$$GM1 = 1.112\ (TF1.5)^{0.649} \qquad [R^2 = 45.1\%,\ fse = 1.32] \qquad -(14)$$

provides a half-day ahead forecast. Neither the multiplier nor the exponent inspires confidence. For example, substituting Q90 for Tafolog (0.136 cumecs) yields 0.305 cumecs for Grosmont - which is rarer than Q99. The model cannot therefore be recommended.

6.7 Composite forecast for Redbrook

Combining the models from of Eqns. 9, 11, 12 and 13, and estimating GM1 by a linear exponential recession ($GM1 = 0.98^2\ GM3$), yields:

$$RBO = 13.57\ DF3^{0.086} DS2.5^{0.119} CM2.5^{0.151} TM3^{0.074} BN3^{0.074} GM3^{0.305} \qquad -(15)$$

Re-fitting the model indicated that not all these variables are significant. A strip-down regression analysis yielded:

$$RBO = 17.37\ CM2.5^{0.133} DF3^{0.139} TM3^{0.391} GM3^{0.270} \qquad [R^2 = 73.0\%,\ fse = 1.26] \qquad -(16)$$

However, adoption of Eqn. 15 or 16 to forecast Redbrook flows 2½ days ahead would preclude the possibility of using data from Erwood, Belmont and Lugwardine to "correct" forecasts by reference to recent errors at these intermediate stations.

7. IMPLEMENTATION PROBLEMS

There is a wide gap between what is desirable and what can be readily achieved. The two basic difficulties are the lack of automatic data entry and the drawbacks of a forecasting method based on daily mean flows.

The Wye basin is large and its flow behaviour complex. The gauging network and telemetry system offer much relevant information but the absence of automatic data entry severely limits its use. How can 15-minute telemetered river level data for many stations be processed into daily mean flows in near real-time without automatic data entry to a programmable computer?

The predilection for daily mean flows has strengths and weaknesses. A daily analysis is in accord with present operational arrangements which provide for only once daily variations in the Caban Coch release rate. (See Section 5.1). Also, the licence conditions governing abstractions at Lydbrook and Monmouth - notably, the residual flow at Redbrook - are specified as daily means. There is the related asset that working with 24-hour integrated values provides a degree of smoothing and eliminates diurnal variations (arising from water use).

However, the limitations of a daily analysis are severe. Forecasting changes of flow two or three days ahead warrants a finer data interval; in particular, the Section 6 analysis has represented low flow rise travel times very coarsely.

The regression models of Section 6 are coarse in concept as well as in detail. For example, it is possible that bankside storage (alternate influent/effluent behaviour in some river reaches) has an important effect on the propagation of low flow rises. To develop a physically realistic model for low flow forecasting is, of course, no easy matter; but regressions based on daily mean flow data fall a long way short of this ideal.

One possibility considered was to convert the Section 6 equations for use with instantaneous flow values. Unfortunately it is not at all obvious how this should be done. Trials carried out using 3-hourly river level data for a low flow recovery "event" in September 1981 were not encouraging. A particular defect noted was that the forecast flows at Redbrook jumped about from one time step to the next.

Faced with the above difficulties it was decided to reject the Section 6 regression equations in favour of an alternative forecasting method based largely on recession extrapolation. The method rests on the low flow analyses of Section 3, the travel-time estimates of Section 4, and a novel baseflow separation technique.

8. A FORECASTING METHOD BASED ON RECESSION EXTRAPOLATION

8.1 Basic Method

The principle of the method is illustrated for forecasting Erwood instantaneous flows 15 hours ahead. There are two steps.

First, the current flow at Erwood is compared with earlier flows at Ddol Farm, Disserth and Cilmery to assess the contribution from the ungauged area. (See row 4 of Table 1).

$$UG_{now} = EW_{now} - (DF_{now-12} + DS_{now-9} + CM_{now-6}) \qquad -(17)$$

Here EW_{now} denotes the current Erwood naturalized flow, UG_{now} is the estimate of the ungauged contribution, DF_{now-12} is the Ddol Farm flow 12 hours earlier, etc. (Twelve hours is the estimated Ddol Farm to Erwood travel time, taken from Table 4(a).)

