A DECISION SUPPORT SYSTEM FOR AN INITIAL 'LOW-CONFIDENCE' ESTIMATE OF THE QUANTITY COMPONENT OF THE RESERVE FOR RIVERS.

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Table of Contents **Page**

1. INTRODUCTION 1
   1.1 Warning 2

2 STRUCTURE OF THE DSS 3
   2.1 Natural time series preparation 3
   2.2 Setting the ecological management class 4
   2.3 Annual IFR component determination 4
   2.4 Monthly distribution determination 5
   2.5 Establishing the assurance rules 5
   2.6 Summarising the results and generating output data 6

3 NATURAL TIME SERIES PREPARATION (July 1999) 6
   3.1 Within RESDSS (Site specific applications) 6
   3.2 Within SARES 8

4 SETTING THE ECOLOGICAL MANAGEMENT CLASS (March 1999) 10
   4.1 Present status estimation 10
   4.2 Ecological management class by ecological importance and sensitivity . . . 12

5. ANNUAL IFR COMPONENT DETERMINATION (August 1999) 14
   5.1 Flow variability index 14
   5.2 Index of baseflow 15
   5.3 A combined index and estimation of maintenance IFR components 16
      5.3.1 Maintenance low flow requirements 17
      5.3.2 Maintenance high flow values 19
   5.4 Drought IFR components 20
   5.5 Parameter file for the DSS 20
   5.6 Using IFR workshop results 21

6. MONTHLY DISTRIBUTION DETERMINATION (August 1999) 22
   6.1 Monthly distributions of low flows (maintenance and drought) 22
   6.2 Monthly distributions of high flows 24
   6.3 Manual adjustment of monthly values 27

7. ESTABLISHING THE ASSURANCE RULES (August 1999) 28
   7.1 Generic assurance rules and assurance curves 28
   7.2 Additional high flows at low assurance 31
   7.3 User intervention in the assurance rules 32
   7.4 Use of the assurance rules to generate modified time series 33

8. RESULTS SUMMARY AND OUTPUT DATA GENERATION (July 1999) 33
   8.1 Program RESDSS 33
   8.2 Program SARES 35
   8.3 Proposed future options 36

9. REFERENCES 37

List of Tables

3.1 Format of text file input to RESDSS . . . 7
3.2 Part of the quaternary 'Tree Structure' text file . . . 8

4.1 Habitat integrity scoring system according to Kemper & Kleynhans (1998) . . . 10
4.2 Criteria and scoring weights for habitat integrity . . . 10
4.3 Preliminary present status classes based on total scores . . . 11
4.4 Scoring system for EMC according to Kleyhans et al. (1998) . . . 13
4.5 Present status scoring system according to Kleyhans et al. (1998) . . . 13

5.1 Range of CVB index values for all quaternary catchments . . . 16
5.2 Parameter values of the equation to estimate the annual total maintenance low flows . . . 17
5.3 Parameter values of the equation to estimate the annual total maintenance total (low plus high) flows . . . 19
5.4 First part of HYDRO.PAR containing the parameters of the annual IFR estimation equations . . . 21

6.1 Regional parameter values for the monthly distributions of annual values, as well as the assurance rules . . . 25
6.2 Monthly high flow distribution example using quaternary D16D in the Drakensberg region . . . 27

List of Figures

5.1 Maintenance low flow estimation curves over CVB index values 1 to 10 . . . 18
5.2 Maintenance low flow estimation curves over a wide range of CVB index values . 18
5.3 Maintenance total IFR requirements for EMCs A, B, C and D . . . 20

7.1 Examples of generic assurance rule curves for the month of January for region 13 (D'Berg) and region 4 (E.Karoo) . . . 30
7.2 Illustration of the variation in Critical % Assurance and the maximum value (relative to maintenance high flow requirement) of the added high flows for different shape parameters . . . 32

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1. INTRODUCTION

This documentation is designed to be read by users who are reasonably familiar with the basic concepts underlying the quantification of instream flow requirements (IFRs) and the methods used within South Africa. It also assumes some familiarity with the concepts of the 'Ecological Reserve' and the role that it plays in the new legislation relating to management of water resources in South Africa. Readers unfamiliar with these concepts are recommended to the reference section of the document where there are listed a number of recent publications that are referred to in this document.

During the late 1980s and 1990s, the IFR for rivers in South Africa were quantified using the 'Building Block Methodology' (BBM) which is summarised in King and Louw (1998) and fully described by King, et al., (1999) and will be briefly summarised later in this document. As the new South African Water Law was developed during 1997 and 1998 in preparation for its implementation starting in 1999, it became apparent that more rapid methods of assessment were required. This led to the concepts of the 'Planning Estimate' and the 'Preliminary Reserve'. These are now referred to as the 'Desktop estimate' and the 'Intermediate determination', while the most detailed type of study is called a 'Comprehensive determination'.

The desktop estimate began to be viewed as an initial low-confidence estimate that could be applied very rapidly at a large number of sites to provide a first guess at the likely amounts and distribution of water required to sustain the ecology in a given condition. However, it was always made clear that such an estimate should never be considered the final value to be used for managing a river system. The main purpose of the desktop estimate concept was to generate initial values for all the quaternary catchments of the country to provide input to the National Water Balance Model (van Rooyen and de Jager, 1998), developed during 1998 and 1999 to provide a national database on the existing available yield from all the river systems of South Africa. The concept was to determine the yield from the natural flow regimes less that water which is already being used by existing water resource developments, existing streamflow reduction activities (afforestation, etc.) and that which is required to satisfy the reserve (for both basic human needs and the ecology). It was clear that the application of the more detailed methods to so many sites (1946 quaternary catchments) would be impossible and that a very rapid method was required. It was also clear that our knowledge and understanding of the variability of eco-hydrological relationships throughout the country is not advanced enough to be able to develop a method that would provide anything more than a low-confidence estimate.

Conservative!

The initial implementation of the new Water Act during 1999 also meant that there would be many occasions when estimates with much higher confidence would be required and where there would not be enough time (or financial resources) to apply the full BBM. The intermediate determination methodology was therefore developed as an approach which was based on the same principles as the BBM, but uses fewer resources of time and money. The details of the intermediate determination and its development are documented on the web site of the IWQS (Institute for Water Quality Studies - http://iwqs.pwv.gov.za/cgi-bin/password.pl).

In establishing a possible method for the desktop estimate the authors considered that it should form the lower end of a continuum of approaches, the BBM (or equivalent) forming the upper end and all the methods being based on the same fundamental principles of relating ecological response to changes in flow regimes. The strength of such a system should then be that developments in understanding that emerge from the application of the more complex approaches would 'feedback' to the simpler approaches and improve the confidence of the estimates. A further consideration in developing the desktop estimate was that, while it is mainly designed for application of regional 'generic' type relationships at a large number of sites, it should also be applicable at sites where additional information is available and where the results of the generic relationships could be modified to improve the confidence of a quick estimate. Thus the requirements of the decision support system should include a facility for 'manual override'.

This document therefore represents a 'User Manual' to guide a potential user through the use of the computer programs that comprise the DSS, as well as an explanation of the source of the components of the DSS. The detail of these components are likely to change quite rapidly during the initial period of the DSS usage and all prospective users are advised to consult the web site of the Institute for Water Research (http://www.ru.ac.za/departments/iwr) for the most up-to-date version of this manual (see date of latest revision on the first page). More detail on the nature of each of the revisions is included in the headings of the main methodology sections of this document. Revised versions of the software and associated databases will also be available from the IWR (consult the web site for details).

1.1 Warning

The final paragraph of this introduction provides a warning to all potential users and a disclaimer from the authors.

The results given by the generic regional relationships that form the default options of the DSS have to be considered as initial low-confidence estimates and should not be considered as the final answer. While every attempt has been made by the developers of the method to incorporate as much as possible of the current understanding of the relationships between ecological functioning and flow regimes of rivers, there is no guarantee that the estimates given by the DSS will be close to estimates provided by methods based on the inputs from a range of ecological specialists and more detailed site specific information.

The results are therefore NOT scientifically defensible and anyone ignoring this warning and using them out of context does so at their own risk.

2. STRUCTURE OF THE DSS

The DSS consists of two computer programs written using the DELPHI language, as well as some accompanying data files and database tables. The first program (*RESDSS*) is designed for site specific applications of the methodology and incorporates various facilities for user intervention and the ability to manually adjust certain of the estimated values. The second program (*SARES*) provides a facility to rapidly access an initial low-confidence estimate of the quantity component of the Reserve for rivers at the outlet of any quaternary catchment in the country, but provides for virtually no user intervention.

Both programs rely on six basic procedures to provide the required information. These are summarised below, but discussed in more detail within later sections of this document.

It is the detail of these later sections that is most likely to change during the revision process and each section heading is followed by a date that represents the most recent revision. These dates can be compared with the date of the version of the software.

A further two programs (*WR90MAN* and *IFREDIT*) are provided for some database management functions. *WR90MAN* allows the Paradox database of quaternary WR90 data to be constructed and edited, as well as individual quaternary catchment incremental flow time series to be viewed. *IFREDIT* provides a program untility for entering the results of IFR workshops into a Paradox database, which is then available if the user wishes to override the monthly table of ecological flow requirements that are estimated from the regional generic relationships (see sections 2.3 and 2.4).

2.1 Natural time series preparation

The method has to be based on readily available information and the only flow data that have been generated countrywide are the monthly time series for quaternary catchments included in WR90 (Midgley, et al., 1994). The flow time series provided are incremental flows for all 1946 quaternary catchments covering South Africa, Lesotho and Swaziland, while for IFR determination, accumulated flows at quaternary outlets are required.

Within *RESDSS* the user selects the quaternary catchments to be included, either by selecting a group of files from the WR90 CD ROM (or alternative source of the same files), or a group of records from the paradox database of WR90 flow data compiled by the IWR (and available with the DSS software). The individual time series are then simply accumulated into a single time series representing flow at the outlet of the most downstream quaternary. It is therefore the users responsibility to select the appropriate files or database records. ***It is now accepted that there are problems with some of the original WR90 time series related to the way in which they were naturalised to account for afforestation influences.*** New versions of the data sets are expected to be available soon and will be incorporated into the IWR versions of the database as soon as possible.

