NRA

National Rivers Authority

Low Flow Estimation in Artificially Influenced Catchments

INTERIM REPORT, DECEMBER 1991

A. Bullock, A. Gustard, K. Irving, and A Young

FLOW REGIMES & ENVIRONMENTAL MANAGEMENT
INSTITUTE OF HYDROLOGY

NRA R&D PROJECT 257

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
OXON., OX10 8BB

Contents

FIGURES AND TABLES

Tables

Figures

Executive summary

The objective of the project is to develop procedures for estimating low flows on catchments where processes are artificially influenced. Specifically, the project is aimed at the production of methods of low flow estimation in ungauged or partially gauged catchments which are subject to (man's) influences. The project is extending the existing MICRO LOW FLOWS software (currently commercially available through the Institute of Hydrology) to produce estimation procedures which account for the following:

1) Surface water influences including abstractions, discharges and reservoirs

2) Bulk effects of groundwater abstraction

3) Land-use change in the form of afforestation/deforestation

The project aims to incorporate best practices currently applied in the NRA regions and to optimise the use of all relevant data archives.

The project commenced in December, 1990 and is due for completion in November 1993. The project leader was the late Dr. John Pirt of NRA Severn-Trent region and is now Mr. Nigel Fawthrop of NRA Anglian region. The project is a component of the Flow Regimes (B02) Topic of the Water Resources (B) Commission. The Institute of Hydrology are the sole research contractors. The project benefits from an Advisory Group comprising three representatives from the NRA, and one representative from the water utilities, universities and consultants.

This Interim Report covers the reporting period of December 1990 to November 1991. Staffing of the project by the Institute is as follows:

Project manager:	Dr Alan Gustard
Project leader:	Dr Andy Bullock
Project staff:	Andrew Young
	Karen Irving
	Ann Sekulin

The Project Investment Appraisal (Appendix 1) lists 7 work items, excluding reporting requirements, which are to be achieved during the three year duration of the project. Good progress has been made with these objectives and the project remains on schedule for completion in November 1993. The following tasks have commencement dates during the period prior to November 1991:

1. A review of NRA procedures for naturalising low flow statistics.

An assessment of the regional methods used for calculating and adjusting low flow statistics was required in order to identify the best procedures which can be modified and incorporated into the MICRO LOW FLOWS software.

A questionnaire was sent to each of the ten regional NRA headquarters requesting information about the procedures used to estimate low flow statistics in gauged and ungauged catchments. The results have been collated and presented in a report entitled "Review of Existing NRA Procedures" (Appendix 2).

2. Simulation of the impact of artificial influences upon low flow statistics.

An assessment of the sensitivity of low flows to the magnitude and seasonality of abstractions has been undertaken.

Adjustments have been made to continuous daily gauged records from ten catchments in England and Wales to represent different abstraction scenarios. The monthly minima and long term flow duration curves have been derived under different scenarios of abstraction. Abstraction scenarios were based on multiples of MAM(7). Assessment of different procedures for adjusting monthly minima and developing generalised relationships for catchments with different flow regimes are well advanced. Preliminary results are presented in a report entitled "Simulating Abstraction Impacts Upon Low Flows" (Appendix 3).

3. Software development for low flow adjustment and residual flow diagram production.

Software developments include procedures for the bulk loading and editing of artificial influence data, their graphical display in relation to the river network, the identification and summation of all occurrences of a particular attribute, and the generation of preliminary residual flow diagrams.

4. Procedures for estimating the impact of ground water abstractions upon low flows.

A review of groundwater modelling techniques appropriate to the study has been initiated. An aquifer simulation model has been calibrated for a catchment and a sensitivity analysis is being carried out to evaluate the sensitivity of the model parameters on the impact of groundwater abstraction upon low flows.

KEY WORDS

Artificial Influences, Low Flow Estimation, Abstraction Licences, Discharge Consents, Gauged and Ungauged Sites, Abstraction scenarios, Mean Monthly Minima, Base Flow Index, Flow Duration Curve, MICRO LOW FLOWS Software, River Network, Residual Flow Diagrams, Groundwater Modelling, Aquifer Simulation Model.

1. INTRODUCTION

This Interim Report covers the period December 1990 to November 1991 for the NRA R & D project 257, Low Flow Estimation in Artificially Influenced Catchments. Included are two completed reports which form part of the project objectives (2.1 and 2.2) and a summary of progress made on the remaining objectives (2.3 and 2.4).

2. PROGRESS WITH OBJECTIVES

2.1. Review of NRA procedures for naturalising low flow statistics

A questionnaire was sent to each of the ten regional NRA headquarters requesting information on procedures currently applied for the calculation of natural low flow statistics and techniques for adjusting statistics and flow data for artificial influences.

The review identified that approximately 4000 requests for low flow statistics have been processed in the year to 31st May 1991, representing approximately 2.5 man years per annum. On a national scale, 45% of the requests are for discharge consent purposes and 40% are required for abstraction licence applications. However, discharge consents account for over 60% of requests in six regions.

The flow statistics that are most commonly calculated from daily gauged flows are the mean flow and flow duration curves from which the 95 percentile flow is calculated. These statistics are calculated by computer programs in all ten NRA regions. Less common statistics (for example, low flow frequency curve and MAM(7)) are calculated using software in some regions and manually in others.

At ungauged sites different methodologies are used to estimate low flow statistics. Four regions use catchment characteristic-based methods. Other regions derive statistics by applying an adjustment factor to nearby gauged data or spot gauging data.

Little consistency exists between the regions regarding making adjustments for artificial influences. Gauged flow data are not routinely naturalised in all regions. Adjustments are made when required and are most commonly applied to gauged flow data where available. Adjusted statistics at ungauged sites are derived from gauged estimates. Two regions make adjustments to the estimated statistics at ungauged sites. The use of regional models is more significant than the estimation of individual statistics in four regions.

The best methods identified in the review will be modified and incorporated into the Micro Low Flows software. Further work is required to identify the detail of estimation procedures (for example, probability distributions fitted to low flow minima) and adjustment methods. This will be achieved by discussion with NRA staff.

2.2. Simulation of the impact of artificial influences upon low flow statistics

Progress with this topic is described in more detail in Appendix 3. This describes a preliminary investigation into the impact of abstracting water from rivers in terms of the sensitivity of low flows to the magnitude and seasonality of the abstractions. The relationship between the degree of impact and catchment geology is further investigated.

Ten catchments are selected with long continuous daily flow records where artificial influences are not significant. The catchments were selected to represent a range of geological conditions. The criterion used to characterise catchment geology is the Base Flow Index (BFI) which is a measure of the amount of water that reaches the river that is derived from stored water sources.

Rates of abstraction are represented by multiples of the mean annual 7-day minimum (MAM(7)) for each catchment derived from the flow record. MAM(7) is the mean of the lowest consecutive 7-day period in each year on record.

Artificial data sets are derived from the ten natural gauged flow records by subtracting multiples of MAM(7) from the time series of daily flow values. Two different cases are investigated; annual abstractions in which all 365 daily flow values are adjusted and summer-only abstractions in which only the April to September flows are adjusted. The multiples of MAM(7) considered for the abstraction scenarios are 0.5, 1.0, 2.0 for annual abstractions; 1.0, 2.0, 4.0 for summer abstractions. In other words, the summer abstractions are double the rate for half the time. The lower, middle and higher multiples represent the same amount of abstracted water, but with a different seasonal distribution.

Three methods are used to calculate the monthly minima simulated under the different abstraction scenarios; adjustment of the gauged daily flow data, adjustment of the long-term mean monthly minima and adjustment of the series of mean monthly minima. Differences in the calculation of the simulated monthly minima increase with the introduction of more zero flows (when the rate of abstraction is greater than the river flow) into the simulated time series.

The seasonality and magnitude of natural monthly minima are investigated prior to the assessment of impact of abstraction upon low flows. Lowest mean monthly minima are higher as a percentage of average flow and occur later in the year in catchments with higher BFI values. For example, the lowest mean monthly minima in catchments with BFI in excess of 0.8 occur most commonly in September or October, with minima of approximately 40% of the mean flow. The lowest mean monthly minima in catchments with BFI less than 0.4 occur most commonly in June or July, with minima below 20% of the mean flow.

Assessment of impact on monthly minima is directed towards variations with the Base Flow Index under different scenarios of abstraction. General relationships are developed which express the impact on monthly minima of different abstraction scenarios across the range of the Base Flow Index. The impact is expressed in terms of the simulated flows as a percentage of the natural flows.

The results provide a basis for understanding the sensitivity of low flows to different abstraction scenarios. In addition, they identify the limits within which estimated mean monthly minimum statistics at ungauged sites can be adjusted by subtraction of multiples of MAM(7) without introducing errors associated with the occurrence of zero flows. The results will enable more appropriate adjustments to be made to natural flow statistics using the MICRO LOW FLOWS software.

2.3. Software development for low flow adjustment and residual flow diagram production

Technical achievements:

1. Attachment of a feature to a river stretch.

A feature (abstraction, discharge, reservoir or spot gauging) can be allocated to a river stretch based on the coordinates of that feature and the array of coordinates representing a river stretch.

2. Graphical presentation of river network with artificial influences

A screen display and hard-copy (colour or monochrome) can be generated which displays the river network with artificial influence features superimposed. An example of the graphical output is illustrated in Figure 1.

3. Creation of attribute tables for each feature

For each feature a table of attributes has been created in which to store data relating to that feature. The attribute headings for abstractions are presented in Table 1; discharge headings are presented in Table 2 and attribute headings for spot gaugings are presented in Table 3. The parameters represent a provisional classification at this stage.

4. Bulk loading of data archives

To load attribute data into the attribute tables, data formats have been specified and the procedure established for bulk loading into Micro Low Flows.

5. Interactive menu-driven editor for features and attributes

A menu-driven editor for accessing, editing and storing feature and attribute data has been developed. The editor allows the addition, deletion and relocation of features and the editing of each attribute that is archived. The editor in the final version may be password protected.

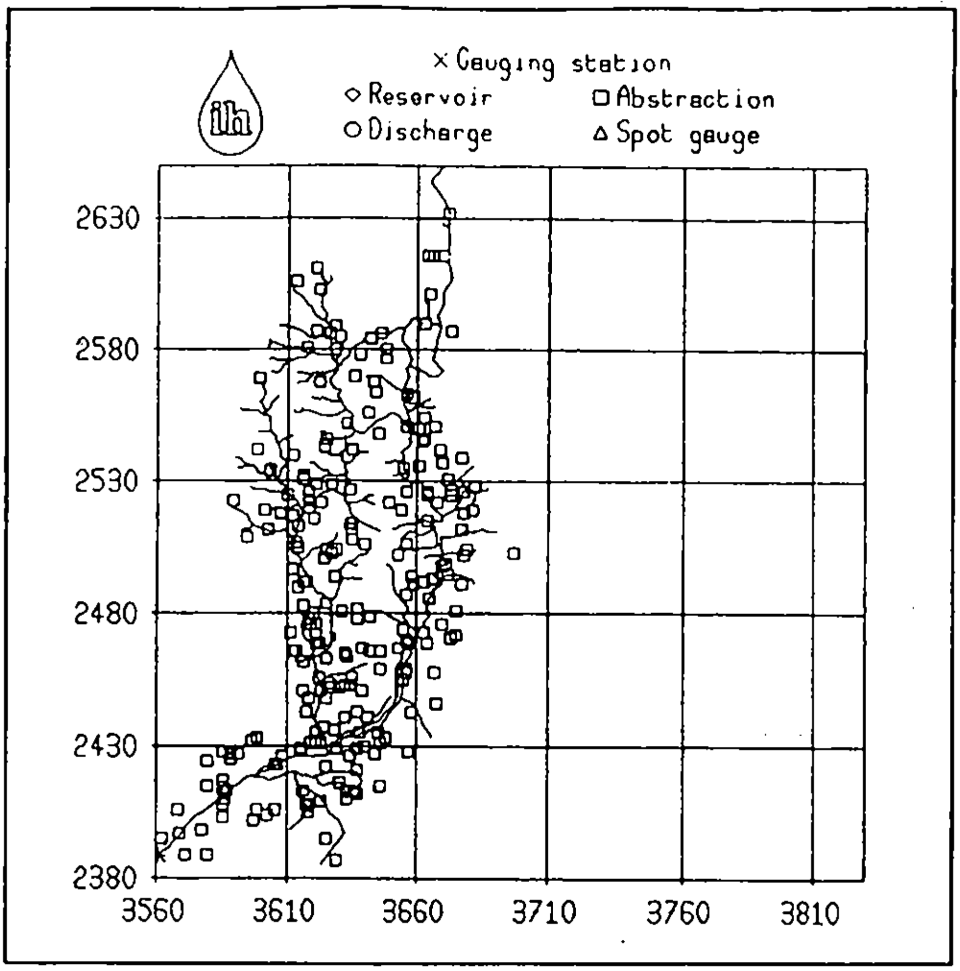


Figure 1 Graphical presentation of the river network with artificial influences superimposed

6. Identification of all upstream features

Software has been developed to identify all occurrences of a particular feature which are located upstream of any selected stretch.

7. Register of all upstream features

Software has been developed to generate a hard-copy listing of all occurrences of a particular feature which are located upstream of any selected stretch.

8. Quantification of all upstream attributes

Software has been developed to sum the values of all upstream occurrences of any artificial influences above any selected point.

Table 1 Attribute headings for surface water abstractions

No	PARAMETERS	DEFINITION	TYPE	FIELD LIMITS
1	NGRE	National Grid Reference Eastings	numerical	min 4
2	NGRN	National Grid Reference Northings	numerical	min 4
3	LISMONTH	start month of licence period	numerical	max 2
4	LIEMONTH	End month of licence period	numerical	max 2
5	LMAXDAY	Maximum daily licensed abstraction	numerical	no limit
6	LMAXHR	Maximum hourly licensed abstraction	numerical	no limit
7	TOTANP1	Total annual licensed for purpose 1	numerical	no limit
8	TOTANP2	Total annual licensed for purpose 2	numerical	no limit
9	TOTANP3	Total annual licensed for purpose 3	numerical	no limit
10	TOTANP4	Total annual licensed for purpose 4	numerical	no limit
11	ANLTOT	Total annual licensed abstraction	numerical	no limit
12	MRF	Minimum required flow	numerical	no limit
13	LINO	National Licence number	character	max 13
14	OPERATOR	Licence holder	character	max 27
15	TYPE	Type of abstraction	character	1
16	SLOCATN	Source location of abstraction	character	max 27
17	LIPERIOD	Period of year to which the licence applies	character	6 or 7
18	PURP1	Abstraction purpose 1	character	2
19	PURP2	Abstraction purpose 2	character	2
20	PURP3	Abstraction purpose 3	character	2
21	PURP4	Abstraction purpose 4	character	2

Table 2 Attribute headings for discharge information

No	PARAMETERS	DEFINITION	TYPE	FIELD LIMITS
1	NGRE	National Grid Reference Eastings	numerical	min 4
2	NGRN	National Grid Reference Northings	numerical	min 4
3	DESDWF	Design dry weather flow	numerical	no limit
4	CAVDAY	Consented average daily flow	numerical	no limit
5	CMAXDAY	Consented maximum daily flow	numerical	no limit
6	VDATE	Consent review date	numerical (mmyy)	4
7	CONNO	Consent number	character	max 27
8	OPERATOR	Licence holder	character	max 27
9	RECEIVER	Receiving river	character	max 21
10	LOCATION	Location of discharge	character	max 24
11	SOURCE	Source of discharge	character	2
12	TYPE	Consent type	character	3
13	CONTCOND	Special operating conditions	character	max 27