Second, a forecast of Erwood naturalized flow is calculated from:

$$EW_{now+15} = UG_{now} \cdot RF_{UG}^{15/24} + DF_{now} \cdot RF_{DF}^{3/24} + DS_{now} \cdot RF_{DS}^{6/24} + CM_{now} \cdot RF_{CM}^{9/24} \qquad -(18)$$

Here the RF's are daily recession factors taken from the master recession analysis*. The basis of the forecast is the budget:

$$EW_{now+15} = UG_{now+15} + DF_{now+3} + DS_{now+6} + CM_{now+9} \qquad -(19)$$

The 15-hour ahead forecast for Erwood is subsequently used to calculate a 42-hour ahead forecast for Belmont which in turn contributes to a 72-hour ahead forecast for Redbrook.

---

* The identity $RF = e^{-\alpha} = 2^{-1/h90}$ allows calculation of the daily recession factor from the recession half-life. (See Section 3.3.) For the ungauged areas, h90 is estimated from BFI (Equation 6) which in turn is estimated from the geologyu of the area. (See also Table 2.)

8.2 Treatment of low flow recoveries

The above method is appropriate when flows are in dry weather recession. However, if a flow recovery has occurred at (say) Cilmery, the baseflow component of the recovery is established by the hydrograph separation outlined in Fig.5, for which a 3-hour data interval is suggested. It is then the baseflow component that is used in the two-step procedure described in Section 8.1.

The forecasts produced by this technique should in general be rather conservative: short-term runoff is disregarded (one pessimism) and the flow is assumed to decay at the master dry weather recession rate (another pessimism). It is suggested that this cautiousness is entirely appropriate to the operational requirement to limit over-releasing without risking shortfalls in the residual flow at Redbrook.

8.3 Trials

Preliminary trials with the technique were made for "snapshots" during four low flow recovery events in summer 1981. An example is given in Appendix 2. It is considered that the method shows promise and merits further trials, either in a follow-up study or through cautious implementation. It is undoubtedly a method capable of further refinement.

9 IMPLEMENTATION

A listing of the FORTRAN program used to test the method is given in Appendix 1. The program is interactive and requests entry of a minimum of river level data. The method is not invalidated by missing data but it is recommended that stations are not gratuitously omitted.

Although the forecasting method is relatively simple, the overall program is quite lengthy. Some translation and modification would be necessary before the program could be run on the authority's PET microcomputer.