One problem with the simple accumulation of quaternary time series is that there is ***no account taken of natural losses that might occur during the transmission of flows generated upstream as they pass through successive downstream quaternary catchments***. This is unlikely to be a problem in many catchments, particularly in the wetter parts of the country and where the total catchment area is not very large (less than several thousand km^2). However, this becomes an important issue where headwaters of catchments lie in relatively wet, high runoff areas and then pass through drier parts of the country. No account of such losses is allowed for in ***RESDSS*** but the user is not restricted to using standard WR90 data sets. For more accurate representation of accumulated streamflow regimes in such cases, users are recommended to generate their own time series, the only restriction being that the file format should be the same as the standard WR90 data files.

As ***SARES*** is designed to be a stand-alone method using WR90 data (original or updated) without user intervention, it was necessary to include an attempt to account for losses during accumulation. The accumulation process is automatic and based on a file representing the 'tree structure' of quaternary catchments (provided with the software), while losses are estimated using a simple approach based on mean annual net evaporation as well as the sizes of the quaternary catchment and the total accumulated catchment. The details of this approach are provided in Section 3.

2.2 Setting the ecological management class

Within ***SARES*** the default ecological management classes (EMCs) for all the quaternary catchments has been derived from the Provincial assessments carried out as part of the National Water Balance Model project. These are meant to be the first guesses of the likely EMCs, but include no consideration of the views of local stakeholders. There are no procedures within ***SARES*** for determining the EMC, but the classes can be changed and the Reserve requirements regenerated if necessary.

Within ***RESDSS*** both the present status and the default management class can be determined following the procedures of Kemper and Kleynhans (1998) and Kleynhans, et al. (1998). The present status of the instream and riparian components are determined using the habitat integrity scoring system of Kemper and Kleynhans (1998) which is usually applied on a river reach (about 5 km long) basis, prior to IFR workshops. The default management class determination is based on the ecological importance and sensitivity scoring approach of Kleynhans, et al. (1998). More details are provided in Section 4, although the original references should be consulted if the user requires more information about the background and motivation for these approaches.

2.3 Annual IFR component determination

The BBM normally quantifies monthly values for four components of the IFR. These are the maintenance and drought low flow requirements and the maintenance and drought high flow requirements. The first step in the DSS procedure is to estimate the annual values of these four components as a percentage of the mean annual runoff of the natural flow regime. The estimation equations were initially based on an analysis of past IFR results in which reasonable confidence could be expressed in the outcome. This process was totally based on the hydrological characteristics of the flow regimes and is documented in Hughes, et al. (1998), a copy of which is included on the IWR web site.

Subsequent to the development of the initial estimation approaches, a short term project (financed by the WRC) was started to try and build more ecological information into the estimation procedures. The current (or final) results of that project are given in Münster and Hughes (1999), also included on the web site. Section 5 provides detailed information on the estimation equations for the annual Reserve requirements used within the current DSS.

2.4 Monthly distribution determination

The annual values of the Reserve components are based on a single set of estimation equations that are applied to all parts of the country (although later revisions may include regional corrections), while the distribution of these values into monthly values will inevitably vary according to regional flow regime characteristics. The monthly distribution procedures are therefore based on regionalised sets of parameters which have been determined from a countrywide analysis of the seasonal baseflow and highflow characteristics of South African rivers. Within ***RESDSS*** the user is required to select the region most appropriate to the individual river system being dealt with, while in ***SARES*** the default region is provided as a field within the database. A GIS coverage and text file of the regions associated with the outlet of all quaternary catchments is provided with the software, while more details about the regionalisation process is provided in Sections 6 and 7.

It is now possible to select an existing IFR workshop result from a database and replace the annual values and monthly distribution with those volumes that were set by the specialists.

2.5 Establishing the assurance rules

Before the monthly distributions of IFRs can be considered useful for water resource planning and management, it is necessary to determine a basis for deciding when the maintenance (or above) components of the recommended flows should apply and when lower flows (i.e. down to and including the drought recommendations) should apply. During 1997 and 1998, these decisions were made during a number of workshops on the basis of a model (Hughes, et al., 1997) which allows a set of rules to be applied and the results visualised, by the various specialists, through representative time series of IFR modified flows. The model could then be 'calibrated' until the specialists were satisfied that the rules were generating an adequate pattern of frequency of occurrence of maintenance and drought flows. A similar system has been incorporated into the DSS based on monthly data and these are referred to as 'Assurance Rules'. They are essentially curves relating the % of time that certain flows will be equalled or exceeded in the modified flow regime and can be used in conjunction with the natural time series and associated flow duration curves to generate representative time series of flows required to satisfy the Reserve requirements.

The same regions referred to in Section 2.4 have been used to define generic curve shapes on the basis of the hydrological characteristics of the natural flow regimes of the regions and following guidelines and principles discussed during past IFR workshops with a number of specialists. The generic curve shapes are fixed within the ***SARES*** program, while they form the default shapes, which can be modified by the user, within the ***RESDSS*** program. More details and example curves are provided within Section 8.

2.6 Summarising the results and generating output data

The final result of the application of the DSS using either program is a representative time series of monthly flow volumes (the same length as that used to represent the natural flow regime) recommended for the quantity component of the Ecological Reserve for the selected management class. However, both programs can also generate a table of assurance rules that can be used by the Water Resource Yield Model, a systems model used extensively by DWAF (and associated consultants) for determining the yields of complex systems under alternative scenarios of development and water use. Section 9 provides more details of the output and summary options.

3. NATURAL TIME SERIES PREPARATION (*Dated July 1999*)

To conform to the principle that the DSS should be applicable to as many sites within South Africa as possible without the necessity to expend resources to prepare hydrological data, the system is based on the use of time series data with a resolution of 1 month. Such data are readily available for all quaternary catchments within South Africa, Swaziland and Lesotho from the WR90 (Midgley, et al., 1994) CD ROM which is available from the Water Research Commission. However, it has been recently recognised that the way in which these data were generated in catchments where there have been significant afforestation influences does not conform to our present understanding of the differential influences of afforestation on low and high flows. These data sets are therefore currently being updated and corrected time series are expected to be available in the near future.

A further problem with the use of WR90 data is that any analyses will inevitably be restricted to quaternary scale catchments. While many of the results generated by the DSS are provided as values in % MAR and can therefore be scaled down, there are currently no clearly defined guidelines for down-scaling from quaternary flow regimes to smaller catchments.

The final problem with the use of WR90 data is that the raw time series are only for incremental flows (i.e. those flows generated within the quaternary catchment itself) and no guidelines are provided for estimating transmission losses when a number of incremental flow time series are accumulated to provide a total time series at the outlet of a quaternary catchment.

The WR90 data that are currently used by the Institute for Water Research are the updated time series that have modified afforestation influences included in them. This modification arose due to a change in the approach used to naturalise the flow regimes for those catchments affected by afforestation. The old approach used during the initial compilation of the WR90 data sets has been changed.

3.1 Within *RESDSS* (Site specific applications*)*

RESDSS allows the monthly time series that will be used to create a representative time series of natural flows at the site of interest to be accessed from two different sources.

Individual text data files :

A user is not restricted to using WR90 files but the format of the input files has to be identical in most respects to the WR90 data files contained on the CD ROM and illustrated in Table 3.1. The following are the critical format specifications :

- There must be three lines of text (blank lines are acceptable) before the real data starts.
- The 'R' of region in the first line is used to recognise the start of the data title.
- The ':' before the quaternary catchment number is used to recognise the start of the quaternary ID.
- The year must be given as a full four digits.
- The monthly data must start with October.
- The 12 monthly values must be separated by a least one space.
- The annual total at the end of each line is optional.
- The monthly values must be given in $m^3 * 10^6$ (million cubic metres).
- WR90 data start in 1920 and are 70 years long. This is not fixed and the start year and length of record can be varied
- The average monthly values and any text comment lines at the bottom of the file are optional.

Table 3.1 Format of text file input to ***RESDSS***

```
REGION C  SIMULATED NATURAL RUNOFF FOR QUATERNARY : C11A    (MILLION CUBIC METRES)

YEAR    OCT     NOV     DEC     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     TOTAL
1920   46.63   12.42    1.04     .53     .59   27.89    9.56     .22     .11     .09     .06     .07     99.21
1921    5.48   43.16   17.27    1.75     .59     .50     .25     .24     .31     .23     .26     .26     70.31
1922   45.31   28.34   14.14   39.45   12.55     .23     .08     .07     .08     .10     .09     .05    140.50
.
.
.
1987   25.92   48.20   14.32     .77     .43     .39     .28     .13     .14     .21     .16     .19     91.14
1988   17.39    6.20    4.72    1.95     .95     .51     .14     .13     .70     .62     .25     .10     33.66
1989     .23   25.22    9.06     .42     .81     .89    1.18     .66     .19     .09     .07     .04     38.82
AVE     5.06   12.26   10.01   11.00    7.32    4.55    2.20     .79     .30     .24     .20     .65     54.56

NOTE: YEAR 1920 IS YEAR OCT 1920 THROUGH SEPT 1921
```

Using this option it is possible to prepare time series data files that incorporate losses down a system, or that represent flow regimes at sub-quaternary scales.

The WR90 data files do not contain any information about the area of the quaternary catchment and these areas are not explicitly required by the program. However, they can be entered manually by highlighting the quaternary catchment in the list displayed on the screen and entering the area in the edit box provided. The total area will then be accumulated as quaternary data sets are added.

IWR database records :

The second available option is to access WR90 data from a Paradox database (with a table name of ***WR90***) that has been established by the Institute for Water Research. These data are stored as BLOBs (Binary Large Objects) together with information on the quaternary name, catchment area, hydrological zone, response zone, MAR, MAP and MAE for all the quaternary catchments in the country. An additional program (***WR90MAN***) is available to provide some facilities to manage and edit the database. If this option is chosen, the user is restricted to selecting only WR90 data that starts in 1920 and extends for 70 years.

Regardless of the source of the data, all the time series that are selected are then accumulated into a single total time series. While both sources can be mixed (i.e. some data from text files and some from database records), ***it should be made clear that they should all start with the same year and have the same length record.*** There are no facilities within the program at present to filter out only those data that are coincident across all the selected files/records. ***There is a restriction in the program that a maximum of 50 original time series data sets can be accumulated.***

When all the original data sets have been selected the accumulated time series data are determined and some summary statistics displayed on the screen. Further options allow the total time series to be written to a text file (WR90 format) for re-use later and for all the incremental time series to be cleared and the accumulation process started again.