Table 3 Attribute headings for spot gauging information

No	PARAMETERS	DEFINITION	TYPE	FIELD LIMITS
1	NGRE	National Grid Reference Eastings	numerical	min 4
2	NGRN	National Grid Reference Northings	numerical	min 4
3	DATE	Date of reading	numerical DDMMYY	6
4	PTILE	Percentile exceedance assigned to the flow reading	numerical	no limit
5	LREF	Local reference text	numerical	no limit
6	RECFL	Recorded flow	numerical	7

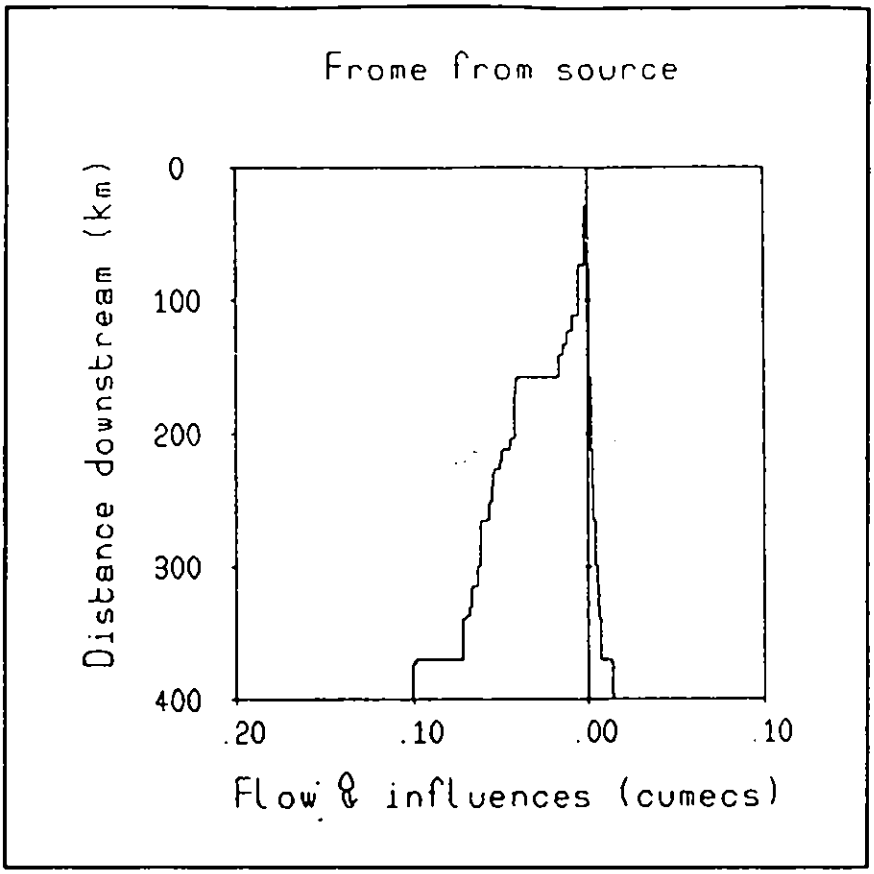


Figure 2   Graphical presentation of the residual flow diagram

9. Preliminary residual flow diagram construction

Software has been developed to select the upstream and downstream reaches to be used in diagram construction by use of the cursor on the screen. Graphical presentation of the diagram has been developed to display both the natural and artificial components of flow on the horizontal axis against distance downstream from the upstream reach on the vertical axis. An example of the graphical output is illustrated in Figure 2.

The natural component of flow is derived from natural low flow estimates of a particular flow statistic (either mean flow, Q95 or MAM(7), but any other (e.g. 30 day minimum flow of 10 year return period) could be selected. The diagram is based on natural flow statistic estimates at the downstream ends of stretches, and for each stretch a cumulative total of distance downstream is calculated. The artificial flow component can be calculated for any of the attributes stored for the features (for example, the dry weather flow discharge from STW or the average flow from STW). For each stretch, the upstream total of the attribute is summed and plotted against the cumulative distance downstream. Both screen display and hard-copy output of the residual flow diagram have been developed.

2.4. Procedures for estimating the impact of ground water abstractions upon low flows

An internal seminar was held at the NERC Wallingford site in September 1991, attended by staff of the Institute of Hydrology and the British Geological Survey. The seminar reviewed approaches, data requirements and application of techniques for modelling the interaction between ground water abstractions and streamflow.

A preliminary literature review of modelling techniques has identified alternative approaches to the problem. Consequently, a pilot model of the Lambourn catchment is being established to identify the parameters controlling the impact of ground water abstraction upon low flows and perform a sensitivity analysis on the parameters. The Lambourn is an unconfined chalk catchment within the Thames basin.

The objectives of the Lambourn study are to:

i) develop suitable techniques for modelling the impact of groundwater abstraction on low flows,

ii) identify the controlling parameters and develop procedures for performing sensitivity analyses of the abstraction impact on low flows with respect to these variables.

The factors influencing catchment choice were:

i) The degree of complexity of catchment hydrogeology. For developing basic techniques a simple catchment hydrogeology is necessary.

ii) Data availability.

The Lambourn catchment was selected as it is a natural, relatively simple unconfined chalk catchment. The catchment formed part of the Thames groundwater scheme thus the catchment is well documented with an abundance of long, high quality data records and a history of prior modelling work.

The numerical model being applied to the Lambourn is the Aquifer Simulation Model (ASM). ASM is a finite difference two dimensional model, with solution of the flow equations based on the Iterative Alternating Direction Implicit (IADI) method. Surface waters are modelled as fixed head water bodies connected to the aquifer via a semi-permeable layer.

The dataset used for the modelling work consists of:

1) Monthly gauged river flows within the catchment at:

1) The Lambourn at Shaw, 1962-89
2) The Lambourn at Welford, 1962-83
3) The Lambourn at East Shefford 1966-83

2) Monthly recharge data over the period 1962-89, estimated using the MORECS procedure & values given within the literature.

3) Storativity & initial Transmissivity maps, derived from observations made during the Thames Groundwater Scheme.

4) Groundwater potential maps derived from observations from wells held on the NRA well archive during the years 1976,1988,1989 & 1990.

5) Identification of all abstraction wells and licensed quantities within the catchment.

The techniques developed in the Lambourn study will be applied to catchments on other hydrogeological units to construct a sensitivity analysis of the impact of abstraction on low flows.

This will form the basis for estimating the impact of groundwater abstraction using MICRO LOW FLOWS. The variables which will be incorporated into the procedure will include:

Hydrogeological unit
Distance of abstraction from the stream
Pumping rate and the seasonality of abstraction.

3. CONCLUSIONS AND RECOMMENDATIONS

1. The importance of the interaction between the seasonal variability of river flows and abstractions has been identified. It is recommended that a provisional technique is developed for estimating the seasonal variability of minimum flows.

2. Good progress has been made with software development and residual flow diagrams can now be estimated and displayed using MICRO FLOWS. It is recommended that the NRA and the Advisory Group agree upon a specification for a standard residual flow diagram. Data formats have been specified for bulk loading of artificial influences data from NRA archives. It is recommended that these are modified if the NRA develop a standardised abstraction and discharge archiving system.

3. The Lambourn catchment in the Thames NRA region has been selected for modelling the influence of groundwater abstraction in low flows. The data set has been collated and preliminary calibration of the model is complete. It is recommended that monthly groundwater pumping data is obtained from

Thames NRA to improve model calibration.

4. It is clear from the questionnaire responses that several diverse methods of low flow estimation and flow adjustment procedures are adopted by NRA regions. It is recommended that further information be obtained from certain regions to supplement the questionnaire returns.

5. It is recommended that the NRA consider standardisation upon the low flow statistics used by the different regions in consent and licensing procedures. Further, it is recommended that NRA regions compare software for the calculation of low flow statistics from gauged flow data, to create a consistent suite of analysis programs that are applied by each region. Particular emphasis should be directed towards the standardisation of algorithms and probability distributions/fitting procedures.

6. It is recommended, in anticipation of the application of techniques relating to reservoir influences upon low flows, that the NRA regions review and update the national reservoir archive (Institute of Hydrology 1987, A study of compensation flows in the UK) to complete missing data and add omitted reservoirs.

7. It is recommended, in anticipation of the application of techniques relating to reservoir influences upon low flows, that the NRA regions identify the principal catchwaters on 1:50,000 maps and classify them using a generic scheme to be developed by the Institute of Hydrology.

8. It is recommended, in advance of the modelling of land use change impacts, that the Institute of Hydrology takes steps to obtain the most appropriate national land use classification in MICRO LOW FLOWS - compatible format.

References

Gustard, A & Bullock, A; 1989; Average and Low Flow Estimation in the South West Region; Wallingford.

Gustard, A & Bullock, A; 1989; Average and Low Flow Estimation in the North West Region; Wallingford.

Institute of Hydrology; 1980; Low Flow Studies Report; Wallingford.

Pirt, J & Douglas, R; 1980; A Study of Low Flows in the Severn and Trent Catchments.

Southern Water Authority, 1979; Report on Low Flow Studies for SWA Area.

Appendix 2 Report: "Review of Existing NRA Procedures"

Estimation of low flows in artificially influenced catchments

REVIEW OF EXISTING NRA PROCEDURES

R & D Commission B Water Resources
Topic B2 Flow Regimes
Project No. B2.3

IRVING, K
&
BULLOCK, A

INSTITUTE OF HYDROLOGY
NOVEMBER 1991

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
Oxon
OX10 8BB

Estimation of low flows in artificially influenced catchments

Review of existing NRA procedures

Contents

Illustrations

Figures

Tables

Preface

This report forms part of a three year contract with the National Rivers Authority to estimate low flow statistics in artificially influenced catchments. It describes the procedures currently applied by the ten NRA regions to calculate natural low flow statistics and to apply adjustments to artificially influenced catchments.

The information was obtained from a questionnaire which was circulated to the ten regional NRA headquarters. The authors wish to acknowledge the following people for their co-operation in completing the questionnaire: Nigel Fawthrop and Angela Wallis (Anglian Regional Head Office), Julie Stanton (Anglian Eastern Area), John East (Anglian Northern Area), David Archer (Northumbria), Meg Owens (North West), Anthony Jones (Thames) Peter Dempsey (Severn Trent), Geoff Burrow (Southern), Robert Grew (South West), John Mosedale (Welsh), Richard Symonds (Wessex), Philip Procter (Yorkshire).

Executive summary

The Institute of Hydrology is currently undertaking a three year contract for the National Rivers Authority to estimate low flows in artificially influenced catchments. The objectives of the project include the estimation of the effects of abstractions and discharges on surface waters, the abstraction of groundwater and the effects of land use change.

This review of current procedures in the ten National Rivers Authority regions identified that approximately 4000 requests for low flow statistics have been processed in the year to 31st May 1991, representing approximately 2.5 man years per annum worked on low flow estimation. On a national scale, 45% of the requests are for discharge consent purposes and 40% are required for abstraction licence applications. However, discharge consents account for over 60% of requests in six regions.

The flow statistics that are calculated at gauged sites in all regions are the mean flow and flow duration curves from which the 95 percentile flow is calculated. These statistics are calculated by computer programs in all regions. Less common statistics (for example, low flow frequency curve and MAM(7)) are calculated using software in some regions and calculated manually in others.

At ungauged sites different methodologies are used to estimate the low flow statistics. Four regions use catchment characteristic-based methods. Other regions derive statistics by applying an adjustment factor to nearby gauged data or spot gauging data.

Little consistency exists between the regions regarding making adjustments for artificial influences. Gauged flow data are not routinely naturalised in all regions. Adjustments are made as required and are most commonly applied to gauged flow data from which adjusted estimates at ungauged sites are derived. Two regions make adjustments to the estimated statistics at ungauged sites. The use of regional models are more significant in four regions where a link between surface and groundwater sources is important instead of estimating individual statistics.

KEY WORDS

National Rivers Authority; Low Flows; Estimation; Gauged & Ungauged Sites; Artificial Influences; Abstraction Licences; Discharge Consents.

1. INTRODUCTION

This report forms part of a three year contract with the National Rivers Authority to estimate low flow statistics in artificially influenced catchments. The aim of the project is to develop and improve methods for adjusting low flow statistics in catchments where artificial influences exist. More specifically, the objectives are to:

1) estimate the effects of artificial surface water influences, in particular, abstractions, discharges and reservoirs

2) account for the effect of groundwater abstractions

3) estimate the impact of land use change on the flow regime (afforestation and deforestation)

These calculations are to be developed and incorporated into Micro Low Flows software.

Existing NRA procedures are reviewed in this report to identify the techniques currently being used to estimate low flow statistics and to assess the extent to which adjustments for artificial influences are made. A questionnaire was circulated to the ten regional National River Authority headquarters.

Section 2 summarises which low flow statistics are used in each region (2.1); whether software or manual calculation techniques are used at gauged sites (2.2) and the techniques applied for estimation at ungauged sites (2.3). Information is provided on the number of low flow estimates that each region has been requested to provide, with a breakdown of requests for different purposes. Based on the estimated time required to provide an estimate, the total time commitment of each region is calculated.

Section 3 reviews the adjustment procedures that are applied to estimates of natural low flows to take account of artificial influences. Adjustment procedures are reviewed for surface water abstractions (3.1); discharges to surface waters (3.2); groundwater abstractions (3.3); reservoirs (3.4) and land use changes (3.5).

Section 4 reviews the hydrological data requirements of abstraction licensing (4.1) and discharge consent procedures (4.2).

Section 5 identifies the extent to which key variables relating to abstractions and consents are held on computer databases by each NRA region.

Section 6 summarises the major conclusions that can be drawn from the information provided by the NRA regions.

2. REGIONAL VARIATIONS IN LOW FLOW STATISTICS AND THEIR COMPUTATION

2.1 Regional flow statistics

Question: Since the formation of the NRA, which flow statistics have been calculated from gauged flow data or estimated at an ungauged site?

Responses to this question are summarised in Table 1. The most commonly estimated statistics are the mean flow and a flow duration curve. Flow duration curves and the 95 percentile exceedance low flow (Q95) are estimated based on 1-day data increments in 9 of the ten regions, although longer increments (7 and over 30 days) are additionally calculated. Southern region are unique in exclusively calculating 10-day flow duration curves and Q95(10). Common use is made of seasonal flow duration curves although their calculation is not adopted nationally. Estimation of Q95 and the flow duration curve is common at both gauged and ungauged sites, although seasonal flow duration curves are restricted more to gauged sites.

Estimation of MAM(7) and low flow frequency curves is less common than Q95 and the flow duration curve, and has been carried out in only half of the regions. Estimation of low flow frequency is, with the exception of Southern region, confined to gauged sites. Low flow frequency is, without exception, based on 7-day duration.

To a lesser degree, rates of hydrograph recession, Base Flow Index and storage-yield relationships are calculated from gauged flow data, but these statistics have not been widely estimated at ungauged sites.

Some statistics are specific to certain regions, for example, modal flow in North West and minimum residual flow in Anglian Eastern area.

Wessex region appear to make no estimation of low flow statistics at ungauged sites.

Question: Have there been any changes in indices used following the formation of the NRA?

All regions have indicated that no changes have been made in the statistics used in low flow estimation since the formation of the NRA in 1989.

Other statistics include monthly mean, daily and monthly minima/maxima, mean etc of flows above a threshold.