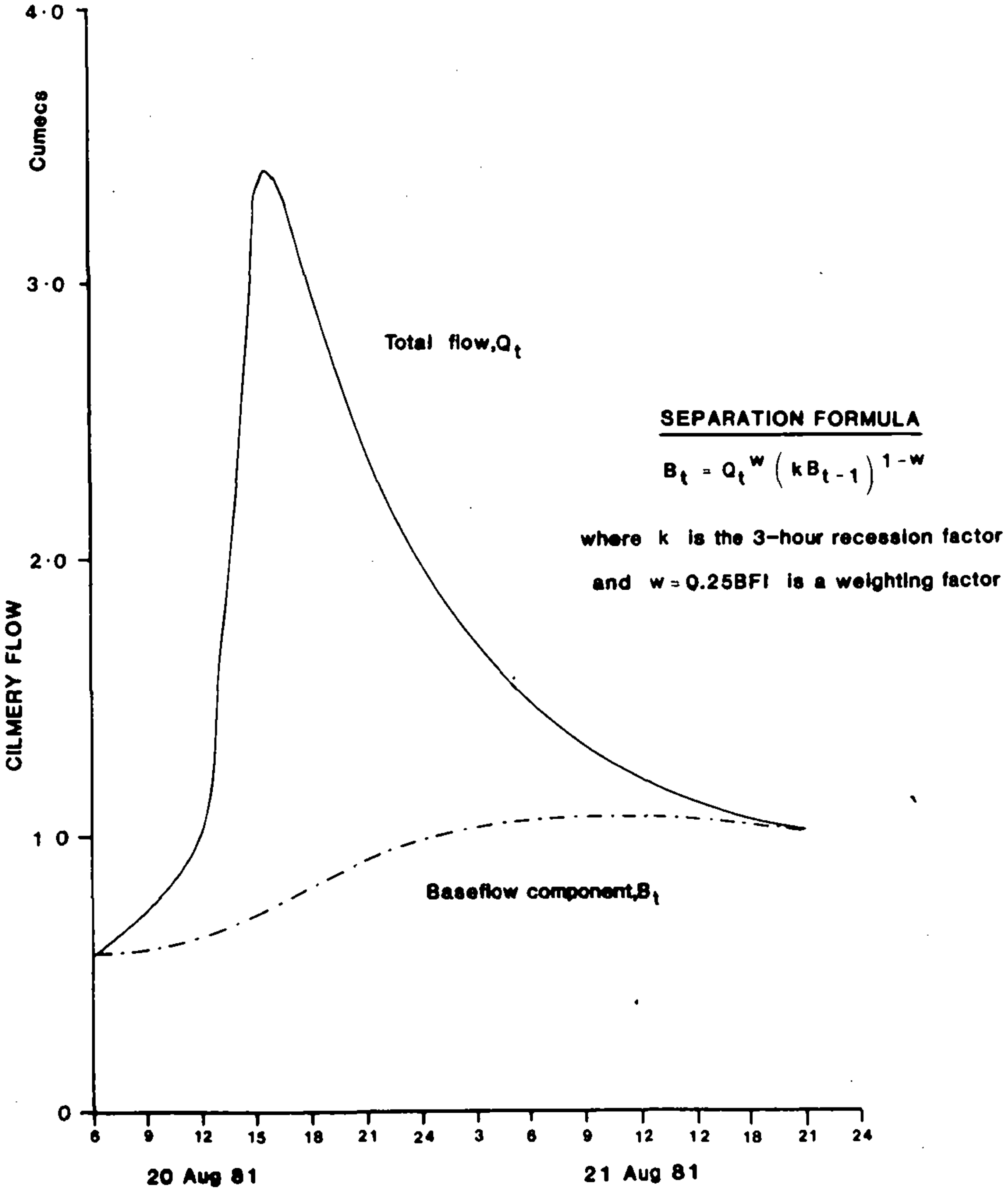


Fig 5. Baseflow separation technique - example for short-lived flow recovery at Cilmery.

10. SUMMARY AND RECOMMENDATIONS

(i) The study has assessed the low flow behaviour of the Wye through various standard and semi-standard analyses.

(ii) Regression models based on daily mean flow data have been developed for forecasting Redbrook flows up to 2 days ahead. However, implementation of the approach has practical difficulties and is not recommended.

(iii) An alternative forecasting method based on recession extrapolation has been developed. A feature of the method is the treatment of low flow recoveries by a novel baseflow separation technique, to ensure that forecasts are not unduly optimistic.

(iv) It is recommended that the forecasting method - for which a FORTRAN program is appended - be given further trials, either in a follow-up study or through cautious implementation.

(v) If the recession approach proves workable in practice - which appears likely - the following refinements are suggested:

- a more objective master recession analysis, allowing nonlinear recessions
- a more detailed study of "low flow rise" travel times, using 3-hourly data
- further study of the baseflow separation technique introduced in Fig. 5.

(vi) Should the recession approach prove to be too cautious, a time series study using 3-hourly flow data would be a further avenue to explore.

(vii) The configuration of the Wye basin is such that the Trothy and Monnow are likely to be a frequent source of initial low flow recoveries at Redbrook. Because of the very short travel times from Mitchel Troy and Grosmont, rainfall-based forecasts of runoff from these catchments are desirable.

(viii) In view of the significance of the Monnow, it is desirable that the low flow behaviour at Tafolog and Grosmont be reconciled by a detailed scrutiny of river level data and rating curves.

(ix) Finally, it is suggested that the forecasting method presented in Section 8 can be used to forecast release requirements throughout a regulation period.