A recent addition to the program allows the mean annual runoff of the accumulated flow time series to be changed by the user through applying a percentage correction factor. The individual months of the time series are adjusted by the same percentage value, the effect being a simple constant percentage correction. This may be required in those cases where the site of interest is not at an exact quaternary boundary and the user needs to make an adjustment to the overall natural flow volume.

3.2 Within SARES

The ***SARES*** program is designed to operate only on WR90 data from the IWR's Paradox database (table ***WR90***) and the total natural time series for the outlet of all quaternary catchments are created automatically by the program from a data file containing the 'Tree Structure' (or linkage structure) which defines all the upstream quaternaries (Table 3.2).

Table 3.2 Part of the quaternary 'Tree Structure' text file used to define the upstream catchments above all quaternary catchments in the country (Sabie catchment).

```
X31A   0
X31B   1
 1  1  X31A
X31C   0
X31D   2
 1  2  X31B  X31C
 2  1  X31A
X31E   0
X31F   0
X31G   1
 1  2  X31E  X31F
X31H   0
X31J   1
 1  1  X31H
X31K   3
 1  3  X31D  X31G  X31J
 2  5  X31B  X31C  X31E  X31F  X31H
 3  1  X31A
X31L   0
X31M   4
 1  2  X31K  X31L
 2  3  X31D  X31G  X31J
 3  5  X31B  X31C  X31E  X31F  X31H
 4  1  X31A
```

As each upstream quaternary is loaded automatically in the program (starting with the headwater areas), a potential mean annual transmission loss value is also estimated on the basis of the mean annual net evaporation and two size factors. The first size factor (*LENGTH*) is used to represent the channel length within the quaternary and is estimated (in units of km) from :

$$LENGTH = (Quaternary\ area)^{0.5} \quad \text{Eq. 3.1}$$

The second size factor (*WIDTH*) is used to represent the channel and riparian width and is estimated (in units of m) from :

$$WIDTH = 4.5 * (Total\ Upstream\ Area)^{0.32} \quad \text{Eq. 3.2}$$

Mean annual losses (*MAL*) are then estimated from the following equation :

$$MAL = (MAE - MAP) * LENGTH * WIDTH * 10^{-6} \quad \text{Eq. 3.3}$$

Where MAE and MAP are mean annual evaporation and rainfall depths (mm) respectively;
the units of MAL are $m^3 * 10^6$
and MAL is limited to positive values.

The value of MAL is compared with the accumulated MAR at the upstream end of the quaternary and if MAR is less than MAL, then MAL is reduced to the accumulated MAR (i.e. it is not possible to have more losses than water available). Individual accumulated monthly values are then reduced by 1/12th of the MAL.

While the approach to estimating losses clearly has its limitations and does not adequately cater for seasonal, nor dry/wet year variations, it does at least provide an estimate that is better than not allowing for losses at all. The results for various points along the lower Orange River have been compared to estimates of losses given for the same sites by McKenzie and Craig (1997) and there is reasonable agreement (however, the power and scale parameters in the estimate of width was largely based on the Orange River estimates, such that this agreement was inevitable).

The *SARES* program generates (or updates) a database table (named *WR90RES*) and one of the fields is the total MAL of the accumulated flow record at the quaternary outlet. Users are therefore able to compare these values with the accumulated MAR and their own perceptions of likely losses within specific river systems. ***Any comments on practical (and simple) methods that could be applied to improve the loss estimates will be gratefully received by the developers.***

4. SETTING THE ECOLOGICAL MANAGEMENT CLASS (*Dated March 1999*)

Within the *SARES* program, the Ecological Management Class (EMC) is specified within a field in the database table using an integer value, where 0 represents class A, 1 class A/B and the lowest class possible is 6 or class D. In both programs classes intermediate between the standard classes of A, B, C and D have been used to extend the flexibility of the estimates and to allow for borderline cases. Thus A/B (or 1), B/C (or 3) and C/D (or 5) represent those situations where the EMC is expected to lie at the upper end of the lower class or the lower end of the upper class.

Consult will
determine
by EMC

SARES assumes that the EMC has been previously determined and forms part of both the **WR90** and *WR90RES* database tables. The program has no facilities for estimating the class. ***If the class is changed within the database then the IFR estimates should be re-generated to ensure that the other information contained within the database table is compatible with the current EMC.***

RESDSS includes specific components to allow the EMC (and Present Status) to be estimated, although these procedures need to be carefully checked.

4.1 Present status estimation

These procedures are based on the methodology presented in Kemper and Kleynhans (1998) using a scoring system to assess the habitat integrity of a reach of a river. The details of and motivation for the approach are available from the original reference but essentially the method relies on being able to specify scores for various impact criteria (water abstractions, flow modification, channel modification, indigenous vegetation removal, etc.) on either the instream or riparian environments, or both.

The basis of the scoring system is summarised in Table 4.1 and the program allows the user to first specify the impact class and then adjust the final score within the given ranges.

Table 4.1 Habitat integrity scoring system according to Kemper and Kleynhans (1998)

Impact Class	Range of Scores
None	0
Small	1 to 5
Moderate	6 to 10
Large	11 to 15
Serious	16 to 20
Critical	21 to 25

Once the scores for all the impact criteria for instream and riparian environments have been entered a series of weighting factors are applied and the preliminary present status class is estimated. The criteria and scoring weights are given in Table 4.2.

Table 4.2 Criteria and scoring weights for habitat integrity (Kemper and Kleynhans, 1998)

Instream Zone	Weight	Riparian Zone	Weight
Water abstraction	14	Water abstraction	13
Flow modification	13	Flow modification	12
Bed modification	13		
Channel modification	13	Channel modification	12
Water quality	14	Water quality	13
Inundation	10	Inundation	11
Exotic macrophytes	9	Bank erosion	14
Exotic fauna	8	Exotic vegetation encroachment	12
Solid waste disposal	6	Indigenous vegetation removal	13
TOTAL	100	TOTAL	100

The score contribution of each criterion is calculated as follows :

*Weight * Score / Maximum Score* .... Eq. 4.1

After which they are all summed to provide a total for both instream and riparian environments. The present status can then be estimated within ***RESDSS*** using the guidelines given in Table 4.3. The fact that these are not based on exactly the same scoring system as the original Kemper and Kleynhans (1998) procedure is not really that important as the Present Status class is only used to define a default EMC. The user can then over-ride the default value as required.

Table 4.3 Preliminary present status classes based on total scores

Class	Brief Description	Score
A	Unmodified	94 to 100
A/B	Transitional A to B	88 to 93
B	Largely natural with few modifications	82 to 87
B/C	Transitional B to C	75 to 81
C	Moderately modified	65 to 74
C/D	Transitional C to D	55 to 64
D	Largely modified	45 to 54
D/E	Transitional D to E	35 to 44
E	Natural habitat loss extensive	25 to 34
E/F	Transitional E to F	15 to 24
F	Modifications at a critical level	0 to 14

Any number of reaches can be specified in the program component that sets the present status scores, although this is not the normal procedure by which an estimate of the EMC would be derived. The normal procedure would be to use the Ecological Importance and Sensitivity procedure outlined in the following section.

4.2 Ecological Management Class by Ecological Importance and Sensitivity

The procedures explained in Kleynhans et al. (1998) have been incorporated into the ***RESDSS*** program as accurately as possible (Tables 4.4 and 4.5), but there still appear to be some inconsistencies due largely to the developers mis-interpretation of the use of the scoring system. ***These need to be resolved before the scoring system within RESDSS can be used with any confidence. The approach generally used was changed during July/August 1999 but this has yet to be incorporated into the DSS.***

Even if the current system that is coded into ***RESDSS*** is used, the final management class to be used in setting the IFR values can be changed by the user.

The average of the first 8 category scores is used to estimate the EMC, with the limitation that if this average is lower than either of the scores for the modifying determinants then the highest of their scores is used. There are also a few other over-riding factors that control the final score.

Table 4.5 presents the basis of the scoring system used by Kleynhans et al. (1998) to determine the present status of a river. The class is based on the average of the scores for the 5 criteria.

Table 4.4 Scoring system for EMC according to Kleynhans et al. (1998)

Category/criterion	Score: high = Important or Sensitive
Indigenous Instream and Riparian Biota	
Rare and endangered species	0 to 4
Unique biota	0 to 4
Intolerant biota	0 to 4
Species/Taxon richness	0 to 4
Aquatic and Riparian Habitats	
Diversity of habitat types and features	0 to 4
Refuge value of habitat types	0 to 4
Sensitivity to flow changes	0 to 4
Sensitivity to water quality changes	0 to 4
Modifying Determinants	
Migration route/corridor - instream and riparian	0 to 4
Presence or importance of conservation and natural areas	0 to 4

Table 4.5 Present status scoring system according to Kleynhans et al. (1998)

Category/criterion	Score: High = Natural
Deviation from natural of :	
Flow	0 to 5
Inundation	0 to 5
Water quality	0 to 5
Stream bed condition	0 to 5
Riparian condition	0 to 5

5. ANNUAL IFR COMPONENT DETERMINATION (*Dated August 1999*)

The paper by Hughes, et al. (1998) explains the background and original basis of the approach that was used to develop the estimation equations for the annual values of the IFR components. These components are the low and high flow maintenance quantities and the high and low flow drought quantities. The original approach was to look for a hydrological index that was logically reasonable and could be used to explain at least some of the variation in IFR requirements between sites where the same Ecological Management Class was assumed.

The basic assumption of the approach is that variations between sites would be function of variations in hydrological regime characteristics, specific ecological functioning, flow-habitat relationships determined by channel physical characteristics and noise related to the inherently subjective (expert judgement) nature of the IFR workshop process. At the time at which the approach was being developed the only component of that functional relationship that had the potential to be readily quantified was the hydrological regime characteristics. The remaining components would then have to be treated as 'noise' until more clarity could be obtained on how best to quantify them. ***It is therefore inevitable that the initial relationships developed would have a great deal of scatter and that their use to predict likely IFR results would have to be treated with caution and assumed to represent initial low-confidence estimates.***

Ideal situation :

IFR = F(Hydrological regime) + F(Ecological functioning) + F(Flow-habitat Relationships) + Noise

Current situation :

IFR = F(Hydrological regime) + Noise

To move closer to the ideal situation, more information is required about regional eco-hydrological relationships and how these are affected by changes in the physical characteristics of channels brought about by flow regime modifications (see Münster & Hughes, 1999).

Two hydrological characteristics were selected as being logically relevant to estimating IFR components, given the constraint that they also have to be readily quantifiable from available streamflow time series. Section 3 indicates that the default source of flow data is the WR90 (original or updated) database of monthly flows. The two characteristics are measures of flow variability and that proportion of the total flow that occurs as baseflow.