Table 1 Regional low flow statistic requirements

REGION		A			N	NW	ST	S	SW	TH	W	WX	Y
PARAMETER		NO	EA	NA									
MEAN FLOW		GU	GU	GU	GU	GU	GU	GU	GU	GU	GU	G	
MAM(D)							G	U		G			G
LOW FLOW FREQUENCY							G	GU	G	G			
Q95(D)		GU		GU	GU	GU	GU	GU	GU	GU	GU	G	GU
FLOW DURATION CURVE		GU	GU	GU	GU	GU	GU	G	GU	G	GU	G	G
SEASONAL FDC		G	GU	GU	G	G	G	G	GU	G	U		
RATE HYDR RECESSION		G				GU	G	G			G	G	G
ESTIM FUTURE INFLUENCE		GU	U		GU	GU		GU	G		GU	GU	
STORAGE/YIELD								GU	G		U		
BASE FLOW INDEX		G		G		G			GU		GU	G	
MODAL FLOW						GU							
OTHER STATISTICS				U								G	
MINIMUM RESIDUAL FLOW			U										
OTHER PERCENTILES									G			G	
DURATION D DAYS	1	GU		GU	GU	GU	GU		GU	GU	GU	G	GU
	7	GU					G			G			G
	10							GU					
	>30				G					UG			

G = GAUGED; U = UNGAUGED SITES

2.2 Calculation of low flow statistics from gauged flow data

Question: For calculating low flow statistics from gauged daily mean flow data, please indicate whether you apply software or manual calculation techniques.

The responses to this question are presented in Table 2. All regions possess software for the calculation from gauged flow data of the mean flow and flow duration curves. Only half of the regions possess software for the calculation of seasonal flow duration curves. Low flow frequency curves are calculated using software in Anglian, Severn

Table 2 Software applications to calculate statistics from gauged flow data

REGION / PARAMETER	A			N	NW	ST	S	SW	TH	W	WX	Y
	HO	EA	NA									
MEAN FLOW	S	S	S	S	S	S	SM	S	S	S	S	S
MAM(D)	S					S	SM		S	M		S
LOW FLOW FREQUENCY	S					SM	SM	M	M	M		
Q95(D)	S		S	S	S	S	SM	S	S	SM	S	S
FLOW DURATION CURVE	S	S	S	S	S	SM	SM	S	S	SM	S	S
SEASONAL FDC	S	S	S	M	S	SM	SM	M	S	M		
RATE HYDR RECESSION	S				S	M	M			M	M	M
ESTIM FUTURE INFLUENCE	S			M	S		SM	M		M	SM	
STORAGE/YIELD	S						SM	M		SM		
BASE FLOW INDEX	S		S		M			M		SM	S	
MODAL FLOW					M							
MONTHLY STATISTICS											S	
STATS FOR FLOWS ABOVE/ BELOW A THRESHOLD			M									
OTHER PERCENTILES								S			S	

S = SOFTWARE; M = MANUAL;

Trent and Southern regions but manually in South West, Thames and Wessex regions. Anglian region possess the capability to calculate the less common low flow parameters, including BFI, storage/yield and rate of hydrograph recession, using software but many of the other regions rely on manual methods for the calculation of the same statistics.

2.3 Estimation of low flow statistics at ungauged sites

Question: At ungauged natural sites, briefly describe the methodology applied to the estimation of flow statistics.

Methods used to estimate statistics have been summarised into 5 categories as follows:

1) Adjustments to gauged data - using gauged data from a nearby catchment or one with similar characteristics and applying an areal adjustment factor or similar.

2) Catchment characteristics methodologies - a general heading including the Low Flow Studies Report (Institute of Hydrology, 1980); Micro Low Flows and regional catchment characteristic methodologies

3) Simulation modelling - either deriving new data sets from gauged data or using catchment models

4) Spot gauging - in addition to, or instead of estimating parameters using other methods

5) Others - to include methods which are specific to a particular statistic for example water balance and superimposing plots.

Table 3 illustrates that there is little consistency between regions in the methods used to estimate low flow statistics at ungauged sites. For example, four different methods are adopted for the estimation of flow duration curves.

Four regions have specifically developed local regional catchment characteristics-based methodologies: North West (Bullock & Gustard, 1989), Severn Trent (Pirt & Simpson, 1980), Southern (SWA, 1979) and South West (Bullock & Gustard, 1989). These methods are applied to the estimation of the mean flow and flow duration statistics.

Adoption of the methods other than catchment characteristic techniques by the other six regions indicates that the Low Flow Study Report (Institute of Hydrology, 1980) is not commonly used. As a result catchment characteristic techniques are only applied where a specific local regional flow study has been developed.

Adjustments of gauged data and spot gaugings are the common alternatives to catchment characteristic methods and regions vary in using either one or other or both. For example, Anglian and Welsh regions make greater use of transferring data from gauging stations, while Wessex rely almost exclusively upon spot gaugings.

Question: How many man hours, on average, are spent estimating low flow statsitics?

The amount of time taken in estimating a single statistic ranges from 0.5 for routine calculations of the mean flow and Q95 to 7 hours for the derivation of new data sets and flow duration curves. Estimates of the total amount of time spent per year in estimating low flow statistics is shown in Table 4. Clearly, the amount of time varies between each region. For example, Northumbrian region devotes only 2% of a man year for calculating parameters compared to Yorkshire who devote 83% of a man year. The average among the regions is approximately 25% of a man year, equivalent to 2.5 man years annually at a national scale.

Question: Approximately how many requests for low flow information have been received and processed in the period June 1st 1990 to May 31st 1991?
What proportion of these requests have been generated for different purposes?

Figure 1 illustrates the percentage of low flow statistics which have been requested for different purposes.

TABLE 3 Methods of estimation of low flow statistics at ungauged sites

REGION		A		N	NW	ST	S	SW	T	W	WX	Y
PARAMETER	HO	EA	NA									
MEAN FLOW	1,4	1	1	1,2	2	2	2	2	1,4	2	4	
MAM(D)	1,4											
LOW FLOW FREQUENCY	1,4						2					
Q95	1,4	1	1,4	4	2		2	2	1,4	1	4	2
FLOW DURATION CURVE	1,4	1	1,4	1	3	2		2		1	4	
SEASONAL FDC	4		1,4					1,2		1		
RATE HYDR RECESSION	2,4									5	4	
ESTIM FUTURE INFLUENCE	2,3	1,3		3	3		5				3	
STORAGE/YIELD	3						1			5		
BASE FLOW INDEX	1,4							2		2	4	
MODAL FLOW					2							
OTHERS		1,5	1					2			4'	

1 ADJUSTMENT TO ADJACENT GAUGED DATA
2 CATCHMENT CHARACTERISTICS
3 SIMULATION MODELLING
4 SPOT GAUGING
5 OTHERS

Approximately 4000 low flow estimates were requested and processed in England and Wales during the year ending May 31st 1991. There are clear regional trends, with over 50% of all estimates being processed by South West region. Six regions processed between 100 and 500 low flow estimates with Southern, Welsh and Northumbrian regions processing the smallest number of requests. No data is available for the Wessex region.

In 9 of the 10 regions, the dominant source of requests is for discharge consent applications with slightly fewer requests for abstraction licence applications. Consent applications represent over 60% of all low flow requests in six of the ten regions. However, at a national scale, requests for consent applications represent 45% of all requests processed. 40% of all requests at a national level have been for abstraction licences. Fisheries purposes represent less than 10% of requests in all regions and only 2% at a national scale.

3 ADJUSTMENT OF FLOW STATISTICS FOR ARTIFICIAL INFLUENCES

Question: At gauged or ungauged sites, briefly describe the methods used to adjust flow statistics for artificial influences.

Sections 3.1 to 3.5 summarise the procedures used within the regions for adjusting for the impacts of surface water abstractions, discharges to surface waters, groundwater abstractions, reservoirs and land use change.

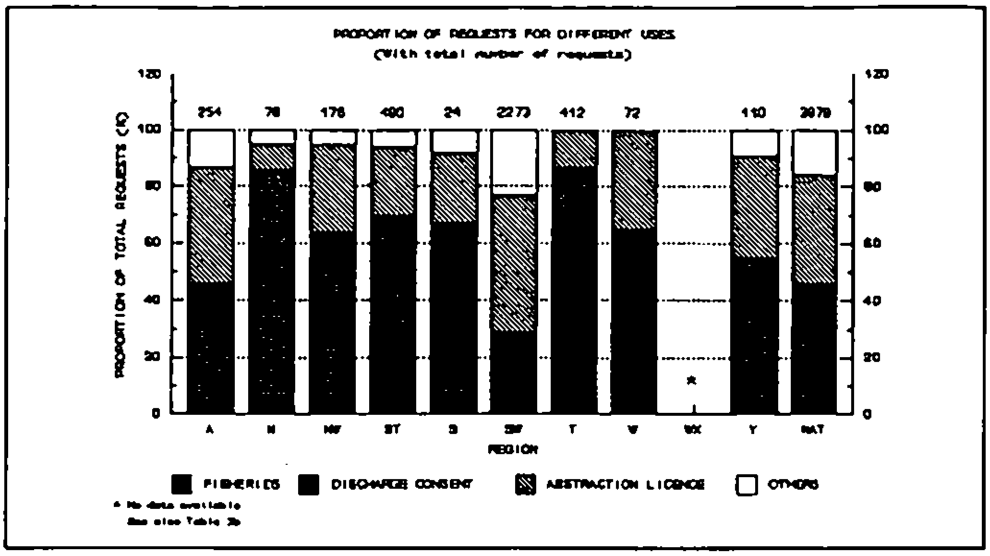


Figure 1 Proportion of requests in each region for different purposes

Table 4 Time spent calculating flow statistics

REGION	A	N	NW	ST	S	SW	T	W	WX	Y	TOT
TOTAL No. OF REQUESTS	254	78	176	480	24	2273	412	72	-	110	3879
TOTAL NUMBER OF HOURS	309	37	710	240	?[2]	573	412[1]	121	?[2]	1628	4030
NUMBER OF DAYS	42	5	96	32	-	77	56	16	-	220	544
NO. ANN. WORKING DAYS	264	264	264	264	-	264	264	264	-	264	2112
PERCENT OF TOTAL TIME	16	2	36	12	-	29	12	6	-	83	26%

1 Some of the values have been estimated based on similar calculation times of other regions
2 No figures given for number of requests and/or number of hours spent on calculations

Note: Some of the figures may not be true represenations of the average annual number of requests. In Thames, for example, the number of requests for discharge consent purposes are higher than usual as a result of a re-appraisal of discharge consents at sewage treatment works. Also, South West received more requests for other purposes as part of a freshwater investigation.

3.1 Surface water abstractions

Adjustments made for abstractions from surface waters (Table 5) are based on subtracting abstraction quantities from time series data and statistics. In some regions, gauged flow data at key sites are naturalised routinely, for example in Thames region and the River Medway (Southern).

In most regions, an exception being Yorkshire, allowance is made for major abstractions. However, the abstraction rates used when making the adjustments can vary between regions and returns at the abstraction point may or may not be taken into account. For example, licensed quantities which may be annual or daily (Anglian & Severn Trent), average net abstractions (North West) , or actual abstraction quantities (Wessex).

Small abstractions are generally ignored. Adjustments are made based on transfer from an adjacent gauging station or based on residual flow diagrams.

3.2 Discharges to surface waters

Adjustments made for the influence of discharges to surface waters are more consistent, commonly using Dry Weather Flows (either design or actual) to naturalise the flows by subtraction (Table 6). Spot gaugings at ungauged sites are occasionally used for this purpose.

3.3 Groundwater abstractions

Abstractions from groundwater (Table 7) are treated no differently to abstractions from surface waters in six of the regions. Wessex region make the assumption that only 50% of water taken from groundwater sources is at the expense of the river flow. Anglian (Eastern area) and South West apply stream depletion calculations to assess the impact of groundwater abstractions on river flows. For major abstractions or for abstractions in sensitive areas a more detailed investigation of the impact upon flow is undertaken.

TABLE 5 Adjusting statistics for surface water abstractions

REGION	METHOD
ANO	WATER BALANCE USING LICENCE RETURNS (EITHER MANUAL, SPREADSHEET/PROGRAM, LUMPED CATCHMENT MODELLING)
AEA	ADJUSTMENTS FOR LICENCE ASSESSMENT: FLOW PU AREA AT PROPOSED ABSTRACTION POINT, TAKING INTO ACCOUNT THE EXISTING LICENSED DOWNSTREAM ABSTRACTION REQUIREMENTS AND CONSENT DILUTION CONDITIONS. ALSO CUMULATIVE WINTER RUNOFF CURVES PRODUCED
ANA	NO ROUTINE NATURALISATION OF GAUGED DATA. ALLOWANCES MADE FOR MAJOR ABSTRACTIONS (PWS & RIVER TRANSFERS). SPRAY IRRIGATION IS ESTIMATED IN ONLY A FEW CASES
N	LARGE PWS ABSTRACTIONS USUALLY HAVE ASSOCIATED GAUGING STATIONS. FLOW DURATIONS OVER A RECENT PERIOD OF YEARS MAY BE USED TO REFLECT CURRENT REGULATION AND ABSTRACTION CONDITIONS. OTHER ABSTRACTIONS ARE SMALL THEREFORE NO ADJUSTMENTS.
NW	THE LONG TERM AVERAGE NETT ABSTRACTION FOUND FROM ANN LIC AMOUNT AND RETURNS. SMALL ABSTRACTIONS, TOTAL RETURNS TO THE RIVER AND INFREQUENT ABSTRACTIONS ARE IGNORED. SPRAY IRRIGATION ARE DEALT WITH SEPARATELY; MAX DAY ABSTR USED;
ST	COMPARISON OF MAX DAILY QUANTITIES WITH LICENSING MAPS, INCLUDING CONSIDERATION OF RETURNS, DERIVATION OF RESIDUAL FLOW DIAGRAMS.
S	MEDWAY CONDITION FOR TONBRIDGE DISTRICT - DAILY QUANTITIES ABSTRACTED ACCOUNTED FOR IN ADJUSTING THE R. MEDWAY RECORD.
SW	AT UNGAUGED SITES SUBTRACT MAX DAILY LICENSED AMOUNTS OR ADJUST THE THEORETICAL ESTIMATES USING RATIOS OF REAL AND THEORETICAL VALUES FROM THE NEAREST REPRESENTATIVE GAUGING STATION IN THE CATCHMENT.
T	NATURALISED FLOW RECORDS FOR THREE SITES ON THE THAMES AND ONE ON THE LEA PRODUCED ROUTINELY BY ADDING MAJOR NON-RETURNING PWS ABSTRACTIONS.
W	RESIDUAL FLOW DIAGRAMS EXIST FOR ALL SIGNIFICANT RIVERS
WX	FOR SIGNIFICANT ABSTRACTIONS, ACTUAL ABSTRACTIONS TAKEN INTO ACCOUNT
Y	NO ADJUSTMENTS

TABLE 6 Adjusting statistics for discharges to surface waters

REGION	METHOD
ANO	AS SURFACE WATER ABSTRACTIONS
AEA	STREAM DEPLETION CALCULATIONS (THEIS & CONOVER, C.T JENKINS' EQUATIONS) ASSESS THE PERCENTAGE OF THE PROPOSED ANNUAL ABSTRACTION QUANTITY THAT WOULD BE DERIVED FROM A NEARBY RIVER.
ANA	NO ADJUSTMENTS
N	NO ADJUSTMENTS
NW	NO ADJUSTMENTS
ST	COMPARISON OF GROUND WATER ABSTRACTIONS & LICENSING MAPS. CURRENT METERINGS FOR SENSITIVE AREAS.
S	NO ADJUSTMENTS
SW	LITTLE ABSTRACTION IN REGION. ANY ADJUSTMENT IS DONE BY APPLYING JENKINS' METHOD (DONE ON SITE)
T	NO ADJUSTMENTS
W	UNDER REVIEW WITH COLLAPSE OF MINING INDUSTRY - MAJOR ABSTRACTIONS INCLUDED IN RFD'S
WX	MAJOR ABSTRACTIONS INVESTIGATED TO ASSESS THE EFFECT ON THE RIVER. OTHERWISE ASSUME 50% OF GROUNDWATER ABSTRACTIONS IS AT EXPENSE OF RIVER
Y	NO ADJUSTMENTS