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APPENDIX 1:   PROGRAM LISTING

Listing of interactive program (FORTRAN) for forecasting Redbrook naturalised flow 72 hours ahead.

```
10C   ***   PROGRAM TO TEST IMPLEMENTATION OF RECESSION-BASED FORECASTS   ***
20       COMMON/ONE/RECFAC,RFUG,LAG,SNAME
30       COMMON/TWO/QPAST,QNOW,QFUT,IREF
40       COMMON/THREE/CCREL,ABSCOM
50       DIMENSION CCREL(48),ABSCOM(48)
60       DIMENSION QPAST(16),QNOW(16),QFUT(16),IREF(16)
70       DIMENSION RECFAC(16),RFUG(16),LAG(16)
80       CHARACTER SNAME*8(16)
90C
100       CALL NENTER(CCREL,ABSCOM)
110C
120       IREF(16)=0
130C
140C   ***   NOTE WHICH STATIONS AVAILABLE   ***
150       WRITE(6,961)
160  961 FORMAT('OWHICH STATIONS AVAILABLE ?'/
170      &' ENTER 0 FOR "NO"'/'          1 FOR "YES"')
180       DO 20 IS=1,15
190   15 CONTINUE
200       WRITE(6,962)SNAME(IS)
210  962 FORMAT(' ',A8,' ?')
220       READ(5,951)IREF(IS)
230  951 FORMAT()
240       WRITE(6,960)IREF(IS)
250  960 FORMAT(I6)
260       IF (IREF(IS).LT.0.OR.IREF(IS).GT.1) GOTO 15
270   20 CONTINUE
280C
290C   ***   ENTER RELEVANT RIVER LEVEL DATA   ***
300       DO 30 IS=1,15
310   30 IF(IREF(IS).EQ.1) CALL ENTER(IS)
320C
330C   ***   EXECUTE MODELS TO BUILD UP FORECAST OF REDBROOK FLOW   ***
340       WRITE(6,963)
350  963 FORMAT('1      STATION       UGNOW   QNOW      QFUT       QUG',
360      &'        Q1       Q2        Q3       Q4      LEAD TIME'//)
370       CALL MODEL(4,1,2,3,0)
380       CALL MODEL(6,-4,5,0,0)
390       CALL MODEL(8,7,0,0,0)
400       CALL MODEL(10,-8,9,0,0)
410       CALL MODEL(12,11,0,0,0)
420       CALL MODEL(14,13,0,0,0)
430       CALL MODEL(15,-6,-10,-12,-14)
440       WRITE(6,964)QNOW(15),QFUT(15)
450  964 FORMAT('OREDBROOK NATURALIZED FLOW - CURRENT',F8.3/
460      &'                  - 72-HOUR AHEAD FORECAST',F8.3//)
470C
480       STOP
490       END
```

```
500C
510       SUBROUTINE NENTER
520C   ***    ENTER RELEASE AND ABSTRACTION DATA FOR FLOW NATURALIZATION    ***
530       COMMON/THREE/CCREL,ABSCOM
540       DIMENSION CCREL(48),ABSCOM(48)
550C
560       WRITE(6,970)
570   970 FORMAT('1ENTER CABAN COCH RELEASE AND LYDBROOK/MONMOUTH COMBINED A
580      &BSTRACTION')
590       READ(5,951)CC,AB
600   951 FORMAT()
610       WRITE(6,960)CC,AB
620   960 FORMAT(2F8.3)
630       DO 200 I=1,48
640       CCREL(I)=CC
650       ABSCOM(I)=AB
660   200 CONTINUE
670       RETURN