5.1 Flow variability index

The flow variability index selected has been designed to summarise variability within the wet and dry seasons and is based on the average coefficient of variation (Standard Deviation/Mean) for the three main wet season months and the three main dry season months (excluding those that have zero mean monthly flows). The actual index used is the sum of these two means. Where more than two of the months in the dry season experience zero flows all the time (i.e. means and standard deviations of zero), a further month (earlier or later in the year) is used to estimate the index so that the average dry season CV is based on at least two months.

The assumption is that rivers with a high degree of variability (high index value) will require lower proportions of their natural mean annual runoff (within a single EMC) because they are used to experiencing such conditions. More reliably flowing and less variable rivers are assumed to be less well adjusted to frequent low extremes and would therefore be expected to require a higher proportion of their mean annual runoff to sustain ecological functioning.

5.2 Index of baseflow

A hydrological definition of baseflow relates to the extent to which rainfall, occurring in relatively short duration storms, is buffered through various runoff generation processes to produce streamflow patterns which are usually of longer (if not continuous) duration. Some of the rainfall passes through sub-surface storages (ground water), which respond and drain relatively slowly, producing the low amplitude component of streamflow hydrographs. The high amplitude streamflow response is derived from surface runoff processes, or drainage from near surface and rapidly reacting storages. The assumption is made here that for ecological purposes the relatively smooth 'seasonal' baseflow response is the relevant streamflow characteristic to consider when attempting to quantify the low-flow component of the IFR.

There are various methods available for separating the baseflow component from a time series of total flow, most of which operate with daily time steps or lower. Smakhtin and Watkins (1997) discuss these in more detail and the procedures are not explained here. What is important is that the procedures used in the DSS have to be based on widely available monthly data and the standard separation procedures are no longer valid. Fortunately, Smakhtin and Toulouse (1998) found that there is a consistent relationship between low flow indices extracted from flow duration curves and the baseflow proportion of total flow when daily flow data are used. There is also a reasonably consistent relationship between low flow indices extracted from flow duration curves compiled using monthly data and the same indices taken from daily flow duration curves.

Specifically, for South African rivers the following relationship between Q75 (the flow equalled or exceeded 75% of the time) based on monthly and daily data can be assumed to apply :

$$\underline{Q75D} = 0.89 * \underline{Q75M} - 0.0099 \quad \ldots\ldots \quad \text{Eq. 5.1}$$

where Q75D and Q75M are the 75th percentiles of the daily and monthly flow duration curve, respectively, using non-dimensional flow data (i.e. flows divided by mean daily or mean monthly flow)

Further, the following relationship between BFI (proportion of total flow occurring as baseflow - a value between 0 and 1) and Q75D can be considered applicable over a wide range of South African rivers if the correction using T0 (percentage number of months with zero flow) is included to account for ephemeral or seasonal flow regimes :

$$BFI = 0.832 * Q75D + 0.272 - 0.006 * T0 \quad \text{Eq. 5.2}$$

The assumption has been made that rivers with high baseflow indices will require higher proportions of their natural mean annual runoff because such flow regimes have lower degrees of short term variability. Lower baseflow indices suggest flow regimes where frequent periods of low flow occur between higher flow, short duration events.

An Arc View spatial coverage of BFI and estimated mean annual baseflow depth (mm) for incremental quaternary catchments is available with the programs and associated databases.

5.3 A combined index and estimation of maintenance IFR components

The variability index can vary from a small number less than 1 to a quite large number (above 10) and decreasing IFR values are expected with increasing variability. The BFI is constrained to lie between 0 and 1 and decreasing IFR values are expected with decreasing BFI. Therefore the logical combination of the two indices (CVB) is variability divided by BFI; generating an index that can lie between a number less than 1 to a number close to infinity (i.e. no baseflows).

Table 5.1 illustrates the range of index values for the 1946 quaternary catchments (based on accumulated flow time series) covering the whole of South Africa, Swaziland and Lesotho, an Arc View coverage of these data is available with the software and other databases.

The experience base (past IFR workshop results) upon which to base estimation equations using the CVB index only includes rivers with index values up to 9.0, while most of them are in the region of 1.8 to 6.0 (representing only about 30% of possible conditions throughout the country). ***There will inevitably be a great deal of uncertainty associated with applying any estimation equations outside the area of experience and particularly in the drier and more variable flow regimes with index values of greater than 10.***

Table 5.1 Range of CVB index values for all quaternary catchments.

CVB index	No. of catchments	% of catchments	Cumulative %
< 1.0	1	0.1	0.1
1.0 to < 2.0	47	2.4	2.5
2.0 to < 4.0	187	9.6	12.1
4.0 to < 6.0	387	19.9	32.0
6.0 to < 10.0	390	20.0	52.0
10.0 to < 15.0	212	10.9	62.9
15.0 to < 25.0	125	6.4	69.3
25.0 to < 50.0	207	10.6	80.0
50.0 to < 75.0	270	13.9	93.9
75.0 to < 100.0	30	1.5	95.4
> 100.0	90	4.6	100.0

The original equations used were later found to be difficult to apply at high index values and generated negative values (corrected to zero) for more than 20% of the catchments. These have now been modified to generate positive estimates for the IFR components, even at relatively high CVB index values.

5.3.1 Maintenance low flow requirements

Figures 5.1 and 5.2 illustrate the shape of the estimation relationships for maintenance low flow requirements (for EMCs A, B, C and D) over CVB ranges of 1 to 10 and 1 to 1000, respectively, while the actual equation is given below and the parameters of the equation for all EMCs are given in Table 5.2.

Estimation equation for MLIFR (maintenance low flow total as % natural MAR) :

$$MLIFR = LP4 + (LP1 * LP2) / (CVB^{LP3})^{(1 - LP1)} \quad \text{.......................... Eq. 5.3}$$

Table 5.2 Parameter values of the equation to estimate the annual total maintenance low flows.

Parameter	Ecological Management Class						
	A	A/B	B	B/C	C	C/D	D
LP1	0.900	0.905	0.910	0.915	0.920	0.925	0.930
LP2	79	61	46	37	28	24	20
LP3	6.00	5.90	5.80	5.60	5.40	5.25	5.10
LP4	8.0	6.0	4.0	2.0	0.0	-2.0	-4.0

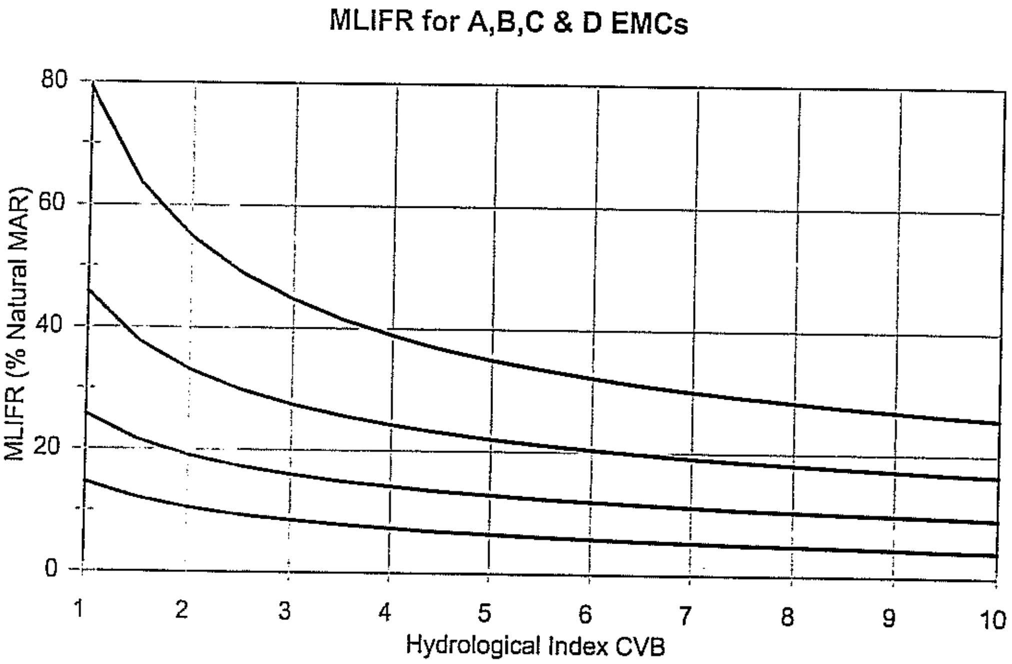

Figure 5.1 Maintenance low flow estimation curves over CVB index values 1.0 to 10.0 (the curves give progressively lower values for EMCs A to D)

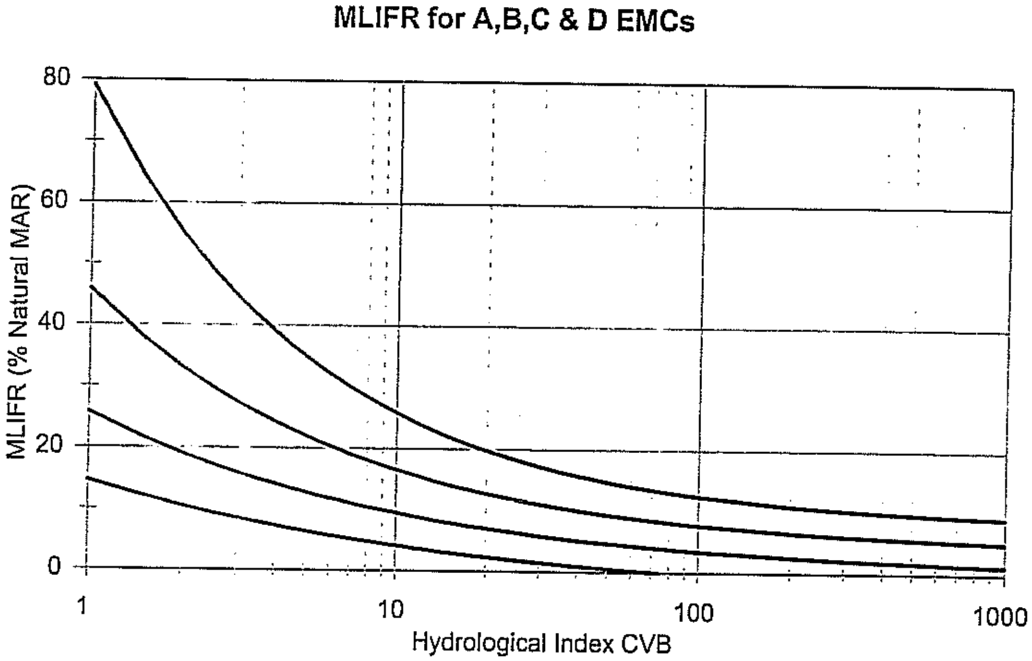

Figure 5.2 Maintenance low flow estimation curves over a wide range of CVB index values (the curves give progressively lower values for EMCs A to D)

5.3.2 Maintenance high flow values

It was found to be very difficult to construct estimation equations for the maintenance high flow requirements, largely because there seems to have been a greater degree of subjectivity and inconsistency in the setting of high flows in past IFR workshops than for the low flows. This is perhaps inevitable given the state of our understanding of the importance of channel forming discharges (related to magnitude-frequency relationships and geomorphological processes).