TABLE 7 Adjusting statistics for groundwater abstractions

REGION	METHOD
AHO	AS SURFACE WATER ABSTRACTIONS
AEA	ADJUSTMENTS MADE TO FLOW DATA FOR DISCHARGES FROM THE ELY OUSE/ESSEX TRANSFER SCHEME. LOSSES AND TIME OF TRAVEL CURVES RELATE THE QUANTITY DISCHARGED AT THE HEADWATERS OF THE STOUR & BLACKWATER TO THE QUANTITY AFFECTING THE GAUGING STATION DOWNSTREAM
ANA	MEAN EFFLUENT DISCHARGE AFFECTS THE MEAN RIVER FLOW; DWF AFFECTS THE Q95(1). WHERE FLOWS HAVE BEEN AUGMENTED UPSTREAM OF A GAUGING STATION THE STATISTICAL ANALYSIS IS RESTRICTED TO THE PERIOD OF RECORD WITHOUT AUGMENTATION.
N	AT UNGAUGED SITES: ESTIMATE STATS FOR A POINT U/S AND ADD STW DWF/AVERAGE MINEWATER PUMPED DISCHARGE OR ESTIMATE D/S STATS BASED ON SPOT GAUGING DATA INCORPORATING DISCHARGES
NW	ADD DESIGN DRY WEATHER FLOW TO THE NATURAL COMPONENTS (MEAN, Q95, MODAL ETC)
ST	COMPARISON OF DISCHARGES WITH CONSENT REGISTER. DERIVATION OF RESIDUAL FLOW DIAGRAMS.
S	PERIODIC CURRENT METERING; USE OF Q95 PERCENTILES
SW	CONSENTED DWF ADDED TO Q95. (RARE THAT ADJUSTMENTS ARE MADE)
T	NO ADJUSTMENTS
W	AS GROUNDWATER
WX	ESTIMATED DISCHARGES ARE TAKEN INTO ACCOUNT IF SIGNIFICANT
Y	NO ADJUSTMENTS

TABLE 8 Adjusting statistics for the presence of reservoirs

REGION	METHOD
AHO	RESERVOIRS ARE INCLUDED IN NATURALISATION PROCEDURES BY SIMULATING INFLOWS/IMPOUNDMENT/RELEASES IE RESERVOIR SIMULATION IS PART OF A CATCHMENT WATER BALANCE ANALYSIS
AEA	NO ADJUSTMENTS
ANA	NO ADJUSTMENTS
N	NORMALLY ON GAUGED RIVERS, THEREFORE RECORDS INCORPORATE CURRENT OPERATING POLICY
NW	THE NATURAL FLOW UPSTREAM OF THE DAM IS SUBTRACTED FROM NATURAL COMPONENT AND COMPENSATION FLOW ADDED. IF OUTFLOW DETERMINED BY LAKE LEVEL THEN IT IS TREATED AS A NATURAL LAKE WITH ABSTRACTIONS
ST	CONTROL RULES & OPERATING PROCEDURES ARE CONSIDERED, OCCASIONAL GAUGING REQUESTED.
S	DAILY WATER BALANCE USED WHERE POSSIBLE, OTHERWISE WEEKLY OR MONTHLY
SW	SUBTRACT ESTIMATED Q95 FOR CATCHMENT AREA ABOVE RESERVOIR FROM Q95 DOWNSTREAM AND ADD SUMMER COMPENSATION FLOW (REACHES CLOSE TO RESERVOIR). MEAN FLOW ADJUSTED BY SUBTRACTING AVERAGE YIELD. IF REGULATING, EXCLUDE CATCHMENT ABOVE RESERVOIR AND ADD SUMMER REGULATED FLOW.
T	NO ADJUSTMENTS
W	USE COMPENSATION OR REGULATION RELEASE UNDER APPROPRIATE FLOW PERCENTILE
WX	COMPENSATION DISCHARGES AND CATCHMENT AREAS OF THE RESERVOIRS ARE TAKEN INTO ACCOUNT
Y	NO ADJUSTMENTS

3.4 Reservoirs

Reservoirs are considered by most of the regions in terms of a water balance to include simulated inflows to the reservoir and compensation releases (Table 8). North West, South West and Welsh regions make adjustments to calculated low flow statistics. Others (Anglian and Southern) adjust the time series.

3.5 Land use change

Impacts of land use are not widely considered (Table 9). Adjustments are made using a lumped recharge model (Anglian) or runoff coefficients (Severn Trent).

In summary, adjustments are most frequently applied when considering the future impacts of abstractions and discharges; a number of regions indicated that most abstractions or discharges are upstream of gauging stations so their effects would already be taken into account in the data. Few regions attempt to routinely adjust gauged flow data for the impact of all artificial influences as a result of lack of staff time or resources.

TABLE 9 Adjusting statistics for changes in land use

REGION	METHOD
ANO	LUMPED MODELLING (VIA A RECHARGE MODEL)
AEA	NO ADJUSTMENT
ANA	NO ADJUSTMENT
N	NO ADJUSTMENTS USUALLY, BUT GAUGED DATA WOULD BE USED IF NECESSARY.
NW	NO ADJUSTMENTS
ST	LOCAL RUNOFF COEFFICIENTS CONSIDERED FOR URBAN AREAS.
S	NOT APPLICABLE
SW	INFREQUENT, Q95 & SPOT GAUGING IN URBAN CATCHMENTS IF THEORETICAL VALUES UNREPRESENTATIVE.
T	NO ADJUSTMENTS
W	NO ADJUSTMENTS
WX	NO ADJUSTMENTS
Y	NO ADJUSTMENTS

4 HYDROLOGICAL DATA REQUIREMENTS OF LICENSING AND CONSENT PROCEDURES

4.1 Abstraction licences

Question: What hydrological information is required when considering a licence application or review?
Does this vary with scale, location, purpose?

Table 10 summarises the type of information required by the regions when abstraction licence applications are being considered. Most regions require a combination of flow regime information, catchment characteristics and legal water requirements to be able to assess abstraction licences. Also, details of the proposals are required.

The amount of information varies between regions and, as is apparent from Table 1, mean, Q95, FDC's are the most commonly used. The amount of information varies with scale, location and purpose of proposals, in particular, the sensitivity of both the location and the proposals are important.

TABLE 10 Hydrological information required for assessing abstraction licence applications

INFORMATION	PARAMETER	REGIONS
LOW FLOW STATISTICS	MEAN FLOW	NW, N, SW, ST.
	Q95	T, NW, SW, N.
	ANNUAL FDC	AHO, ANA, SW, NW, ST
	SEASONAL FDC	ANA, ST, SW
	MAM(?)	
	LOW FLOW FREQ CURVE	
	MAXIMUM FLOWS	SW
	MINIMUM FLOWS	NW, SW
	DWF	ST, W
	MINIMUM RESIDUAL FLOW/WATER BALANCE	AEA, S, ANA, SW, T
	HYDROGRAPHS	SW
VARIATIONS IN DETAIL	SCALE	SW,WX, Y, W, ANA
	LOCATION	SW, ANA, WX, S, Y
	PURPOSE OF ABSTRACTION	SW, ANA, WX, S, Y
	SENSITIVITY OF LOCATION/PROJECT	AHO, SW, ANA, N

S - SOMETIMES

4.2 Discharge consents

Question: What hydrological information is required when considering a consent to discharge?
Does this vary with scale, location, purpose?

Similar information is required for the discharge consents (Table 11), although the quantity of information is less. The amount of detail required also depends on scale, location and project details.

5 LICENSING AND CONSENT DATABASES

5.1 Abstraction licence databases

Question: What variables are held on computer databases for abstraction licences?

Table 12 lists the most common variables held on a database for abstraction licences within each region.

TABLE 11 Hydrological information required for assessing applications for consents to discharge

TYPE OF INFORMATION	PARAMETERS	REGION(S)
FLOW REGIMES	Q95	all A, N, NW, S, ST, SW, T, W, WX, Y
	MEAN FLOW	ANA, ANO, AEA, N, NW, S, ST, SW, W
	ANNUAL FLOW DURATION CURVE	SW, N, NW[1]
	SEASONAL FLOW DURATION CURVE	SW
	MAM(7)	
	LOW FLOW FREQUENCY CURVES	
	MAXIMUM FLOWS	
	MINIMUM RECORDED FLOWS	T
	MODAL FLOW	NW
	HYDROGRAPHS	
	DWF	ST
VARIATIONS IN DETAIL	SIZE OF DISCHARGE	ANA, NW, ST, Y
	PURPOSE OF CONSENT (SOURCE)	ANA
	LOCATION (ESPECIALLY SENSITIVITY)	ANA, ST, WX,

1 Future requirements for modelling

The databases hold a large amount of information which can be summarised into the following categories:

1) the location of the abstraction:
   - National Grid Reference
   - name of river

2) details of the type of abstraction:
   - groundwater, stream, river, spring or reservoir;

3) details of the source of water:
   - type of reservoir or borehole
   - methods of abstraction
   - quality of the water

4) details of the licence:
   - quantities abstracted
   - names and addresses of licence holders
   - variation dates
   - charging details etc.

5) special conditions and restrictions:
   - low flow conditions

TABLE 12 Information held on an abstraction licence database

REGION / PARAMETER	A	N	NW	ST	S	SW	T	W	WX	Y
GRID REFERENCE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LOCATION (DESCRIPTION)	✓		✓	✓	✓	S	✓	✓	S	
ABSTRACTION TYPE (SURF,GW)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AQUIFER FOR GROUNDWATER	✓	✓	✓	✓	✓	✓	✓		✓	✓
SOURCE OF SURFACE WATER	✓	✓	✓	✓	✓	S	✓	✓	✓	✓
SOURCE DETAILS (NO./TYPE RES/BH)	✓		✓							
METHOD OF ABSTRACTION	✓			✓						✓
ABSTRACTION PERIODS/SEASON	✓		✓						✓	
DISTANCE TO/ALONG RIVER										✓
LICENCE NUMBER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LIC HOLDER'S NAME/ADDRESS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OTHER LICENCES IN CONJUNCTION	✓		✓		✓					
LICENCE PERIOD	✓		✓	✓	✓	✓	✓	✓	✓	
ISSUE/REV/VARY DATES, STATUS	✓		✓	✓		✓	✓	✓	✓1	✓
PURPOSE(S)	✓	✓	✓	✓		✓	✓	✓	✓	✓
MAXIMUM HOURLY LICENCE	✓		✓	✓		S	✓	✓	✓	✓
MAXIMUM DAILY LICENCE	✓	✓	✓	✓		✓	✓	✓	✓	✓
ANNUAL TOTAL FOR EACH PURPOSE	✓	✓	S	✓		✓	✓	✓	✓	✓
TOTAL ANNUAL LICENCE	✓	✓	✓	✓		✓		✓	✓	✓
CONTROL/SPECIAL CONDITIONS	✓				✓			✓		
CHARGES (CODE, PERSON BILLED)	✓				✓			✓		✓

1 - Once revoked, licences are removed from archive

5.2 Discharge consent databases

Question: What variables are held on computer databases for consents to discharge?

The amount of information held on the discharge consent database is less detailed than the abstraction licence database. The discharge consent database holds information regarding the location, source, quantity and consent details of the discharge. In addition more information is required on the quality and methods of treatment of the effluent which would relate to the dilutions required etc.

TABLE 13 Information held on a database for consents to discharge

REGION / PARAMETER	A	N	NW	ST	S	SW	T	W	WX	Y
GRID REFERENCE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LOCATION	✓	✓	✓	✓		✓	✓	✓	✓	✓
DESIGN DWF		✓	✓	✓	✓	✓	✓	✓	✓	✓
CONSENTED AVERAGE DAILY DISCHARGE	✓	✓			✓	✓	S	✓		✓
CONSENTED MAX DAILY DISCHARGE		✓		✓	✓	✓	✓	✓		✓
RECEIVING RIVER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DISCHARGE TYPE (STW, IND)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CONSENT NUMBER/OPERATOR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VARIATION DATES	✓	✓	✓	✓		✓	✓	✓	✓	
CONTROL/SPECIAL CONDITIONS	✓	✓	✓			✓	✓	✓	✓	✓
OTHER CONSENTS HELD BY OPERATOR				✓			✓		✓	
OTHER CONSENTS HELD IN CONJUNCT				✓			S		✓	
CHARGE CODE/PERSON BILLED ETC							✓		✓	
SUBCATCHMENT									✓	
TYPE OF TREATMENT									✓	
QUALITY CONDITIONS OF DISCH/RIVER	✓			✓						

S = Sometimes

6. SUMMARY OF CONCLUSIONS

Principal conclusions:

1. Low flow estimation in England and Wales lacks the application of standard and consistent procedures between NRA regions.

2. Approximately 2.5 man years per annum is committed to low flow estimation.

3. Approximately 4000 requests for low flow statistics were processed by the NRA in the year to May 31st 1991. Requests originate almost exclusively for discharge consents and abstraction licensing purposes.

4. The low flow statistics that are estimated in all regions are the mean flow, flow duration curves and 95 percentile. Use of the low flow frequency and MAM(7) is confined to four regions. Other low flow measures are used to a lesser degree.

5. All regions possess software for the calculation of the mean flow and flow duration curves from gauged data, but not for other measures such as low flow frequency. Certain regions possess software for calculating other low flow statistics from gauged data while other regions calculate the same statistics using manual methods.

6. Different methodologies are applied by different regions for the estimation of the same low flow statistics at ungauged sites. For example, at least four different methodologies are applied to the estimation of flow duration curves. In general, those four regions which possess local catchment characteristics-based methods can be distinguished from others which rely upon transferring statistics from gauged data, spot metering or simulation modelling.

7. There is little consistency between regions in the application and type of techniques for making adjustments for artificial influences.

REFERENCES

Gustard, A & Bullock, A; (1989); Average and Low Flow Estimation in the South West Region, Wallingford.

Gustard, A & Bullock, A; (1989); Average and Low Flow Estimation in the North West Water Region, Wallingford.

Institute of Hydrology; (1980); Low Flow Studies Report, Wallingford

Pirt, J & Douglas, R; (1980); A Study of Low Flows in the Severn and Trent Catchments.

Southern Water Authority, (1979); Report on Low Flow Studies for the SWA Area.

Appendix 1

SUMMARY OF ABBREVIATIONS

A	ANGLIAN REGION
EA	EASTERN AREA
NA	NORTHERN AREA
N	NORTHUMBRIA REGION
NW	NORTH WEST REGION
ST	SEVERN TRENT REGION
S	SOUTHERN REGION
SW	SOUTH WEST REGION
T	THAMES REGION
W	WELSH REGION
WX	WESSEX REGION
Y	YORKSHIRE REGION
MF	MEAN FLOW
MRF	MINIMUM RESIDUAL FLOW
DMF	DAILY MINIMUM FLOW

Appendix 3 "Simulating Abstraction Impacts upon Low Flows"

Estimation of low flows in artificially influenced catchments.

Simulating abstraction impacts upon low flows

R & D Commission B Water Resources
Topic B2 Flow Regimes
Project No B2.3

BULLOCK, A
&
IRVING, K

INSTITUTE OF HYDROLOGY
NOVEMBER 1991

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
Oxon, OX10 8BB

Simulating abstraction impacts upon low flows

Contents

Preface

This report forms part of a three year contract with the National Rivers Authority to estimate low lows in artificially influenced catchments. The objectives of the project are to estimate the effects of the abstractions and discharges, the influence of groundwater abstraction and the effects of afforestation and deforestation.

The report describes methods used for adjusting low flow statistics for artificial influences and illustrates the effects on the low flow regime of different hypothetical abstraction scenarios.