680       END
690C
700       SUBROUTINE ENTER(IS)
710C   ***    DATA ENTRY SUBROUTINE    ***
720       COMMON/ONE/RECFAC,RFUG,LAG,SNAME
730       COMMON/TWO/QPAST,QNOW,QFUT,IREF
740       COMMON/THREE/CCREL,ABSCOM
750       DIMENSION CCREL(48),ABSCOM(48)
760       DIMENSION QPAST(16),QNOW(16),QFUT(16),IREF(16)
770       DIMENSION RECFAC(16),RFUG(16),LAG(16)
780       CHARACTER SNAME*8(16)
790       DIMENSION H(48),Q(48)
800C
810       LI=LAG(IS)+1
820C
830C   ***    PROMPT ENTRY OF RIVER LEVEL DATA    ***
840       WRITE(6,971)SNAME(IS)
850   971 FORMAT('0DATA FOR ',A8,' - ANY RECOVERY ?'/
860      &' ENTER 0 FOR "NO"'/'        1 FOR "YES"')
870       READ(5,951)IR
880   951 FORMAT()
890       WRITE(6,960)IR
900   960 FORMAT(I6)
910       IF (IR.EQ.0) GOTO 231
920C
930C   ***    PROMPT ENTRY OF SEQUENCE OF RIVER LEVEL DATA    ***
940       WRITE(6,973)
950   973 FORMAT(' ENTER 3-HOURLY RIVER LEVELS (MM), STARTING WITH CURRENT
960      &VALUE AND'/' WORKING BACK TO POINT WHERE RECESSION BROKEN.',
970      &' TERMINATE WITH 0.')
```

```
980       N=0
990   225 CONTINUE
1000      READ(5,951)LEVEL
1010      WRITE(6,960)LEVEL
1020      IF (LEVEL.EQ.0) GOTO 227
1030      N=N+1
1040      H(N)=0.001*LEVEL
1050      GOTO 225
1060  227 CONTINUE
1070      DO 230 I=1,N
1080      CALL RATING(H,Q,I,IS)
1090      IF (IS.EQ.4) Q(I)=Q(I)-CCREL(I+5)
1100      IF (IS.EQ.6) Q(I)=Q(I)-CCREL(I+14)
1110      IF (IS.EQ.15) Q(I)=Q(I)-CCREL(I+24)+ABSCOM(I+2)
1120  230 CONTINUE
1130C
1140C   ***   SEPARATE BASEFLOW UNDER FLOW RECOVERY   ***
1150      CALL BFSEP(Q,N,IS)
1160      IF (N.LT.LI) GOTO 233
1170      GOTO 235
1180C
1190  231 CONTINUE
1200C   ***   NO RECOVERY   ***
1210      WRITE(6,975)
1220  975 FORMAT(' ENTER CURRENT RIVER LEVEL (MM)')
1230      READ(5,951)LEVEL
1240      WRITE(6,960)LEVEL
1250      H(1)=0.001*LEVEL
1260      CALL RATING(H,Q,1,IS)
1270      IF (IS.EQ.4) Q(1)=Q(1)-CCREL(6)
1280      IF (IS.EQ.6) Q(1)=Q(1)-CCREL(15)
1290      IF (IS.EQ.15) Q(1)=Q(1)-CCREL(25)+ABSCOM(3)
1300      N=1
1310  233 CONTINUE
1320      IF (IS.EQ.15) GOTO 235
1330      WRITE(6,976)LAG(IS)*3.0
1340  976 FORMAT(' ENTER RIVER LEVEL (MM)',F6.2,' HOURS AGO')

1350      READ(5,951)LEVEL
1360      WRITE(6,960)LEVEL
1370      H(LI)=0.001*LEVEL
1380      CALL RATING(H,Q,LI,IS)
1390      IF (IS.EQ.4) Q(LI)=Q(LI)-CCREL(LI+5)
1400      IF (IS.EQ.6) Q(LI)=Q(LI)-CCREL(LI+15)