A graphical illustration of the currently used estimation equations for total maintenance requirements (i.e. MTIFR = MHIFR + MLIFR) is provided in figure 5.3 for the four main management classes over a CVB index range of 1.0 to 20.0. The actual estimation equations are given below and the parameter values for different EMCs in Table 5.3.

Estimation equation for MTIFR (maintenance total flow total as % natural MAR) :

$If\ CVB < 2.0\ then:$

$$MTIFR = MLIFR + (TP1 * 2.0 + TP2 - LP4 + (LP1 * LP2) / (2.0^{LP3})^{(1-LP1)} \quad . \text{ Eq. 5.4}$$

$If\ 2.0 < CVB < 8.0\ then:$

$$MTIFR = TP1 * CVB + TP2 \quad \ldots\ldots \text{ Eq. 5.5}$$

$If\ CVB > 8.0\ then:$

$$MTIFR = TP1 * 8.0 + TP2 \quad \ldots\ldots \text{ Eq.5.6}$$

Equation 5.6 and Figure 5.3 indicate that the total maintenance requirement remains constant at index values of 8 and above. This modification was made following two workshops on drier rivers with high index values (in the Northern Province and the Eastern Province) and is based on the assumption that they require quite large high flow contributions, but that these can occur with relatively low assurance. The low assurance means that the long term mean requirement remains relatively low.

Table 5.3 Parameter values of the equation to estimate the annual total maintenance total (low plus high) flows.

Parameter	Ecological Management Class						
	A	A/B	B	B/C	C	C/D	D
TP1	-4.2	-3.6	-3.0	-2.5	-2.0	-1.7	-1.5
TP2	70	60	48	39	32	27	22

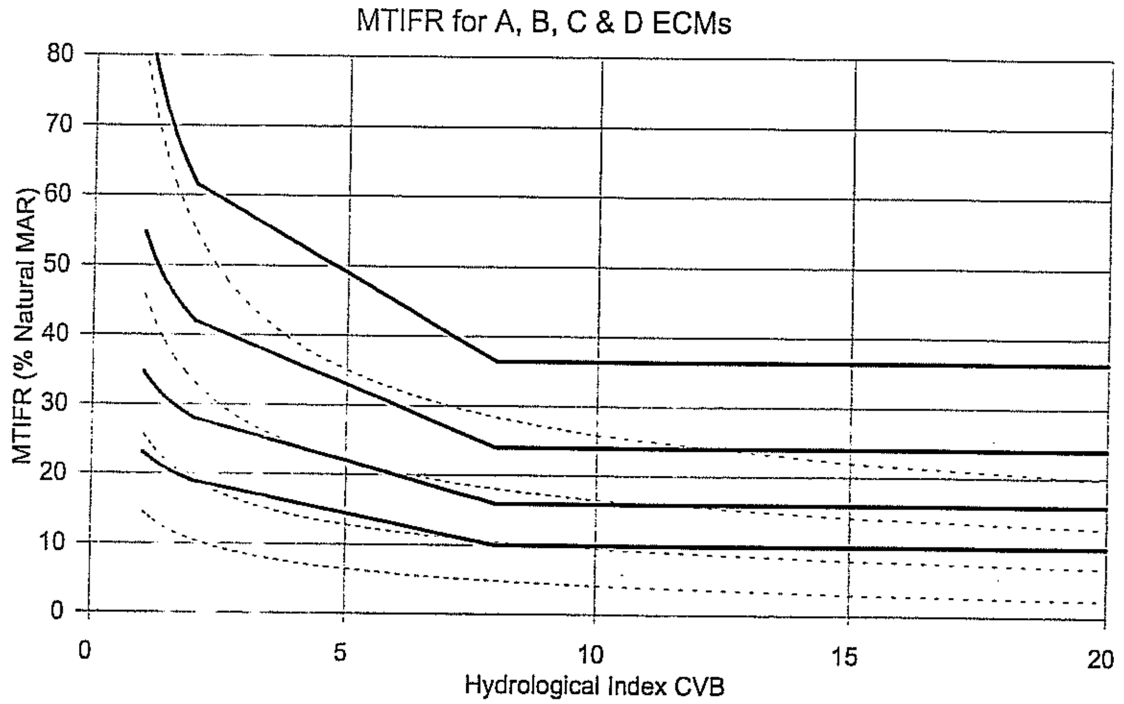

Figure 5.3 Maintenance total IFR requirements for EMCs A, B, C and D. The heavy lines are the total flow requirements, while the broken lines represent the low flow requirements given in Figures 5.1 and 5.2. Clearly the high flow requirements are the differences between the two sets of lines.

5.4 Drought IFR components

There were no discernable patterns or relationships between previous IFR results for either high or low flow drought requirements and any of the hydrological indices that were tested. Subsequently, it has been noted that it does not really make ecological sense to think in terms of varying the drought flow requirements with management class, as drought flows are considered to be the minimum required to prevent the system from collapsing. After some discussions amongst experienced IFR specialists ***it was decided that the drought low flow requirements (DLIFR) for all the management classes should be equivalent to the MLIFR for a 'D' EMC.*** The implication is that if a D class is selected the river would experience drought conditions more or less permanently (although, in practice the situation is slightly different and more water is required after the assurance rules are applied - see Section 7).

In terms of drought high flow requirements, no reasonable estimation approach could be developed and it was decided to handle these separately using the assurance rules (Section 7).

5.5 Parameter file for the DSS

All of the parameters required for the estimation procedures referred to above are contained within a parameter file (currently ***HYDRO.PAR***) which is used by both ***RESDSS*** and ***SARES*** to ensure that the application of the equations conform to the current form of the relationships without having to re-compile the programs. Table 5.4 lists the first part of the parameter file that deals with the calculations of the hydrological index and the annual IFR requirement values.

Table 5.4 First part of ***HYDRO.PAR*** containing the parameters of the annual IFR estimation equations (for EMCs A, A/B, B, B/C, C, C/D & D, in that order) and the parameters of the BFI estimation equation.

```
Parameters for hydro-IFR estimation
10
Parameter P1 in MIFR (%MAR) Equation for A to D classes
   0.90  0.905 0.91  0.915 0.92  0.925 0.93
Parameter P2 in MIFR (%MAR) Equation for A to D classes
  79    61    46    37    28    24    20
Parameter P3 in MIFR (%MAR) Equation for A to D classes
   6.0   5.9   5.8   5.6   5.4   5.25  5.1
Parameter P4 in MIFR (%MAR) Equation for A to D classes
   8     6     4     2     0     -2    -4
Parameter P1 in TIFR (%MAR) Equation for A to D classes
  -4.2  -3.6  -3.0  -2.5  -2.0  -1.75 -1.5
Parameter P2 in TIFR (%MAR) Equation for A to D classes
  70    60    48    39    32    27    22
Two thresholds for TIFR (%MAR) Equation
   2     8
Removed data
   0     0     0     0     0     0     0
Three parameters of the BFI estimate Eq. from Q75/ADf and T0
   0.832 0.272 0.006
Two parameters of the Q75/ADF estimate Eq. from Q75/MMF
   0.89 -0.0099
```

Both programs use a default version of this parameter file, which can be edited at any time by the user (under guidance by the developers). ***RESDSS*** includes an option to load a parameter file with an alternative name (i.e. several parameter files can be established and used as necessary). Further details of other information contained within the parameter files are given in Sections 6 and 7.

5.6 Using IFR workshop results

Should an IFR workshop have been held at the site (or close to the site) in question and the results are considered to be reliable, they can be used by ***RESDSS*** in place of the annual values generated by the generic relationships. This option (Get Obs. IFR Data) accesses a Paradox database table which includes location details, natural and present day MARs, as well as monthly volumes of IFRs for the maintenance and drought, low and high flow requirements. Importing these data override both the annual values estimated from the characteristics of the natural flow data time series as well as the regionalised monthly distributions discussed in the next section. The regional assurance rules are not replaced as many of the past IFR workshop results do not include information on the rules and they do not form part of the database.

The utility *IFREDIT* (provided with the DSS) enables new IFR workshop results to be added to the database or existing data to be edited to reflect revisions that might have been made since the original workshops.

6. MONTHLY DISTRIBUTION DETERMINATION (*Dated August 1999*)

The previous section addressed the issues relating to the estimation of the annual values of the IFR requirements, while this section outlines the procedures used to distribute these annual totals into monthly volumes. The addition of the option to use existing IFR workshop results (referred to in section 5.6) applies to this section as well. It should be pointed out that if this option is used before setting the region and management class, the region must still be specified before continuing with the assurance rules part of the program.

6.1 Monthly distributions of low flows (maintenance and drought)

The basis for the monthly distribution of low flows is the regional analysis of mean monthly baseflow contributions to total streamflow carried out by Cobbing (1998). This study investigated a number of observed daily flow records or simulated time series for South African rivers and carried out baseflow separation exercises on all of them, extracting monthly total and baseflow contributions. A regionalisation analysis then resulted in a number of 'generic' regional monthly distributions of baseflow proportion. Münster (1998) used these distributions in association with the actual monthly distributions of IFR low flows from past IFR results to determine a suitable estimation approach. ***One of the basic principles of the approach is that a higher proportion of the natural monthly flow is required during the dry months than during wet months.*** This principle appears to apply to both the higher and lower flows that occur as a result of seasonal changes, as well as the differences that occur as a result of periods of dry and wet years.