Executive summary

The Institute of Hydrology is currently undertaking a three year contract for the National Rivers Authority to estimate low flows in artificially influenced catchments. The project is aimed at the production of methods of low flow estimation in ungauged or partially gauged catchments which are the subject of human influences. The project is extending the existing MICRO LOW FLOWS software (currently available through the Institute of Hydrology) to produce estimation procedures which account for the following:

1) surface water influences including abstractions, discharges and reservoirs

2) bulk effects of groundwater abstraction

3) land use change in the form of afforestation and deforestation

This report describes a preliminary investigation into the impact of abstracting water from rivers in terms of the sensitivity of low flows to the magnitude and seasonality of the abstractions. The relationship between the degree of impact and catchment geology is further investigated.

Ten catchments are selected with long continuous daily flow records where artificial influences are not significant. The catchments were selected to represent a range of geological conditions. The criterion used to characterise catchment geology is the Base Flow Index (BFI) which is a measure of the amount of water that reaches the river that is derived from stored water sources.

Rates of abstraction are represented by multiples of the mean annual 7-day minimum (MAM(7)) for each catchment derived from the flow record. MAM(7) is the mean of the lowest consecutive 7-day period in each year on record.

Artificial data sets are derived from the ten natural gauged flow records by subtracting multiples of MAM(7) from the time series of daily flow values. Two different cases are investigated; annual abstractions in which all 365 daily flow values are adjusted and summer-only abstractions in which only the April to September flows are adjusted. The multiples of MAM(7) considered for the abstraction scenarios are 0.5, 1.0, 2.0 for annual abstractions; 1.0, 2.0, 4.0 for summer abstractions. The summer abstractions are, therefore, double the annual rate but for only half the time. The lower, middle and higher multiples represent the same amount of abstracted water, but with a different seasonal distribution.

Three methods are used to calculate the monthly minima simulated under the different abstraction scenarios; adjustment of the gauged daily flow data, adjustment of the long-term mean monthly minima and adjustment of the series of mean monthly minima. Differences in the calculation of the simulated monthly minima increase

with the introduction of more zero flows into the simulated time series (when the abstraction rates are greater than the river flow).

The seasonality and magnitude of natural monthly minima are investigated prior to the assessment of impact of abstraction upon low flows. Lowest mean monthly minima are higher as a percentage of average flow and occur later in the year in catchments with higher BFI values. For example, the lowest mean monthly minima in catchments with BFI in excess of 0.8 occur most commonly in September or October, with minima of approxmately 40% of the mean flow. The lowest mean monthly minima in catchments with BFI less than 0.4 occur most commonly in June or July, with minima below 20% of the mean flow.

Assessment of impact on monthly minima is directed towards variations with the Base Flow Index under different scenarios of abstraction. General relationships are developed which express the impact on monthly minima of different abstraction scenarios across the range of the Base Flow Index. The impact is expressed in terms of the simulated flows as a percentage of the natural flows.

These results provide a basis for understanding the sensitivity of low flows to different abstraction scenarios. In addition, they identify the limits within which estimated mean monthly minimum statistics at ungauged sites can be adjusted by subtraction of multiples of MAM(7) without introducing errors associated with the introduction of zero flows. The results will enable more appropriate adjustments to be made to natural flow statistics using the MICRO LOW FLOW software.

KEY WORDS

Low Flow Impacts, Abstractions, Artificial Influences, Mean Annual Minimum, Monthly Minima, Base Flow Index, Flow Duration Curve

Illustrations

Figures

Tables

1 INTRODUCTION

The objectives of the investigation are to understand the magnitude and seasonality of abstraction impacts in catchments which represent the range of geological conditions in England and Wales in order to provide a base of information and experience in techniques for adjustment of natural low flow statistics at ungauged sites.

Abstraction rates are represented by multiples of the mean annual 7-day minimum (MAM(7)). This is the mean of the lowest consecutive 7-day period in each year on record.

The criterion used to characterise the geological conditions is the Base Flow Index (BFI) (Institute of Hydrology, 1980). BFI is an indicator of the amount of water which reaches a river derived from stored sources.

Three methods are considered in the adjustment of the natural flow data; adjustment of the gauged daily flows (Method 1), adjustment of the long-term monthly minima (Method 2) and adjustment of the series of annual monthly minima (Method 3).

In Method 1 series of simulated daily flow data are generated under different hypothetical abstraction scenarios for ten catchments with natural gauged flow data. Comparisons are made between the simulated and natural low flow time series to assess the magnitude of the impact. Monthly minimum series are analysed to identify the seasonal aspects of abstraction. General relationships are developed between the adjusted mean monthly minima and the Base Flow Index. This method of simulating abstraction impacts can be applied only to gauged or simulated time series of daily flows and is not appropriate to the adjustment of estimated natural flow statistics. Method 3 is equivalent to Method 1 but utilises monthly minima rather than daily flow series.

Comparisons are made between these and Method 2 which can be applied to the adjustment of estimated natural flow statistics. Differences can be expected to occur between the three methods as zero flows are introduced into the simulated flow data. The precision of applying adjustments to the estimated monthly minimum statistic will therefore depend on the frequency with which zero flows are likely to occur. This frequency will depend upon the seasonality and magnitude of the natural low flows and the volume of abstraction. General relationships are developed which identify under what conditions zero flows are likely to occur and hence the confidence with which the different adjustment methods can be applied.

In addition to the impact upon monthly minima, the impact of abstraction upon the flow duration curve and the Q95 statistic is investigated and a general relationship between degree of impact and the Base Flow Index is developed.

Section 2 describes the selection procedures and methods of analysis used in the study. Section 3 illustrates the variations in seasonality and magnitude of the natural low flow regime. Section 4 illustrates the impact of abstraction scenarios on the natural monthly minima in individual catchments and on the flow duration curves. Section 5 summarises the major conclusions that can be drawn from the simulations.

2 METHODS OF ANALYSIS

2.1 Selection procedures

From a list of gauging stations in England and Wales ten stations were selected which satisfied the following criteria:

1) long period of record, all stations having continuous daily mean flow records of at least 20 years

2) accurate and reliable low flow hydrometry

3) natural catchments; all stations having little or no artificial influences from abstractions or discharges as defined by the Low Flow Studies Report (IH, 1990). Most are rural agricultural catchments.

4) cover the full range of geological conditions

The following table summarises the values of Base flow Index for different parent materials.

A high BFI indicates an increased storage and permeability, therefore being able to maintain low flows in summer, producing a less variable annual flow regime. Catchments with a high BFI include, for example, chalk and Permo-Triassic sandstones.

A low BFI catchment indicates an impermeable catchment or low storage resulting in a flashy response to rainfall events and artificial influences etc. Catchments dominated by clays and igneous rocks will have a low BFI.

In addition, a further selection was made of five or more stations (including the first selections) with similar base flow indices for each BFI group. The same criteria were included in the selection procedures. The stations that have been included in the grouped analysis fit in the following Base Flow Index classes:

BFI GROUP 2:	0.00-0.25;	BFI GROUP 6:	0.56-0.65;
BFI GROUP 3:	0.26-0.35;	BFI GROUP 7:	0.66-0.75;
BFI GROUP 4:	0.36-0.45;	BFI GROUP 8:	0.76-0.85;
BFI GROUP 5:	0.46-0.55;	BFI GROUP 9:	0.86-0.95.

A total of 61 gauging station records were analysed.

Table 1 *Typical Base Flow Indices for various rock types (from Low Flow Studies Report, IH, 1980)*

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	.46 - .54
		Silurian/Ordovician	.30 - .50
		Metamorphic-Igneous	.30 - .50
	No storage	Oxford Clay Weald Clay London Clay	.14 - .45

Table 2 *Gauging stations selected for the low flow analysis*

STN NO.	STATION NAME	RECORDS	BFI	GEOLOGY	AREA	NGR
25006	Greta at Rutherford Bridge	1960-90	0.21	Carboniferous Limestone	86.1	NZ 034 122
26003	Foston Beck at Foston Mill	1959-89	0.95	Chalk catchment of Yorkshire Wolds	57.2	TA 093 548
28046	Dove at Izaak Walton	1969-90	0.78	Millstone Grit & Carb. Limestone catchment	83.0	SK 146 509
32003	Harpers Brook, Old Mill Bridge	1938-90	0.49	Impervious Oxford Clay	74.3	SP 983 799
34011	Wensum at Fakenham	1966-90	0.82	Boulder clay with sands and gravels	127.1	TF 919 294
40007	Medway at Chafford Weir	1960-90	0.5	Ashdown sands and Wadhurst clay	255.1	TQ 517 405
44006	Sydling Water, Sydling St Nicholas	1966-90	0.86	Lower chalk, some upper and middle chalk.	12.4	SY 632 997
46005	East Dart at Bellever	1963-90	0.42	Natural peat on Dartmoor Granite	21.5	SX 657 775
55003	Lugg at Lugwardine	1939-89	0.63	Lower Old Red sandstone	885.8	SO 548 405
72004	Lune at Caton	1959-90	0.32	Limestone,shales and millstone grit and drift	983.0	SD 529 653

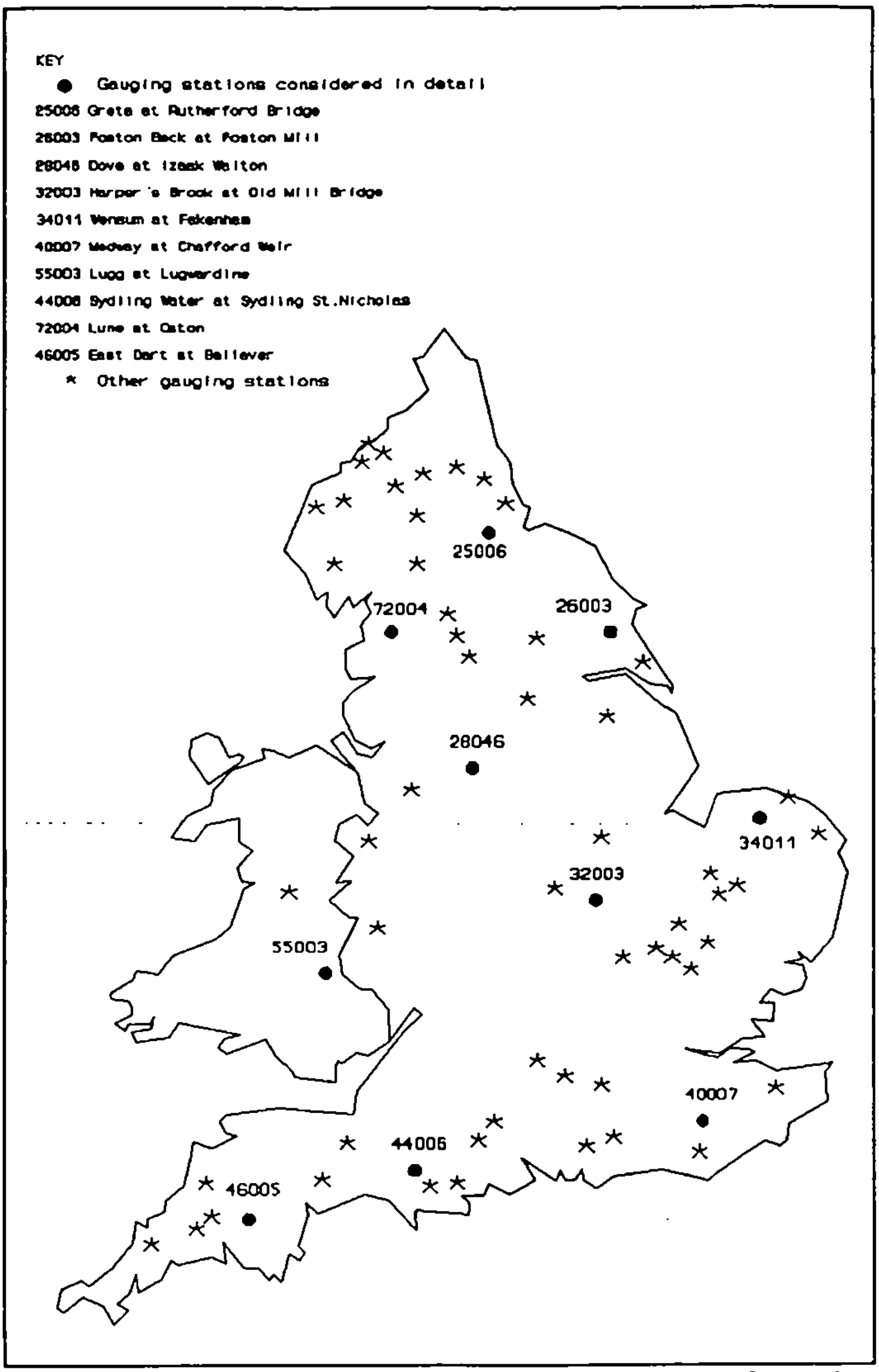


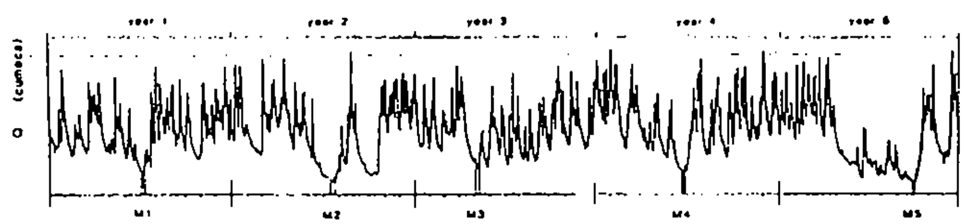
Figure 1 The location of the gauging stations used in the study

The gauging stations selected for the detailed analysis are given in Table 2 and the locations of all 61 stations are indicated in Figure 1.

The rates of abstraction are chosen as factors of mean annual 7-day minimum (MAM(7)). Multiples of between 0 and 4 x MAM(7) are considered. Figure 2 illustrates how the mean annual minimum values are calculated.

Periods of abstraction are varied to represent different demands, for example a constant value may be required for the whole year for Public Water Supply (PWS) or industry, while Spray Irrigation (SI) would only require abstractions during the summer months (April to September). The abstraction volumes should remain the same for both annual and summer abstractions, and as a result the rate of abstraction over the summer period was doubled.

The period April to September is considered to represent the summer period.



M1 = Minimum 7 day flow in year 1

$$MAM(7) = \frac{(M1+M2+M3+M4+M5)}{5}$$

CALCULATION OF THE MEAN ANNUAL D-DAY MINIMUM

From a continuous daily flow record the minimum D-day flow (ie. the minimum flow over seven consecutive days) is found in each year on record.

The mean annual minimum, MAM(D), is the mean of all the minimum D-day flows
D is commonly 1,7,10 or 30 days

The minimum sequence can be considered in terms of the minimum D-day flow in any period.
The mean monthly D-day minimum used in this report is the minimum in each individual month on record (ie. the mean January minimum, February minimum etc)

Figure 2 Calculation of 7-day minimum statistics from daily data

There are a number of assumptions which allow the procedures and results to be simplified:

1. The rate of abstraction is assumed to be constant for every day during period of interest. This may be true for public water supply or industry, but spray irrigation is more variable.

2. There is assumed to be no variations in abstraction conditions over the full period of flow records.

3. There are assumed to be no returns to catchment through discharges, drains etc.

4. There is no account taken of the influence of changes in groundwater abstractions on water level, although this is an important factor in many catchments.

2.2 Calculating the mean monthly minimum statistics

For each station the MAM(7) is found as illustrated in Figure 2. The mean 7-day monthly minimum (MMM(7)) is obtained from the mean of the lowest 7 consecutive days in each calendar month. This was done for all selected gauged catchments to indicate the natural flow pattern throughout the year and to identify in which month the minimum flow conditions occur. The minima are expressed as a percentage of natural mean flow in order to be able to compare catchments of different sizes.

2.3 Adjusting the natural data

Three methods are considered in the adjustment of the natural data.