1410      IF (IS.EQ.15) Q(LI)=Q(LI)-CCREL(LI+24)+ABSCOM(LI+2)
1420  235 CONTINUE
1430C
1440C   ***   REGISTER RELEVANT FLOWS   ***
1450      QPAST(IS)=Q(LI)
1460      QNOW(IS)=Q(1)
1470      RETURN
1480      END
1490C
1500      SUBROUTINE RATING(H,Q,I,IS)
1510      DIMENSION H(48),Q(48)
1520      DIMENSION A(15),B(15),C(15),HMAX(15),AA(15),BB(15),CC(15)
1530      DATA A/7.2839,43.2485,32.56812,7.76252,0.0,28.9059,16.21898,
1540     &15.50091,15.77116,11.79166,0.0,0.0,13.59961,32.00905,22.57937/
1550      DATA B/1.4453,2.7915,2.49329,1.19497,0.0,1.64048,2.52633,
1560     &3.05259,3.71845,1.28414,0.0,0.0,2.24447,2.29856,2.08967/
```

```
1570       DATA C/-0.1,0.0,0.0,0.2,0.0,0.2,0.0,
1580      &0.21,0.03,-0.14,0.0,0.0,-0.02,-0.1,0.4436/
1590       DATA HMAX/0.407,0.603,0.655,0.663,0.0,7.000,0.776,
1600      &0.542,2.000,1.539,0.0,0.0,0.371,0.821,0.456/
1610       DATA AA/27.0676,23.0656,30.057,11.07597,0.0,0.0,17.6654,
1620      &14.5992,0.0,4.32516,0.0,0.0,61.64436,27.6455,20.67871/
1630       DATA BB/3.3590,1.5466,1.61508,3.109,0.0,0.0,2.79967,
1640      &1.3215,0.0,2.556,0.0,0.0,4.1788,1.53573,1.84335/
1650       DATA CC/0.0,0.0,-0.03,0.16,0.0,0.0,0.0,
1660      &0.0,0.0,0.2134,0.0,0.0,0.0,-0.1656,0.4436/
1670C
1680       Q(I)=0.0
1690       IF (H(I)+C(IS).LE.0.0) GOTO 300
1700       Q(I)=A(IS)*(H(I)+C(IS))**B(IS)
1710       IF (H(I).LE.HMAX(IS)) GOTO 300
1720       Q(I)=AA(IS)*(H(I)+CC(IS))**BB(IS)
1730   300 CONTINUE
1740       RETURN
1750       END
1760C
1770       SUBROUTINE BFSEP(Q,N,IS)
1780C   ***   BASEFLOW SEPARATION SUBROUTINE   ***
1790       COMMON/ONE/RECFAC,RFUG,LAG,SNAME
1800       DIMENSION RECFAC(16),RFUG(16),LAG(16)
1810       CHARACTER SNAME*8(16)
1820       DIMENSION Q(48)
1830       DIMENSION BFI(15)
1840       DATA BFI/0.38,0.39,0.42,0.43,0.60,0.46,0.69,
1850      &0.68,0.62,0.64,0.54,0.55,0.54,0.54,0.57/
1860       DATA W/0.5/
1870C
1880       DO 400 II=2,N
1890       I=N-II+1
1900       BF=(Q(I+1)*RECFAC(IS))**(1.0-W*BFI(IS))*Q(I)**(W*BFI(IS))
1910       IF (BF.LT.Q(I)) Q(I)=BF
1920   400 CONTINUE
1930       RETURN
1940       END
1950C
1960       SUBROUTINE MODEL(IS,I1,I2,I3,I4)
1970C   ***   FORECAST FLOW AT STATION 'IS' FROM UPSTREAM DATA   ***
1980       COMMON/ONE/RECFAC,RFUG,LAG,SNAME
1990       COMMON/TWO/QPAST,QNOW,QFUT,IREF
2000       DIMENSION QPAST(16),QNOW(16),QFUT(16),IREF(16)
2010       DIMENSION RECFAC(16),RFUG(16),LAG(16)