The actual estimation equation is based on one set of monthly parameters that represent the mean proportion of total flow (**PAR1**$_i$ for i = 1 to 12) for each month of the year that can be expected to occur as baseflows (based on a hydrological definition). Two additional parameters (**PAR2** and **PAR3**) define the extent to which the natural range of monthly baseflows will be reduced (or increased) in the monthly distribution of maintenance and drought flows (i.e. one parameter for maintenance and one for drought). The maintenance parameter is the value used for an 'A' EMC, while for the classes between 'A' and 'D' (drought flows) linear interpolation is used between the two values. The parameter file (***HYDRO.PAR*** by default) includes values for 20 defined regions of the country. These 20 regions have been identified on the basis of their broad similarity of seasonal distributions of runoff response, as well as their characteristics of flow variability, which is more important for setting the assurance rules discussed in Section 7. Table 6.1 provides the values for the monthly distributions of all the 6 parameters for each of the 20 regions.

The range reduction value is estimated from :

$$FDIST = PAR2 - (PAR2 - PAR3) * EMC/6 \quad \ldots\ldots \text{Eq. 6.1}$$

where EMC is the management class value (0 = A, 1 = A/B, to 6 = D)

The baseflow monthly distribution is calculated from :

$$QBASE_i = QTOT_i * PAR1_i \quad \ldots\ldots \text{Eq. 6.2}$$

where $QTOT_i$ are the mean monthly natural flow volumes for months i and QBMIN is then set as the minimum of the $QBASE_i$ values.

The first estimates of the distributions of monthly IFR flows are calculated from :

for maintenance :

$$Q1_i = QBMIN + (QBASE_i - QBMIN) * FDIST \quad \text{Eq. 6.3}$$

for drought :

$$Q2_i = QBMIN + (QBASE_i - QBMIN) * PAR3 \quad \text{Eq. 6.4}$$

these values are then summed (QTOT1 and QTOT2)

The monthly maintenance values are then given by :

$$QM_i = Q1_i * MLIFR / QTOT1 \quad \text{Eq. 6.5}$$

And the monthly drought values by :

$$QD_i = Q2_i * DLIFR / QTOT2 \quad \text{Eq. 6.6}$$

The values of **PAR2** are always greater than the values of **PAR3**, and both are less than 1.0, suggesting that the distribution of droughts is relatively flatter than maintenance flows and that they are both flatter than the natural seasonal distribution. This is consistent with the concept of 'giving away' relatively more water during the wet season than the dry season. The values of **FDIST** and **PAR3** are displayed on the screen within ***RESDSS*** and can be edited to allow the seasonal distributions of maintenance and drought flows to be modified.

The region names given in Table 6.1 can be very confusing because some of the regions were named after their core area, but the same distributions were then applied to more extensive areas. An Arc View coverage is available (and supplied with the software) which illustrates the regional distribution and allows the default region used for each quaternary catchment to be identified. Within *SARES,* the database table ***WR90*** is accessed and this contains a field which identifies the default region for each quaternary by number. ***The 'Region' field in the database table WR90RES contains the region number relevant to the accumulated flow time series that has been derived after MAR weighting of the region numbers for the upstream incremental quaternary catchments.***

Within *SARES* the monthly distributions associated with the number of the region in the database are used automatically for the estimates. Within ***RESDSS,*** the user first sets the EMC and then manually selects the region to be used, after which the seasonal distributions are calculated and displayed (as either %MAR, $m^3 * 10^6$ of volume, or $m^3 s^{-1}$ of mean monthly flow units).

6.2 Monthly distributions of high flows

Table 6.1 also includes a parameter line for the maintenance high flow distributions and these values are used with the baseflow proportions in the following manner :

For all months (i = 1 to 12) the annual total (HT) of natural high flows is calculated :

$$HT = \sum(\text{Total flows}_i - \text{Baseflows}_i) \quad \text{Eq. 6.7}$$

For each month the natural high flows (H_i) are expressed as a % of the total (HT) :

$$H_i = (\text{Total flows}_i - \text{Baseflows}_i) * 100 / HT \quad \text{Eq. 6.8}$$

The non-dimensional high flows (HND_i) for all months not having -9 parameter values and the balance of the total high flow volume remaining (REM) to be distributed are calculated :

$$HND_i = \text{parameter}_i * H_i \quad \text{Eq. 6.9}$$

$$REM = 100 - \sum HND_i \quad \text{Eq. 6.10}$$

The sum and maximum values of the H_i values for those months with -9 parameters are calculated and the non-dimensional high flow value for the month with the maximum set to the square root of the maximum divided by the sum multiplied by REM :

for only those months with -9 parameters :

$$HND_i(\text{at maximum } H_i) = REM * SQRT(Max(H_i) / \sum H_i) \quad \text{Eq. 6.11}$$

The remaining months with -9 parameters are then estimated from the balance depending on their proximity (in months) to the maximum month and the total number of months with -9 parameters. The final step is to dimensionalise the values using the annual total high flow IFR value :

$$HIFR_i = HND_i * (MTIFR - MLIFR) / 100 \quad \text{Eq. 6.12}$$

Table 6.1 Regional parameter values for the monthly distributions of annual values, as well as the assurance rules (Section 7).

```
Number of regional baseflow distributions (%MMR)
20
dataline 1: Baseflow proportions (% Total monthly flow)
dataline 2: MLIFR and DLIFR Distribution parameters 1 and 2
dataline 3: High flow distribution factors
dataline 4: Summer (Jan) default rule parameters
dataline 5: Winter (Jul) default rule parameters
1. W.Cape(wet)
70.0  62.0  40.0  37.0  35.0  32.0  25.0  20.0  25.0  36.0  42.0  52.0
0.9 0.65
1.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 -9.0 -9.0 -9.0
6.0 98.0 20.0 120.0 6.0
4.0 98.0 20.0 120.0 4.0
2. W.Cape(dry)
65.0  64.0  36.0  10.0  10.0  10.0  12.0  13.0  18.0  24.0  34.0  42.0
0.8 0.55
1.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 -9.0 -9.0 -9.0
7.0 100.0 10.0 130.0 7.0
7.0 100.0 10.0 130.0 7.0
3. W.Karoo
30.0  20.0  18.0  12.0  8.0  10.0  15.0  30.0  38.0  40.0  42.0  40.0
0.80 0.55
1.0 0.0 0.0 0.0 0.0 0.0 1.0 -9.0 -9.0 -9.0 1.0 1.0
25.0 65.0 0.0 200.0 25.0
12.0 80.0 0.0 200.0 12.0
4. E.Karoo
20.0  26.0  22.0  22.0  20.0  20.0  20.0  25.0  25.0  25.0  22.0  20.0
0.80 0.55
0.0 1.0 1.0 1.0 -9.0 -9.0 -9.0 1.0 1.0 1.0 1.0 0.0
15.0 75.0 0.0 200.0 15.0
20.0 70.0 0.0 200.0 20.0
5. S.Cape(dry)
28.0  26.0  22.0  20.0  18.0  19.0  20.0  30.0  28.0  29.0  31.0  29.0
0.80 0.55
-9.0 1.0 0.0 0.0 0.0 0.0 1.0 1.0 0.5 0.5 -9.0 -9.0
12.0 100.0 10.0 130.0 12.0
8.0 100.0 10.0 130.0 8.0
6. S.Karoo
30.0  20.0  18.0  12.0  8.0  10.0  15.0  30.0  38.0  40.0  42.0  40.0
0.80 0.55
-9.0 1.0 0.0 0.0 0.0 0.0 1.0 1.0 0.5 0.5 -9.0 -9.0
14.0 100.0 10.0 150.0 14.0
10.0 100.0 10.0 150.0 10.0
7. S.Cape(wet)
35.4  34.6  45.3  53.6  32.7  39.2  35.1  42.9  41.9  31.6  31.4  35.2
0.85 0.65
-9.0 -9.0 0.0 0.0 0.0 -9.0 1.0 1.0 0.0 0.0 1.0 1.0
8.0 100.0 10.0 130.0 8.0
6.0 100.0 20.0 120.0 6.0
8. E.Cape(arid)
16.0  16.0  16.0  16.0  16.0  16.0  16.0  16.0 16.0 16.0  16.0  16.0
0.80 0.55
-9.0 -9.0 1.0 0.0 0.0 -9.0 1.0 0.0 0.0 0.0 1.0 -9.0
15.0  85.0 0.0 200.0 15.0
20.0  75.0 0.0 200.0 20.0
9. E.Cape
19.0  27.0  27.0  21.0  20.0  13.0  18.0  40.0  40.0  35.0  30.0  22.0
0.75 0.55
1.0 -9.0 -9.0 0.5 0.8 -9.0 1.0 0.0 0.0 0.0 0.0 1.0
8.0 90.0 0.0 130.0 8.0
10.0 95.0 0.0 130.0 10.0
```

```
10. Amatole
36.7  34.5  40.4  43.3  32.3  40.0  51.5  66.1  67.0  69.2  49.1  46.2
0.7 0.5
1.0 -9.0 -9.0 0.5 0.8 -9.0 1.0 0.0 0.0 0.0 0.0 0.0
6.0 96.0 10.0 130.0 6.0
6.0 98.0 5.0 125.0 6.0
11. T Region
27.0  29.0  30.0  33.0  35.0  40.0  50.0  66.0  68.0  70.0  63.0  40.0
0.65 0.4
1.0 1.0 1.0 -9.0 -9.0 -9.0 0.0 0.0 0.0 0.0 0.0 0.0
6.0 98.0 10.0 120.0 6.0
8.0 98.0 5.0 120.0 8.0
12. T Reg. Coast
37.0  35.0  40.0  43.0  32.0  40.0  51.0  60.0  60.0  60.0  80.0  50.0
0.70 0.50
1.0 -9.0 -9.0 0.8 1.0 -9.0 1.0 0.0 0.0 0.0 0.0 0.0
5.0 98.0 10.0 120.0 5.0
6.0 98.0 10.0 120.0 6.0
13. D'berg
38.0  33.0  35.0  36.0  38.0  45.0  65.0  85.0  85.0  85.0  75.0  45.0
0.6 0.45
0.5 1.0 -9.0 -9.0 -9.0 -9.0 0.8 0.0 0.0 0.0 0.0 0.0
5.0 98.0 20.0 120.0 5.0
6.0 98.0 10.0 110.0 6.0
14. S.Natal
26.0  26.0  26.0  28.0  31.0  36.0  52.0  78.0  85.0  85.0  60.0  25.0
0.6 0.45
0.5 1.0 1.0 -9.0 -9.0 -9.0 0.75 0.0 0.0 0.0 0.0 0.0
5.0 98.0 10.0 120.0 5.0
6.0 98.0 10.0 120.0 6.0
15. N.Natal
30.0  30.0  35.0  38.0  40.0  48.0  52.0  65.0  70.0  60.0  55.0  35.0
0.8 0.45
1.0 1.0 -9.0 -9.0 -9.0 0.75 0.0 0.0 0.0 0.0 0.0 0.0
5.0 98.0 10.0 120.0 5.0
6.0 98.0 10.0 120.0 6.0
16. Zululand
30.0  30.0  30.0  35.0  40.0  45.0  55.0  70.0  76.0  65.0  60.0  30.0
0.75 0.5
1.0 1.0 -9.0 -9.0 -9.0 -9.0 1.0 0.0 0.0 0.0 0.5 0.75
6.0  98.0 20.0 120.0 6.0
6.0  98.0 10.0 115.0 6.0
17. E.Escarp
72.0  52.0  45.0  45.0  45.0  55.0  76.0  95.0  96.0  96.0  96.0  85.0
0.55 0.3
1.0 1.0 1.0 -9.0 -9.0 -9.0 1.0 0.0 0.0 0.0 0.0 0.0
5.0 100.0 10.0 120.0 5.0
5.0 100.0 20.0 120.0 5.0
18. Lowveld
60.0  32.0  30.0  30.0  35.0  40.0  60.0  70.0  80.0  80.0  80.0  75.0
0.7 0.4
1.0 1.0 -9.0 -9.0 -9.0 0.75 0.0 0.0 0.0 0.0 0.0 0.0
8.0 80.0 0.0 140.0 8.0
12.0 100.0 0.0 160.0 12.0
19. E.Foothill
80.0  72.0  40.0  30.0  27.0  40.0  75.0  90.0  95.0  95.0  95.0  90.0
0.6 0.4
0.0 0.75 1.0 -9.0 -9.0 -9.0 0.0 0.0 0.0 0.0 0.0 0.0
8.0 95.0 0.0 120.0 8.0
5.0 98.0 10.0 120.0 5.0
20. Vaal
18.0  24.0  30.0  36.0  38.0  45.0  55.0  70.0  76.0  65.0  60.0  25.0
0.7 0.45
1.0 1.0 -9.0 -9.0 -9.0 1.0 1.0 0.0 0.0 0.0 0.0 0.0
9.0 90.0 0.0 130.0 9.0
8.0 98.0 0.0 130.0 8.0
21. Olifants
45.0  30.0  30.0  30.0  32.0  40.0  50.0  70.0  75.0  80.0  80.0  75.0
0.8 0.45
1.0 1.0 1.0 -9.0 -9.0 -9.0 0.5 0.0 0.0 0.0 0.0 0.0
5.0 98.0 10.0 120.0 5.0
6.0 98.0 10.0 120.0 6.0
```