2.3.1 METHOD 1: Time series adjustment

The natural daily flow records of the gauging stations listed in Table 2 have been modified by subtracting different abstraction rates expressed as multiples of the annual minimum from the daily flow. Abstractions equivalent to 1, 2 and 4 times MAM(7) are applied to the period April 1st to September 30th and multiples of 0.5, 1, and 2 times MAM(7) are applied to the annual period.

The hypothetical rate of abstraction is calculated for each of the abstraction scenarios, and is then subtracted from the natural daily flows.

The adjusted monthly minimum is expressed as a percentage of the natural monthly minimum.

In all, a series of six artificially influenced datasets have been produced for each of the gauging stations for the different abstraction scenarios.

2.3.2 *METHOD 2: Monthly Minima adjustment*

For the analysis of all 61 catchments selected for the BFI groups, illustrating the national variations in monthly minima, the mean monthly minimum 7-day flows were calculated (section 2.2) and the abstraction subtracted to derive the adjusted mean quantity, MMM7(ADJ) expressed as a percentage of the natural monthly minimum.

Minimum flows are calculated for twelve months for each station in the selected BFI group. The median value in each month is taken as the representative monthly 7-day minimum for the group.

2.3.3 *METHOD 3: Monthly minimum adjustment in each year*

All 61 catchments can also be adjusted by subtracting the multiples of MAM(7) from the individual minimum monthly values in each year, and expressed as a percentage of the natural monthly minimum. The mean of all the adjusted flows is then found.

2.3.4 *Comparison of the three methods*

Figure 3 illustrates the variations in mean monthly 7-day minima as a result of using different adjustment procedures.

Method 1 can only be applied where natural or naturalised time series of daily flows are available at gauging stations or have been simulated. Method 3 can only be applied where natural D-day time series of monthly minima exist but not the basic daily data. Time series are not required for Method 2, which can be applied to observed or estimated low flow statistics.

All three methods calculate the same adjusted mean monthly minimum statistics when all the adjusted daily flow data remain greater than zero. In this case, Method 2 allows estimation of the natural low flow statistics without error and is recommended. As time series data are not required, application is simple at an ungauged site. Method 2 becomes increasingly inappropriate as more zero flows are introduced into the simulated time series which did not already exist in the natural time series.

Section 3 will illustrate that zero flows are likely to be more common in catchments with a low Base Flow Index, are more frequent in certain months than others and clearly are more frequent with high abstraction rates. When zero flows are included in the simulated time series, then Method 2 will always under-estimate the adjusted mean monthly minimum statistic. In an example of a low BFI catchment (25006, BFI=0.21), in the month in which the lowest flows occur naturally (July), the under-estimate compared with Method 1 is 1.9% of natural MMM(7) under a scenario of 1 x MAM(7) and 12.5% under a scenario of 2 x MAM(7). Under a scenario of 4 x MAM(7) the largest under-estimate occurs in May, being 37% of the natural monthly minimum.

The calculated adjusted mean monthly minimum statistic differs between Method 1 and Method 3 (a) as up to 7 days have zero flows in any one year and (b) as more

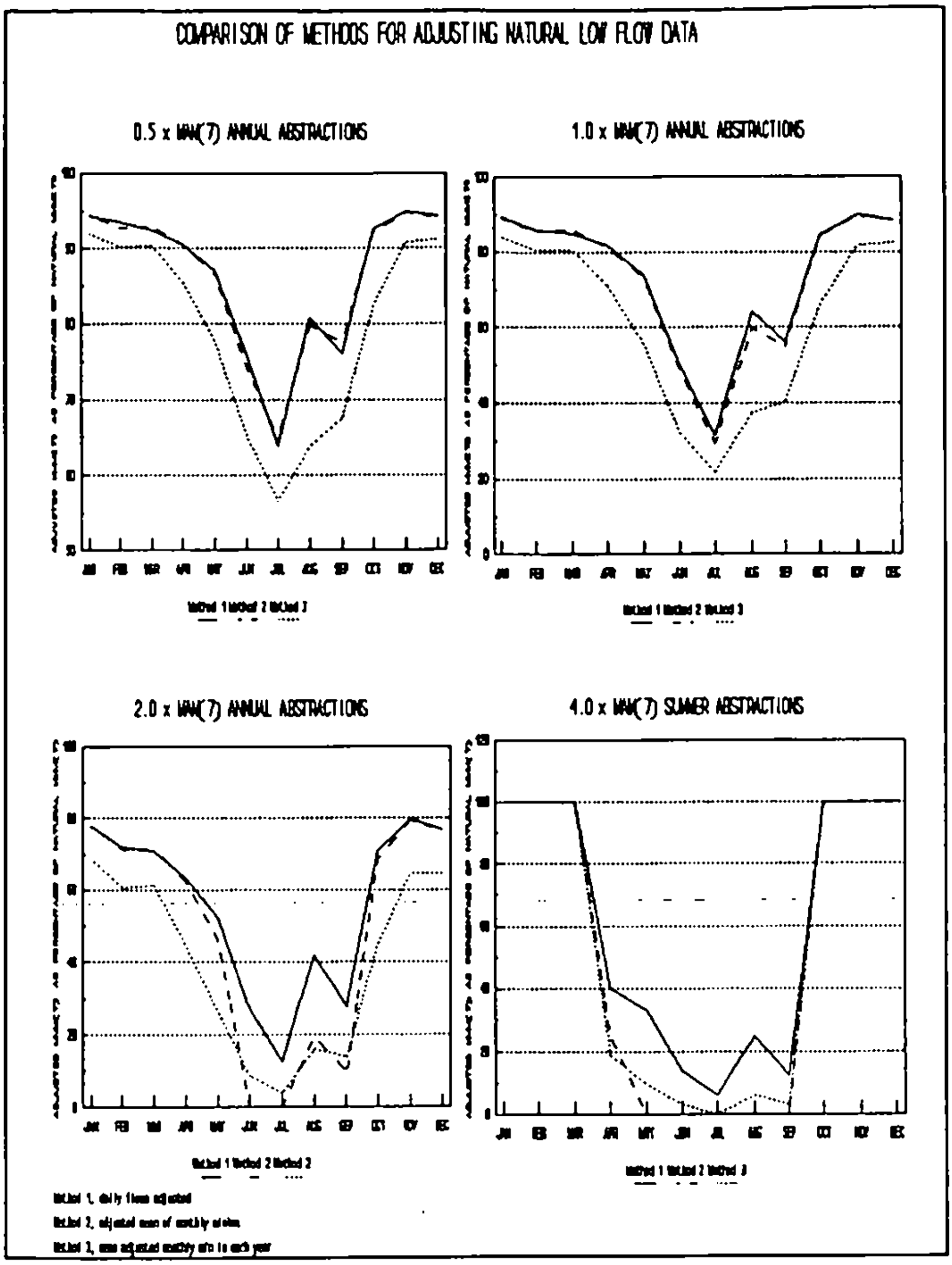


Figure 3 *Comparison of the methods used for adjusting the minimum statistics*

years contain zero flows. Method 3 will increasingly under-estimate the mean monthly minimum statistics as these two conditions become more common. For catchment 25006, the mean July minimum is under-estimated compared with Method 1 by 9.7% of natural MMM(7) under an abstraction scenario of 1 x MAM(7) and 8.6% under a scenario of 2 x MAM(7). Under a scenario of 4 x MAM(7) the greatest under-estimate again occurs in May, the reduction being approximately 28% of the natural monthly minimum.

It is clearly the frequency of occurrence of zero flows in the adjusted time series in addition to the form of the natural low flow data that determines which method is most appropriate for adjusting natural low flow for the effects of artificial influences. In practice the data will rarely be available for applying Method 3. The implications of the analysis in drawing attention to the under-estimation of mean monthly minima when applying simple adjustments to derived statistics for rivers which experience zero flows due to over-abstraction.

3 SEASONALITY AND MAGNITUDE OF THE NATURAL MONTHLY MINIMA

The natural mean monthly minima for ten gaugings stations representing the range of Base Flow Index are presented in Table 3. The flows are expressed as a percentage of the mean flow to allow the catchments to be compared.

Table 3 Natural minimum flow regime of the ten gauging stations used in the catchment study

			MEAN MONTHLY 7-DAY MINIMA (% MEAN FLOW)											
Station number	BFI	Mean flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
26003	0.95	0.67	103	150	141	132	112	89	69	53	45	43	50	70
44006	0.86	0.18	111	148	130	106	82	68	54	46	44	48	53	80
34011	0.82	0.91	111	116	117	106	89	69	53	49	45	56	63	81
28046	0.78	1.94	113	119	111	93	71	55	44	40	39	49	72	93
55003	0.63	10.67	92	112	91	59	47	35	27	25	29	38	69	83
40007	0.50	3.12	84	79	68	60	46	30	23	21	22	36	52	67
32003	0.49	0.41	84	93	74	60	45	32	26	24	24	26	43	60
46005	0.42	1.21	74	68	54	41	35	25	22	24	23	54	62	74
72004	0.32	34.93	57	43	39	29	23	15	19	25	26	41	54	58
25006	0.21	2.26	45	35	35	27	19	10	7	12	11	32	49	43

The month in which the lowest mean monthly minima becomes earlier in the year as the Base Flow Index decreases. The lowest mean monthly minimum flows in the higher BFI catchments occur in September and October, and in the lower BFI catchments in June and July. Clearly, the different seasonality of minima will have implications for the sensitivity of flows to abstractions which are confined to a particular time period. The impact of abstractions in the early summer will be more severe in catchments with surface water dominated regimes.

It is well known that mean monthly minima represent higher percentages of the mean flow in catchments with a dominant groundwater component. This is particularly true in the winter, spring and summer months, but the distinction is less clear in late autumn.

The magnitude of the low flows obviously determines the sensitivity to abstraction and the frequency with which zero flows may be simulated under different abstraction scenarios. The lowest mean monthly minima are in excess of 40% of the mean flow in the high BFI catchments and less than 20% in the low BFI catchments. The lowest mean monthly minimum value is always greater than the mean annual minimum value.

4 IMPACT OF ABSTRACTION ON LOW FLOWS

4.1 Impact of different abstraction scenarios on individual catchments

This section illustrates the impact of different abstraction scenarios on three catchments with different geologies. The purpose is to identify the magnitude of the reductions in monthly minima and the seasons which are most susceptible, particularly in relation to the occurrence of zero flows.

The gauged natural time series of daily mean flows for three catchments were adjusted by the subtraction of multiples of MAM(7) using Method 1 to create synthetic time series of daily mean flows. The three catchments used are Greta at Rutherford Bridge (BFI=0.21), Medway at Chafford Weir (BFI=0.50) and Foston Beck at Foston Mill (BFI=0.95).

Mean monthly minima (MMM(7)) were calculated for each of the natural and synthetic data series. For each scenario, representing a different multiple of MAM(7), the adjusted MMM(7) was expressed as a percentage of the natural MMM(7). These data are presented for the three catchments for the summer months April to September in Figure 4.

For adjustments up to 1 x MAM(7), all of the MMM(7) are greater than zero, irrespective of the value of Base Flow Index. In the low BFI catchment the adjusted MMM(7) are greater than zero in all months up to the abstraction of 4 x MAM(7). In the other two catchments, the MMM(7) are in excess of zero for abstractions of up to 2 x MAM(7) in April and May.