2020       CHARACTER SNAME*8(16)
2030       DIMENSION HTR(16),DFC(16)
2040       DIMENSION I(4),J(4),Q(4)
2050       DATA HTR/69.0,66.0,63.0,57.0,51.0,30.0,72.0,
2060      &51.0,72.0,27.0,48.0,27.0,15.0,9.0,0.0,0.0/
2070C
2080       I(1)=I1
2090       I(2)=I2
2100       I(3)=I3
2110       I(4)=I4
2120C
2130       DO 480 II=1,16
2140   480 DFC(II)=(72.0-HTR(II))/24.0
2150C
2160C   ***   CALCULATE CONTRIBUTION FROM UNGAUGED AREA AT TIME NOW   ***
2170       UGNOW=QNOW(IS)
```

```
      DO 490 K=1,4
      CALL FIDDLY(I,J,K)
      UGNOW=UGNOW-IREF(I(K))*QPAST(I(K))
  490 CONTINUE
C
C    ***   FORECAST FLOW AT LEAD TIME COMPATIBLE   ***
C    ***   WITH 72-HOUR FORECAST FOR REDBROOK.     ***
      QUG=UGNOW*RFUG(IS)**DFC(IS)
      QFUT(IS)=QUG
      DO 495 K=1,4
      Q(K)=J(K)*IREF(I(K))*QNOW(I(K))*RECFAC(I(K))**DFC(I(K))+(1-J(K))*
     &QFUT(I(K))
      QFUT(IS)=QFUT(IS)+Q(K)
  495 CONTINUE
C
C    ***   TABULATE FORECAST AND ITS MAKE-UP   ***
      WRITE(6,981)IS,SNAME(IS),UGNOW,QNOW(IS),QFUT(IS),QUG,(Q(K),K=1,4),
     &24.0*DFC(IS)
  981 FORMAT(I4,2X,A8,2X,2F8.3,2X,F6.3,2X,5F6.3,2X,F8.1)
      QREC=QNOW(IS)*RECFAC(IS)**DFC(IS)
      IF (QREC.LE.QFUT(IS)) GOTO 496
      QFUT(IS)=QREC
      WRITE(6,982)QFUT(IS)
  982 FORMAT(' LIMITED BY MASTER RECESSION TO',F11.3)
  496 CONTINUE
C
      RETURN
      END
C
      SUBROUTINE FIDDLY(I,J,K)
C    ***   A FIDDLY BIT OF CODE !   ***
C    ***   IF I<0 SET J=0 TO USE 'QFUT' RATHER   ***
C    ***   THAN RECESSED 'QNOW' IN MODEL.        ***
C    ***   I=0 IS CODE TO INVOKE DEFAULT TO EXCLUDE STATION   ***
      DIMENSION I(4),J(4)
      J(K)=1
      IF (I(K).GT.0) GOTO 499
      IF (I(K).EQ.0) GOTO 497
      I(K)=-I(K)
      J(K)=0
      RETURN
  497 CONTINUE
      I(K)=16
  499 CONTINUE
      RETURN
      END
C
      BLOCK DATA
      COMMON/ONE/RECFAC,RFUG,LAG,SNAME
      DIMENSION RECFAC(16),RFUG(16),LAG(16)
      CHARACTER SNAME*8(16)
      DATA RECFAC/0.939,0.950,0.946,0.950,0.978,0.959,0.965,
     &0.981,0.931,0.982,0.972,0.973,0.972,0.979,0.966,0.0/
      DATA RFUG/0.0,0.0,0.0,0.947,0.0,0.972,0.0,
     &0.983,0.0,0.983,0.0,0.972,0.0,0.972,0.972,0.0/
      DATA LAG/4,3,2,9,7,10,7,
     &8,15,9,7,9,2,3,0,0/
      DATA SNAME/'DDOL FAR','DISSERTH','CILMERY ',
     &'ERWOOD  ','THREE CO','BELMONT ','BYTON   ',
     &'BUTTS BR','TITLEY M','LUGWARDI','BISHOPS ',
     &'YARKHILL','TAFOLOG ','GROSMONT','REDBROOK','DEFAULT '/
      END
```