An example is provided in Table 6.2 for the D'Berg (13) region using quaternary catchment D16D. The first column provides the mean monthly distribution volume of the assumed high flow contribution based on mean monthly flow * (1 - baseflow proportion). The second column recalculates the first column values as a % of the total high flow contribution. The third column lists the parameter values for this region, while the fourth column lists the non-dimensional requirements for the months that have positive parameter values. Column 5 identifies the peak high flow requirement month and lists the non-dimensional requirement using Eq. 6.5, while column 6 gives the distribution parameters for the remaining -9 months and column 7 their non-dimensional requirements. The values in columns 4, 5 and 7 can then be dimensionalised by the annual high flow requirement. Note the pattern of distribution parameters given in column 6 and the fact that one of the remaining months has double the requirement of the other two and that it is the furthest away from the month with the maximum requirement.

Table 6.2 Monthly high flow distribution example using quaternary D16D in the Drakensberg region (Note that the sum of columns 5, 6 and 8 must equal 100).

Month	Total - Baseflow ($m^3 * 10^6$)	H_i %	Parameter	HND (non -9's)	Max of -9's	Factors for other -9's	HND (other -9's)
Oct	4.1	7.7	0.5	3.85	-	-	-
Nov	6.7	12.5	1.0	12.50	-	-	-
Dec	6.9	12.9	-9.0	-	-	0.5	18.09
Jan	10.3	19.2	-9.0	-	-	0.25	9.05
Feb	11.0	20.6	-9.0	-	43.85	-	-
Mar	8.5	15.9	-9.0	-	-	0.25	9.05
Apr	2.4	4.5	0.8	3.60	-	-	
May	0.5	0.9	0.0	0.0	-	-	
Jun	0.3	0.6	0.0	0.0	-	-	
Jul	0.2	0.4	0.0	0.0	-	-	
Aug	0.4	0.7	0.0	0.0	-	-	
Sep	2.2	4.1	0.0	0.0	-	-	
Total	53.5	100.0	N/A	19.95	43.85	N/A	36.20

6.3 Manual adjustment of monthly values

This option is only available within ***RESDSS*** and both the monthly distributions of low flows and the annual values can be changed (but not the distribution of high flows, except by editing the parameter data). Once all the distribution data are displayed on the screen, the user has the option to increase or decrease the drought low flow, maintenance low flow and/or the maintenance total flow annual values. The monthly distributions are then re-calculated using the methods described in this section.

7. ESTABLISHING THE ASSURANCE RULES *(Dated March 1999)*

The table of monthly volumes generated after the annual values have been calculated and the monthly distributions applied are essentially equivalent to the output (in terms of monthly volume requirements) from IFR workshops where the traditional approach to the BBM was applied. The only real difference is that no values are provided for drought high flow requirements and no details are given for the peaks and durations of the individual high flow events required. The latter detail is inappropriate to a method based on a monthly time step.

Recent IFR workshops have commonly taken the process one step further and provided guidelines on the time series patterns of requirements and specified in more detail under what circumstances and how frequently, different flows (i.e. maintenance or above, between maintenance and drought, or at drought) should occur in the modified time series. This has usually been carried out through the application of the so-called 'IFR Model' (Hughes, et al., 1997). The model generates a modified time series of flow requirements that can be assessed and revised by the workshop participants through a calibration process. One of the possible outputs from the model is an analysis of the % of time that the recommended flows are equalled or exceeded (i.e. a flow duration curve analysis), which can also be thought of as expressions of the assurance with which certain target flows are achieved. ***This information is required by the Water Resource Engineers for planning and management purposes and is equivalent to the normal expressions of assurance that are used to quantify the reliability of a component of a water supply project.***

In developing the structure of the DSS for the planning estimate it was decided to make use of the same concept, but perform the analysis in reverse; that is define the 'rules' for assurance and then use these to generate a representative time series of required flows.

7.1 Generic assurance rules and assurance curves

Generic regional assurance curve parameters have been included in the parameter file shown in Table 6.1 and Figure 7.1 illustrates two possible curve shapes. The x-axis of the curves represents the frequency with which flows specified on the y-axis are expected to be equalled or exceeded in a representative time series of modified flows (and is therefore also the assurance with which such target flows are expected to be met). Within ***RESDSS*** two curves are graphically displayed, one representing the low flow component and one the total flow component. The non-dimensional shape of the curves is defined by four basic parameters and then parameterised by the maintenance and drought flow requirements.

The four parameters are as follows :

Shape factor (1 to 25) :

In figure 7.1 the values used are 5 for Region 13 and 15 for Region 4. A higher shape factor generates a curve that moves down from higher flows to lower flows at a relatively low assurance value. A low shape factor generates a curve which remains at high flows until quite high assurance values.

Upper time shift (65 to 100) :

In figure 7.1 the values used are 98 for Region 13 and 75 for Region 4. This parameter represents the lateral shift (toward the left, or low assurance end) of the lowest point (drought flow) of the assurance curve. If the upper time shift parameter is decreased this will effectively increase the duration that flows within the modified flow regime will be at the specified drought level.

Lower time shift (0 to 50) :

In figure 7.1 the values used are 20 for Region 13 and 0 for Region 4. This parameter represents the lateral shift (toward the right, or higher assurance end) of the maximum point (at or above maintenance flow) of the assurance curve. If the lower time shift parameter is increased this will increase the duration that flows within the modified flow regime will be at the maximum value.

Low flow maximum (100 to 200) :

In figure 7.1 the values used are 120 for Region 13 and 200 for Region 4. One of the principles of the BBM is that the specified maintenance flows are not considered to be the maximum that would be expected. This parameter therefore represents the maximum low flow that is required and is a % of the monthly maintenance low flow requirement.

The first four values of the first line of assurance parameters given in Table 6.1 are for the low flow curve for January, while the last value is the shape parameter for the high flows (at present this is always the same as the low flow shape parameter). The second line of assurance parameters is for the month of July, while the parameters for the other months are determined by interpolation between January and July.

The *low flow rule curve* is finally quantified using the maintenance low flow requirement (Section 6.1) scaled up by the low flow maximum parameter to represent the highest flow and the drought low flow requirement to represent the lowest flow.

The *total flow rule curve* is quantified by adding a high flow curve to the low flow rule curve. The high flow curve is quantified in the following way :

The shape factor is a specified parameter.
The upper and lower time shifts used are the same as for the low flow curve.