In addition to the identification of the frequency of zero flows under different

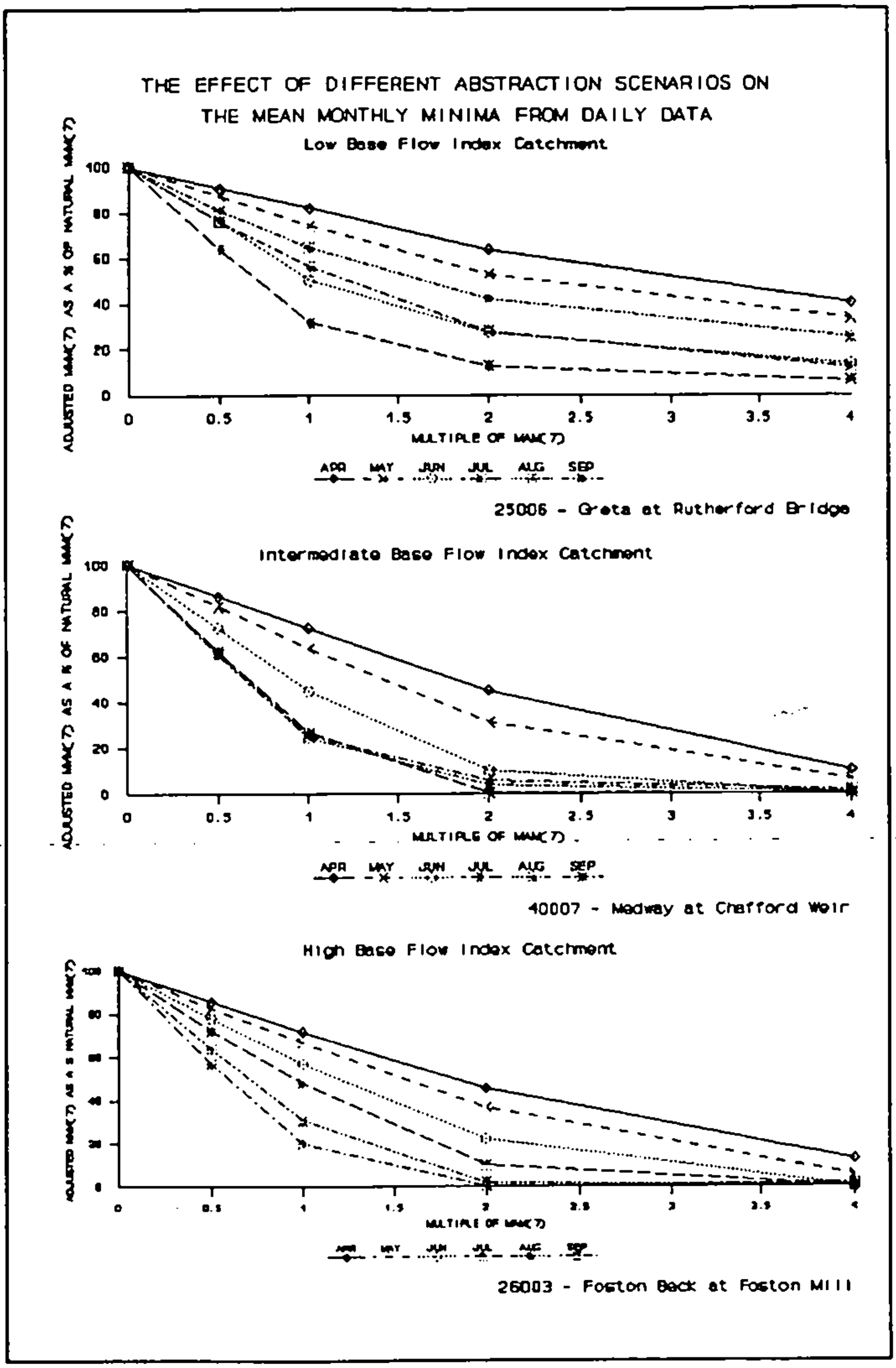


Figure 4 *The impact of abstraction scenarios on individual catchments*

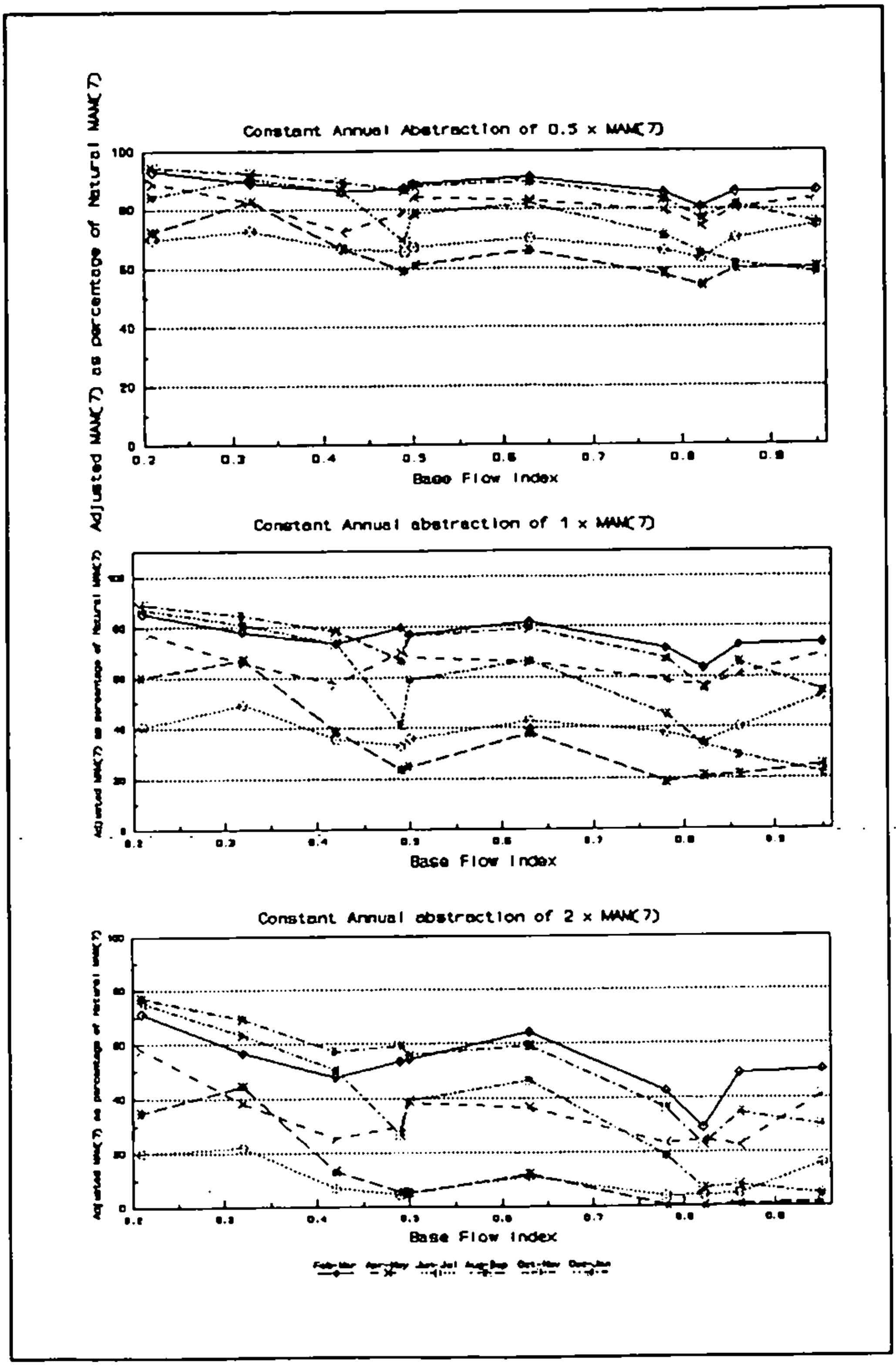


Figure 5 ***Annual variations in adjusted time series data with Base Flow Index***

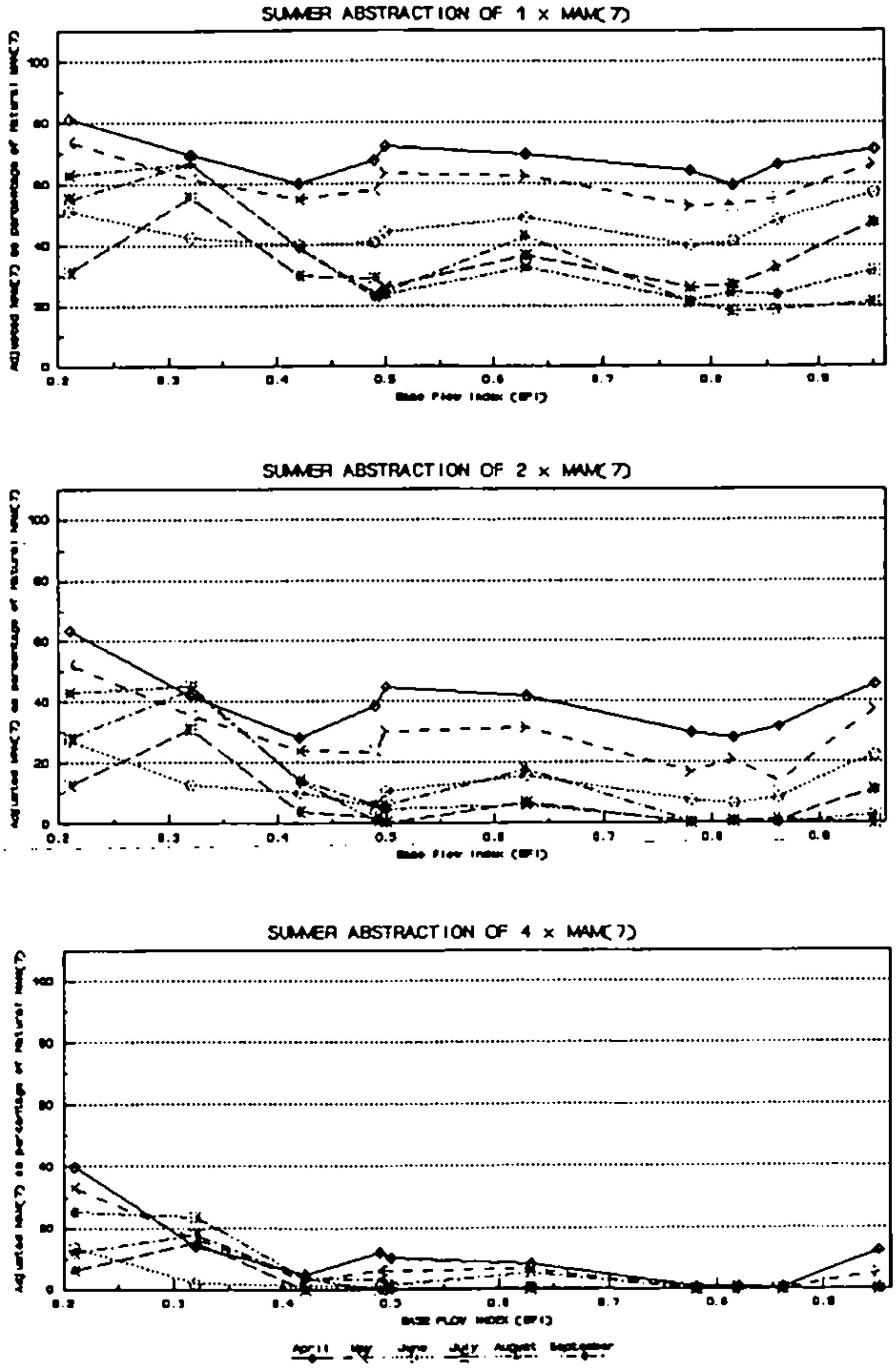


Figure 6 ***Summer variations in adjusted time series data with Base Flow Index***

abstraction scenarios, the graphs illustrate more generally the magnitude of the reduction in monthly minima with these three catchments.

4.2 National variations in the impact of different abstraction scenarios with the Base Flow Index

The investigation described in section 4.1 can be broadened to develop a general relationship between the adjusted MMM(7) as a percentage of the natural MMM(7) and the Base Flow Index for different abstraction scenarios. This is achieved firstly by the application of Method 1 to 10 natural time series of daily flows (section 4.2.1) and secondly by the application of Method 2 to 61 catchments which are grouped into nine BFI classes (section 4.2.2). The extension to 61 classes provides a broader basis for interpretation of the general relationships, but the data processing requirements associated with 61 catchments prohibited the application of Method 1.

4.2.1 General relationship between abstraction impact and Base Flow Index on ten catchments using Method 1.

Figure 5 illustrates the general relationship in the adjusted MMM(7) with Base Flow Index for three annual abstraction scenarios. Figure 6 illustrates the general relationships in the MMM(7) for abstraction scenarios during the summer period.

In general terms, the relative impact of abstraction scenarios based on multiples of MAM(7) become increasingly severe with increasing BFI values. The gradient becomes increasingly steep as the multiple of MAM(7) increases.

In addition, the occurrence of the most severely affected monthly minima varies with the Base Flow Index in reflection of the seasonality of natural monthly minima (section 3). In the low BFI catchments June/July are the most affected months, compared with August/September in the higher BFI catchments. The occurrence of zero flows is shown to be restricted to abstraction scenarios in excess of 1 x MAM(7) in catchments with BFI values greater than 0.75 and then only during the months of August and September.

4.2.2 General relationships between abstraction impact and BFI based on 61 catchments using Method 2

The general relationships presented in section 4.2.1 are based on ten catchments and because each BFI value is represented by a single catchment, the relationships can be sensitive to anomalies. In this section, 61 catchments were placed into nine BFI groups within the following ranges:

RANGE	BFI PLOTTING POSITION
0.00 - 0.25	0.2
0.26 - 0.35	0.3
0.36 - 0.45	0.4
0.46 - 0.55	0.5
0.56 - 0.65	0.6
0.66 - 0.75	0.7
0.76 - 0.85	0.8
0.86 - 0.95	0.9

Each BFI group was assigned a plotting position based on the middle value of the range within the group. The adjusted MMM(7) as a percentage of natural MMM(7) was calculated for each of the 61 catchments using Method 2. Method 2 was preferred to Method 1 because of the reduced data processing requirement. For each BFI group, the median value of the set of catchment adjusted MMM(7) percentages was calculated. The median values are plotted against BFI plotting position in Figures 7 and 8.

Figures 7 and 8 represent a more substantial and "smoothed" general relationship than Figures 5 and 6 because of the larger base of catchments analysed. However, the interpretations of Figures 7 and 8 are hindered by the underestimation of the MMM(7) values derived by Method 2 where zero flows occur. For this reason, interpretation of the scenarios based on 2 x MAM(7) should be used with caution.

4.3 Impacts upon the Flow Duration Curve

4.3.1 Impact on individual catchments

The impacts of abstractions on the long term Flow Duration Curves are illustrated in figures 9 & 10. In Figure 9, all daily flow values have been adjusted by subtraction of multiples of MAM(7). In Figure 10 only those flows in the period April to September have been adjusted.

As the rate of abstraction is increased, the percentage of time that flow is exceeded for a given discharge is reduced. The high flows are less severely affected by abstractions especially in the summer abstraction scenario.

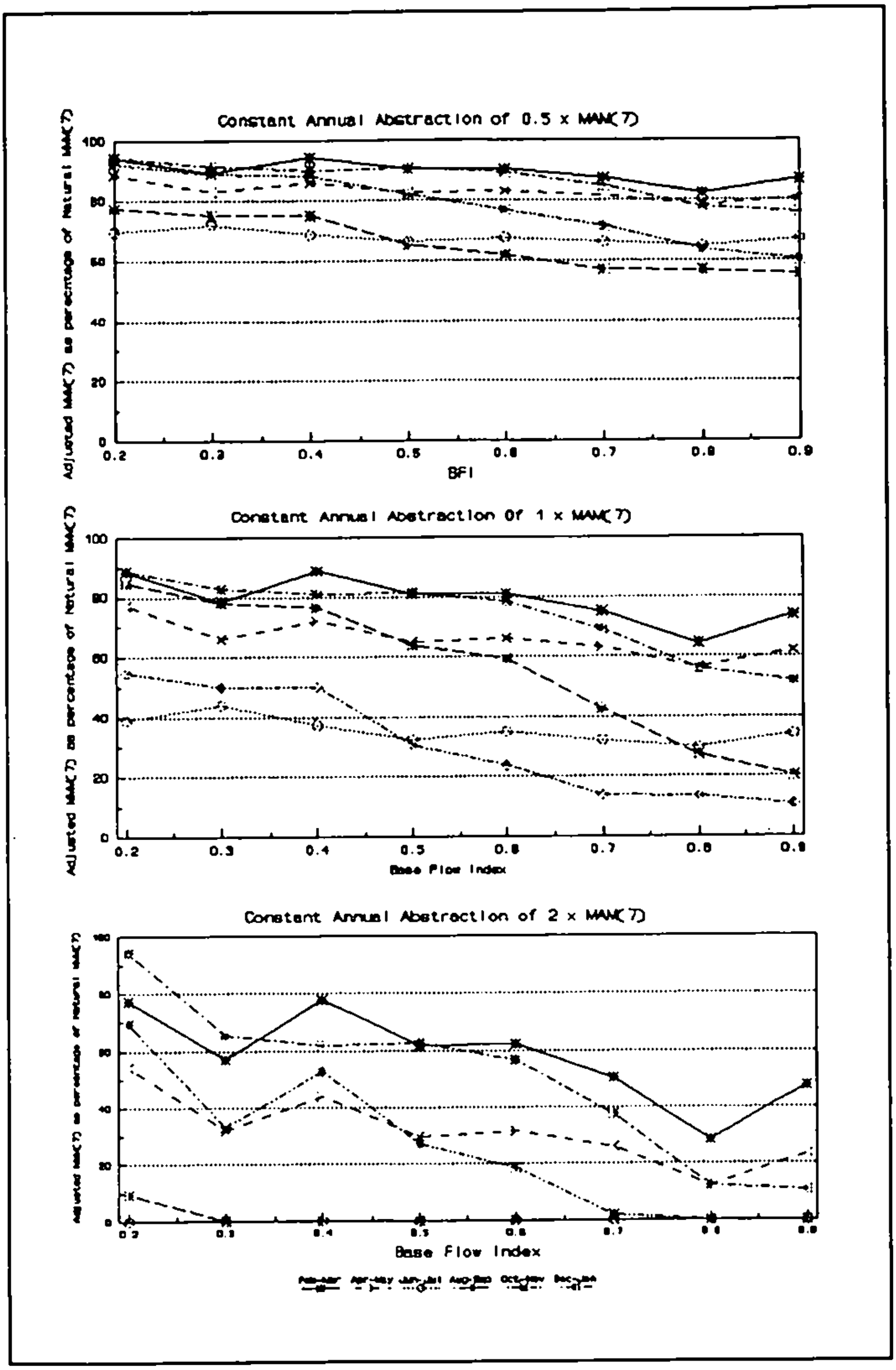


Figure 7 ***National variations with Base Flow Index as a result of annual abstraction rates***

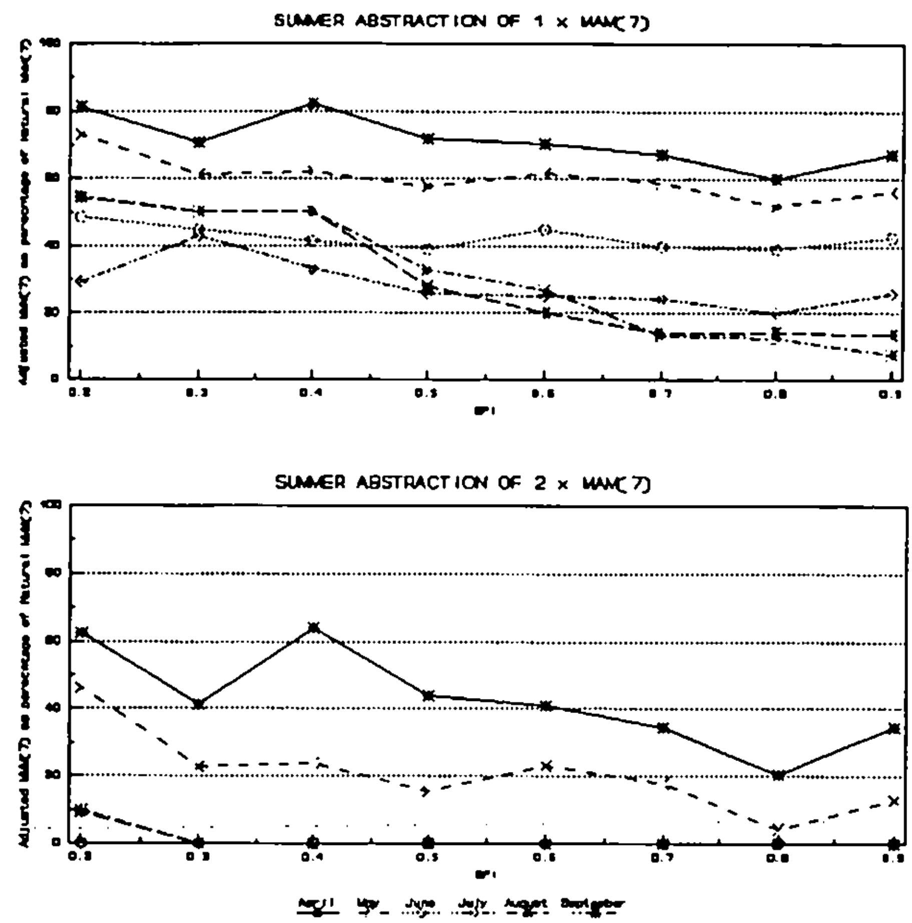


Figure 8 ***National variations with Base Flow Index as a result of summer abstraction***

4.3.2 General relationship upon Q95 and BFI of different abstraction scenarios.

The analysis described in section 4.3.1 was repeated for ten catchments which represent the range of the Base Flow Index. For each catchment, the natural Q95 and the Q95 under each abstraction scenario was calculated. These data are presented as a general relationship between Q95 and BFI under different abstraction scenarios in Figure 11.