APPENDIX 2: SAMPLE RUN

Sample run of program for "now" of 12.00 on 20 Aug 1981

```
ENTER CABAN COCH RELEASE AND LYDBROOK/MONMOUTH COMBINED ABSTRACTION
  1.771    0.331

WHICH STATIONS AVAILABLE ?
ENTER 0 FOR "NO"
      1 FOR "YES"
DDOL FAR ?
    1
DISSERTH ?
    1
CILMERY  ?
    1
ERWOOD   ?
    1
THREE CO ?
    0
BELMONT  ?
    1
BYTON    ?
    1
BUTTS BR ?
    1
TITLEY M ?
    1
LUGWARDI ?
    1
BISHOPS  ?
    0
YARKHILL ?
    0
TAFOLOG  ?
    1
GROSMONT ?
    1
REDBROOK ?
    1

DATA FOR DDOL FAR - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    1
ENTER 3-HOURLY RIVER LEVELS (MM), STARTING WITH CURRENT VALUE AND
WORKING BACK TO POINT WHERE RECESSION BROKEN. TERMINATE WITH 0.
  650
  750
  330
  270
  250
  240
    0
```

```
DATA FOR DISSERTH - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    0
ENTER CURRENT RIVER LEVEL (MM)
  150
ENTER RIVER LEVEL (MM)  9.00 HOURS AGO
  150

DATA FOR CILMERY  - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    1
ENTER 3-HOURLY RIVER LEVELS (MM), STARTING WITH CURRENT VALUE AND
WORKING BACK TO POINT WHERE RECESSION BROKEN. TERMINATE WITH 0.
  250
  220
  200
    0

DATA FOR ERWOOD   - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    1
ENTER 3-HOURLY RIVER LEVELS (MM), STARTING WITH CURRENT VALUE AND
WORKING BACK TO POINT WHERE RECESSION BROKEN. TERMINATE WITH 0.
  450
  450
  450
  440
  400
    0
ENTER RIVER LEVEL (MM) 27.00 HOURS AGO
  390

DATA FOR BELMONT  - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    0
ENTER CURRENT RIVER LEVEL (MM)
  190
ENTER RIVER LEVEL (MM) 30.00 HOURS AGO
  210

DATA FOR BYTON    - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    0
ENTER CURRENT RIVER LEVEL (MM)
  320
ENTER RIVER LEVEL (MM) 21.00 HOURS AGO
  320

DATA FOR BUTTS BR - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    0
ENTER CURRENT RIVER LEVEL (MM)
  250
ENTER RIVER LEVEL (MM) 24.00 HOURS AGO
  250

DATA FOR TITLEY M - ANY RECOVERY ?
ENTER 0 FOR "NO"
      1 FOR "YES"
    0
```

```
ENTER CURRENT RIVER LEVEL (MM)
    80
ENTER RIVER LEVEL (MM) 45.00 HOURS AGO
    80

DATA FOR LUGGWARDI - ANY RECOVERY ?
ENTER 0 FOR "NO"
        1 FOR "YES"
     0
ENTER CURRENT RIVER LEVEL (MM)
   360
ENTER RIVER LEVEL (MM) 27.00 HOURS AGO
   360

DATA FOR TAFOLOG  - ANY RECOVERY ?
ENTER 0 FOR "NO"
        1 FOR "YES"
     0
ENTER CURRENT RIVER LEVEL (MM)
   130
ENTER RIVER LEVEL (MM)  6.00 HOURS AGO
   130

DATA FOR GROSMONT - ANY RECOVERY ?
ENTER 0 FOR "NO"
        1 FOR "YES"
     0
ENTER CURRENT RIVER LEVEL (MM)
   300
ENTER RIVER LEVEL (MM)  9.00 HOURS AGO
   300

DATA FOR REDBROOK - ANY RECOVERY ?
ENTER 0 FOR "NO"
        1 FOR "YES"
     0
ENTER CURRENT RIVER LEVEL (MM)
   340




    STATION      UGNOW   QNOW      QFUT      QUG     Q1      Q2      Q3      Q4       LEAD TI

 4  ERWOOD       1.189   2.406     3.083     1.149   1.097   0.214   0.023   0.         15.0
 6  BELMONT      2.025   4.397     5.010     1.927   3.083   0.      0.      0.         42.0
 8  BUTTS BR     0.537   1.448     1.440     0.529   0.912   0.      0.      0.         21.0
10  LUGGWARDI    0.083   1.887     1.876     0.080   1.440   0.355   0.      0.         45.0
12  YARKHILL     0.      0.        0.        0.      0.      0.      0.      0.         45.0
14  GROSMONT     0.696   0.792     0.736     0.646   0.090   0.      0.      0.         63.0
LIMITED BY MASTER RECESSION TO     0.749
15  REDBROOK     2.675  10.276    10.092     2.457   5.010   1.876   0.      0.749      72.0

REDBROOK NATURALIZED FLOW - CURRENT  10.278
            - 72-HOUR AHEAD FORECAST  10.092
```

Note: Redbrook naturalized flow at 12.00 on 23Aug81 was 16.78 cumecs but the forecast flow of 10.09 cumecs was not exceeded until about 21.00 on 22Aug81.

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The Institute of Hydrology is a component establishment of the Natural Environment Research Council