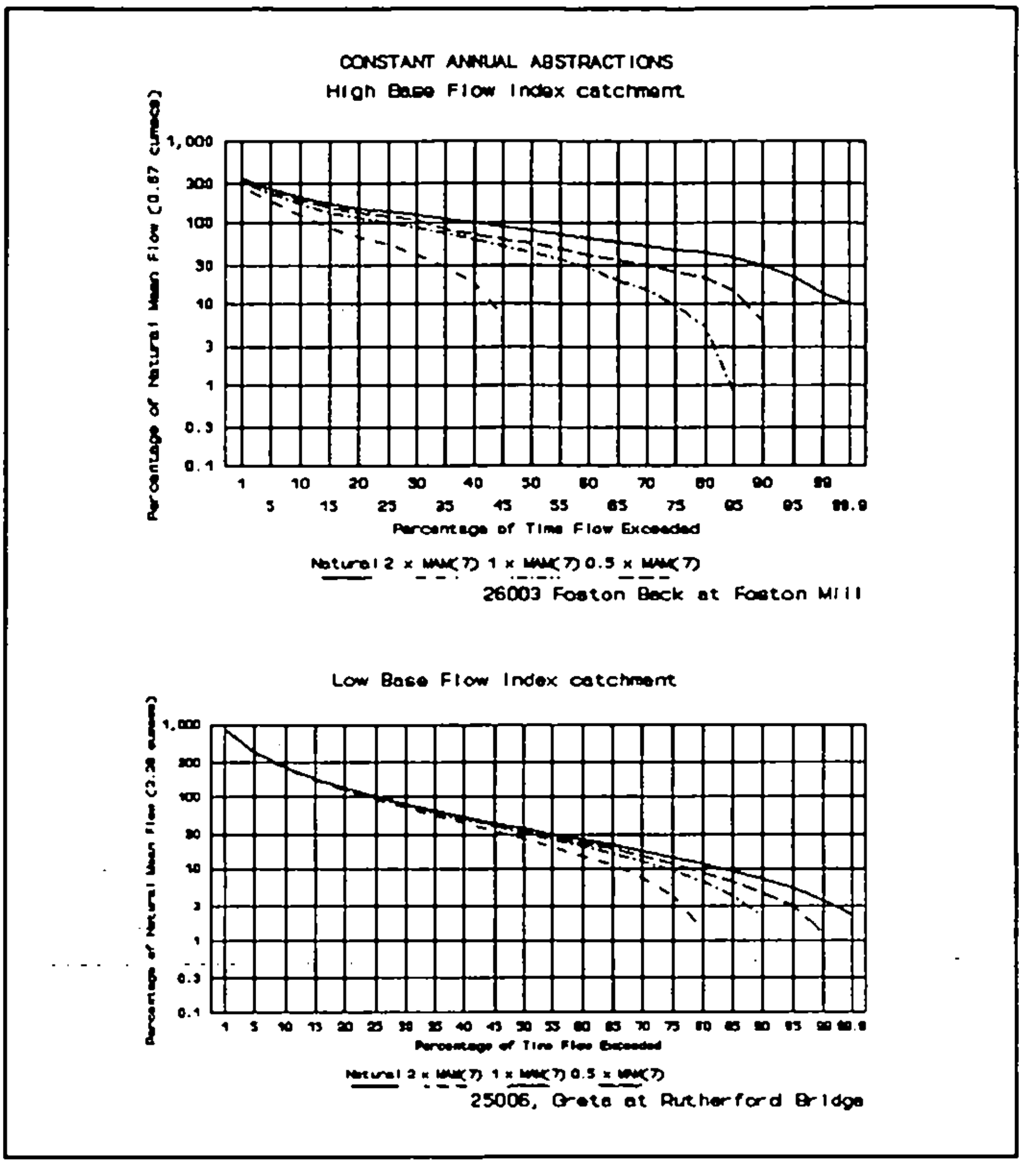


Figure 9 ***The effect of annual abstractions on the FDC***

Adjustment of the Q95 for abstraction regimes requires time series of data at this time. Further work is required to develop a procedure for adjusting a predicted Q95 statistic at ungauged sites

5 CONCLUSIONS

1. This report has investigated the magnitude and seasonality of abstraction impacts in catchments which represent the range of geological conditions in England and Wales. The objective has been to provide a base of information and experience in techniques for adjustment of natural low flow statistics at ungauged sites.

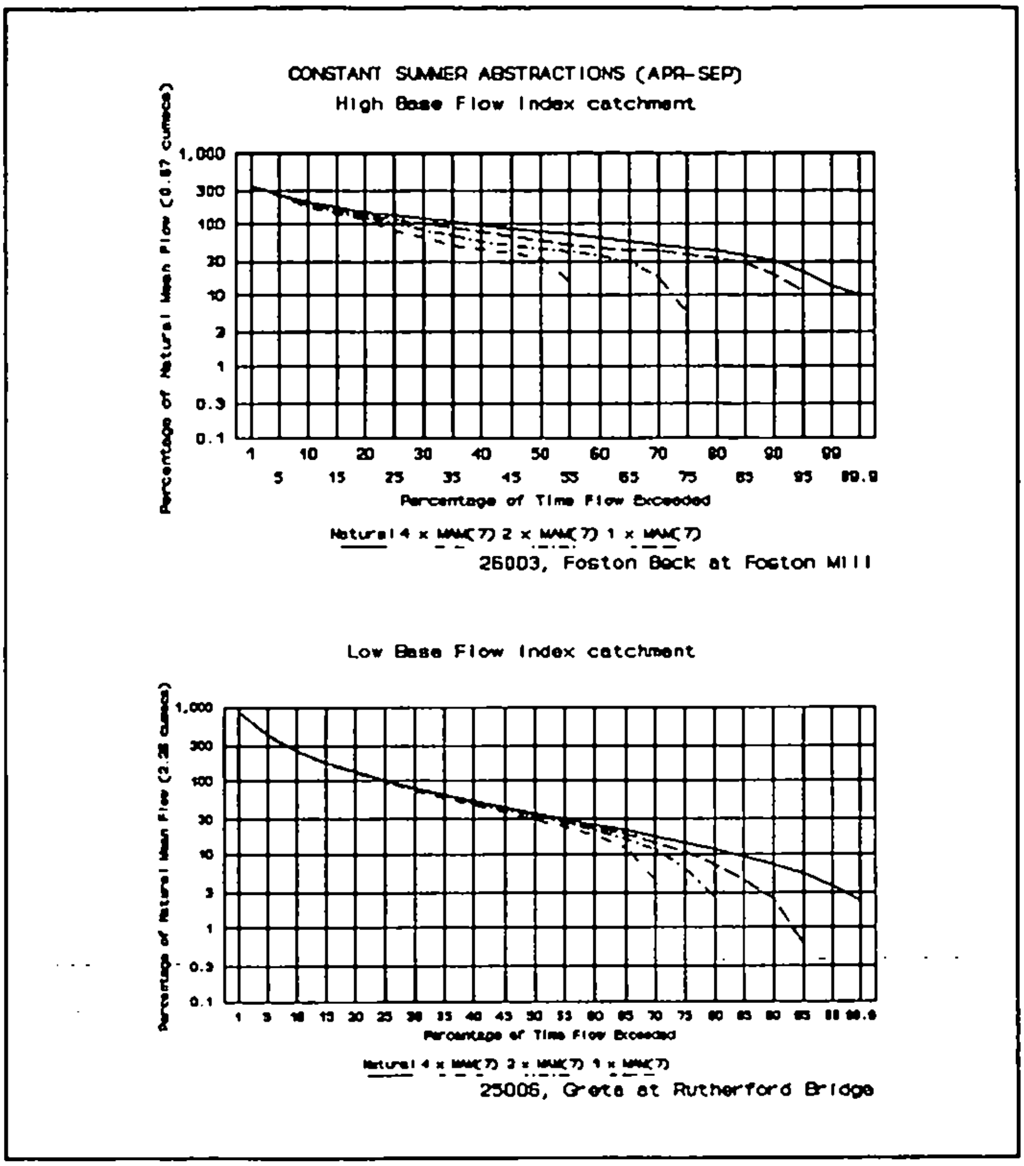


Figure 10 *Impact of summer abstractions on the FDC*

2. Analysis of natural flow regimes in ten catchments has shown that the magnitude and seasonality of low flows is closely associated with catchment geology. Lowest mean monthly minima are higher as a percentage of average flow and occur later in the year in catchments with higher BFI values.

3. The lowest mean monthly minima in catchments with BFI in excess of 0.8 occur most commonly in September or October, with minima of approxmately 40% of the mean flow. The lowest mean monthly minima in catchments with BFI less than 0.4 occur most commonly in June or July, with minima below 20% of the mean flow.

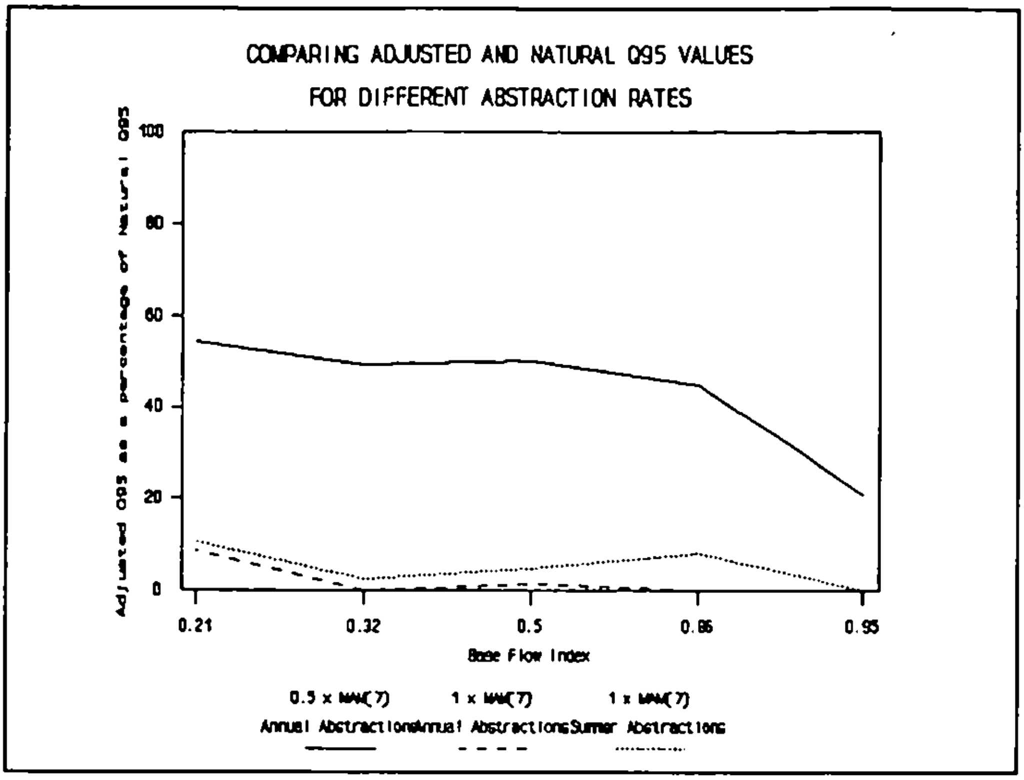


Figure 11 ***Relationship between impacts on Q95 and BFI***

4. The natural flow regime obviously determines the sensitivity of a catchment to abstractions. The relative impact of abstraction scenarios based on multiples of MAM(7) become increasingly severe with higher BFI values. The gradient becomes increasingly steep as the multiple of MAM(7) increases. In addition, the occurrence of the most severely affected month varies with the Base Flow Index, in reflection of the seasonality of the natural monthly minima.

5. Three methods of adjusting the mean monthly minima; adjustment of the gauged daily flow data (Method 1), adjustment of the long-term mean monthly minima (Method 2) and adjustment of the series of mean monthly minima (Method 3) are considered. Methods 1 and 3 require time series of data and only Method 2 can be applied to an estimated natural monthly minimum statistic at an ungauged site.

6. Differences between the three methods only exist when zero daily flows are introduced as a result of the abstraction. Where this is not the case, then Method 2 can be applied without difficulty to the adjustment of an estimated flow statistic. However, where zero flows do occur then the calculated monthly minima from Method 2 under-estimates the "true" monthly minima calculated from Method 1.

7. Based on the above analysis, it is recommended that Method 2 can be applied to

adjust monthly minima where the total abstracted is less than 2 x MAM(7), except in catchments in which the Base Flow Index is higher than 0.75. In such cases the calculated monthly minima for August and September using Method 2 will be in error. The extent to which Method 2 under-estimates the minima compared to Method 1 can be as high as 40% of the "true" monthly minima in a low BFI catchment.

8. These results provide a basis for understanding the sensitivity of low flows to different abstraction scenarios. In addition, they identify the limits within which estimated mean monthly minima statistics at ungauged sites can be adjusted by subtraction of multiples of MAM(7) without introducing errors associated with the introduction of zero flows.

9. The results will enable more appropriate adjustments to be applied to natural flow statistics for incorporation into the MICRO LOW FLOWS software.

REFERENCES

Institute of Hydrology; (1980); Low Flow Studies Report; Wallingford

ABBREVIATIONS

BFI	Base Flow Index
FDC	Flow Duration Curve
MAM(D)	Mean Annual D-day Minimum
MF	Mean Flow
MMM(D)	Mean D-day Minimum in each month
NRA	National Rivers Authority
PWS	Public Water Supply
Q95	95 percentile exceedence flow
SI	Spray Irrigation

Appendix 4 Dates of Advisory Committee Meeting

1st meeting: 30 January 1991 at the Institute of Hydrology

2nd meeting: 26 June 1991 at the Institute of Hydrology

3rd meeting: proposed 31 January 1992 at Kingfisher House,
NRA Anglian Region, Peterborough.