The maximum value is calculated from (i = months 1 to 12) :

$$HIFR_i * (1.0 + (\text{Low flow max. parameter} - 100)/200) \quad \dots\dots\dots\dots \text{Eq. 7.1}$$

The minimum, or drought high flow requirement is calculated from :

$$HIFR_i * 0.1 \quad \dots\dots\dots\dots\dots\dots\dots\dots \text{Eq. 7.2}$$

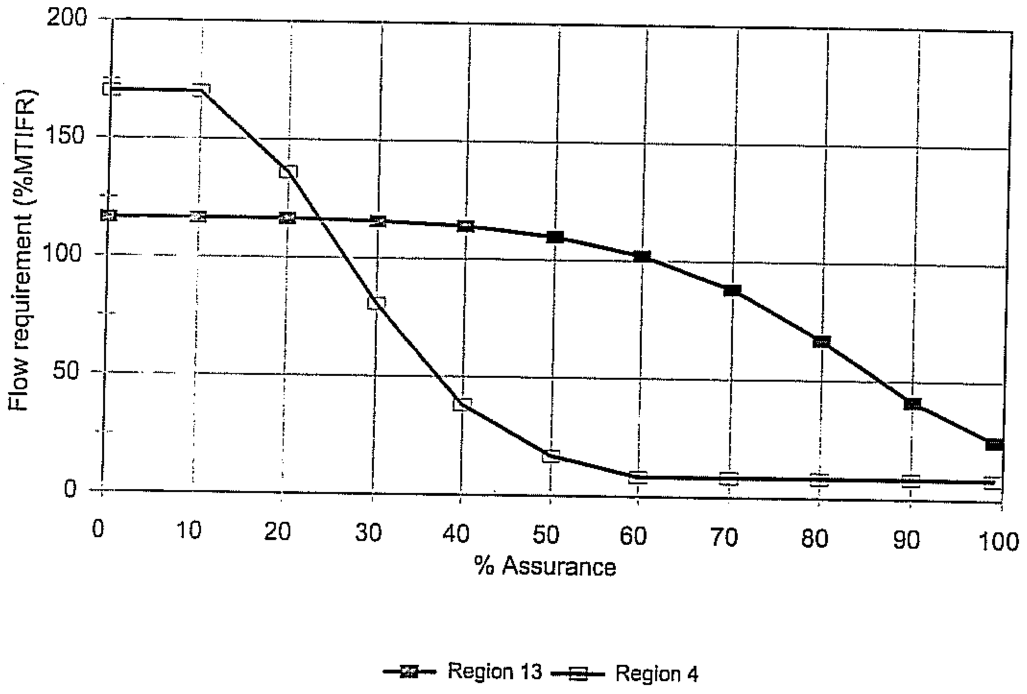

Figure 7.1 Examples of generic assurance rule curves for the month of January for region 13 (D'Berg) and region 4 (E. Karoo).

These generic regional rules have been established on the basis of a number of principles that have emerged out of various discussions with ecologists and other IFR specialists. ***However, there is still a great deal of scope for further debate, particularly around those rules used within the drier catchments of the country where there is no existing experience base of setting environmental flow requirements.*** The general principles are listed below to provide a basis for constructive debate and further refinement of the rules.

- ☐ The *shape factor* and *lower time shift* parameters have been set to result in a relatively high assurance of maintenance flows for natural flow regimes with high baseflow contributions and low variability. This principle has already been established at several IFR workshops. The assurance of maintenance is expected to decrease as the flow regime becomes more variable.
- ☐ Coupled to the lower assurance of maintenance for rivers with more variable flow regimes, is the requirement to allow the ***maximum low flow*** to exceed the specified maintenance flow by a relatively greater amount. This will introduce a relatively high degree of variability into the modified regime to be consistent with the characteristics of the natural regime.
- ☐ The procedure for setting the maximum value for the high flow requirement follows the same principles as for the low flow maximum. However, the conceptual basis for applying this procedure to high flows is less well developed than for low flows.

- ☐ Setting the drought high flow requirement to 10% of the maintenance requirement is a pragmatic (and fairly conservative) approach to a problem that exists because of the lack of any information.

Within SARES the rule tables (one for each calendar month) are written to BLOB fields within the ***WR90RES*** database for later access.

7.2 Additional high flows at low assurance

During two workshops held in July/August 1999 to look at the use of the model in drier rivers with variable regimes (the example rivers were located in the Northern and Eastern Provinces), it was noted that the model does not allow for the higher flow events that are frequently set during Reserve determinations with return periods that are greater than the equivalent of the maintenance assurance level (e.g. 1:3 to 1:5 year events). The workshop participants noted that these events might assume a very important role in the drier and more variable flow regimes, because the other flows which are set have low assurance levels and are usually quite small. The changes in the approach to setting the high flow requirement for relatively high index values has already been outlined in Section 5 and this accounts to a certain extent for the comments that were made during the workshops.

The refined approach is only applied to those months which have a -9 value for the maintenance high flow distribution (see section 6.2) and affects different parts of the total assurance curve depending upon the value of the shape factor. Figure 7.2 shows a plot of the shape parameter versus the 'Critical % Assurance' (the bold line and left hand vertical axis). The 'Critical % Assurance' represents the maximum assurance value at which high flows are affected by this modification and is calculated from :

$$\textit{Critical \% Assurance} = 59.8 - \textit{Shape Factor} * 1.95 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 7.3}$$

This equation was derived on the basis of always having at least the 10% assurance value affected and the 50% value affected for the rivers with the least variable flow regimes (currently a shape factor of 5).

The second component of the modification is to specify the size of the increased high flows and that is illustrated by the thin line and the right hand vertical axis in Figure 7.2. First of all, for the major flood months (-9 distribution parameter) the maximum value of the initial high flow assurance curve is set to **HIFR** $_i$ and not the value given by Equation 7.1. The following algorithm is then used to estimate the additional high flows :

$$HIFR_i * (\textit{Shape Factor} / 4) * \{(100 - \%\ \textit{Assurance}) / 100\}^{Power} \quad \ldots\ldots\ldots\ldots \text{Eq. 7.4}$$

Where

$$Power = (\textit{Shape Factor})^{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 7.5}$$

The value for additional high flows increases from the Critical % Assurance to a maximum value at an assurance of 10% and then remains constant. Figure 7.2 provides a graphical illustration of the variation in maximum additional high flows (as a multiplier of $HIFR_i$) with the shape parameter. If the shape parameter has a value of 5 (Eastern Escarpment rivers, for example), the additional high flows start having an influence at an assurance value of 50%, where 20% of the maintenance high flow value is added. At 30% assurance, 49% of HIFR is added, while the maximum additional value is 95% HIFR. In contrast, for the Eastern Karoo region with a shape parameter of 15 the influence begins at 30% assurance, with 46% of HIFR added and the maximum added is 202% of HIFR. It should be clear that one of the assumptions made is that the ratio of extreme event volumes to maintenance event volumes will increase as the hydrological regime becomes more variable (as reflected by higher shape factors).

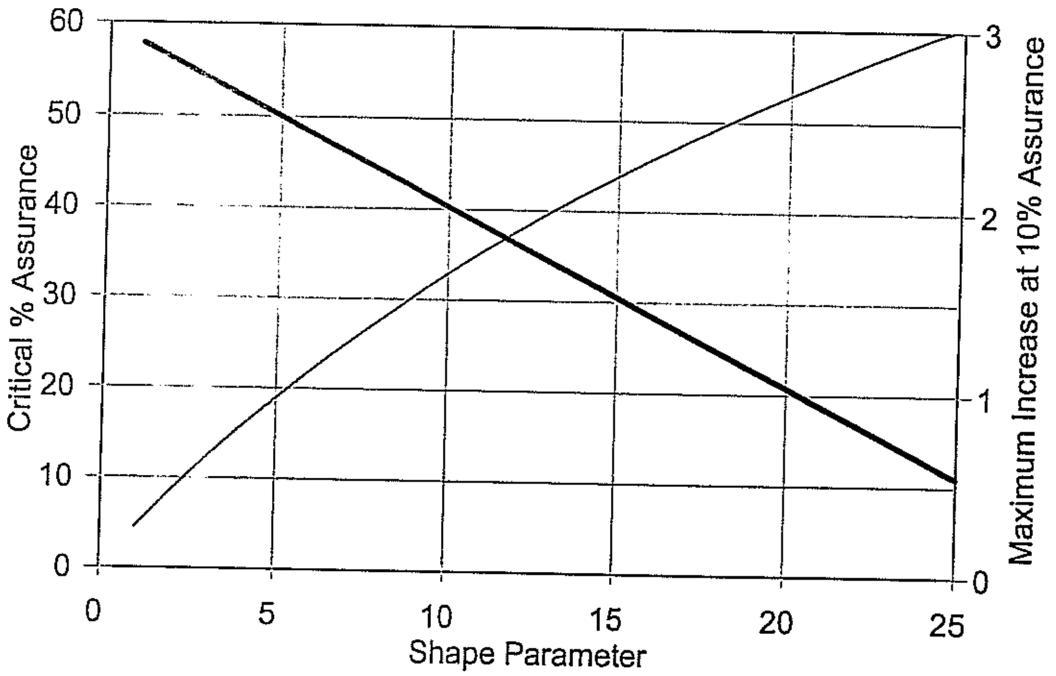

Figure 7.2 Illustration of the variation in Critical % Assurance and the maximum value (relative to maintenance high flow requirement) of the added high flows for different shape parameters.

7.3 User intervention in the assurance rules

The only form of user intervention in the rules within ***SARES*** is by editing the parameter file for a specific region and re-generating the rules and the modified flow time series. The same intervention also clearly applies to ***RESDSS***.

Additional user control of the rules is incorporated into ***RESDSS***. The window that displays the rules graphically, includes an option to toggle between the months of the year and to modify the five parameters that are applicable to each month. These five parameters are the low and high flow shape factors, the lower and upper time shifts and the low flow maximum value. As these are changed the graphical representation of the rule curves are changed as well and these can be compared with the shape of the natural flow duration curve for that specific month.

7.4 Use of the assurance rules to generate modified time series

The final stage of the time series processing for both programs is to generate a modified time series of the same length as the natural time series referred to in Section 3. This is carried out by using the calendar month duration curves of the natural time series and the assurance rule curves referred to above. The programs step through the natural time series, identifying the duration curve percentage point value of each month and generating the modified (IFR) flow as the monthly discharge volume equivalent to the same percentage point on the assurance curve for the same calendar month.

Within *RESDSS* the new time series data are plotted together with the natural values and can then be saved to file.

Within *SARES,* the low flow and the high flow contributions to the total modified flow are written to BLOB (Binary Large Object) fields within the **WR90RES** database table. They can then be written to text files at a later stage.

8. RESULTS SUMMARY AND OUTPUT DATA GENERATION (*Dated August 1999*)

Some comments about the various facilities for generating output data have already been referred to in previous sections. This section is designed to provide an overall summary of the information that can be viewed or extracted from the two programs.

8.1 Program *RESDSS*

Because *RESDSS* is designed for site specific applications of the techniques, there are more facilities for visualising the results at various stages in the estimation process.

Natural time series generation :

> At this stage, a table of annual (mean, standard devitaion, CV, Q75) and monthly statistics (means, standard deviations, CVs) is provided, as well as a facility to save the total time series (i.e. accumulation of all the selected quaternary data) as a text file in WR90 format.

EMC and present status scores :

> These can be saved to a file for later retrieval and editing.

Annual and monthly IFR values :

> These occur simultaneously within the program after the management class and regional type have been selected. A detailed summary of the statistics of the natural time series, as well as the annual and monthly IFR values can then be printed. The printout specifies which quaternaries have been used, the management class selected and the generic regional distribution type. A further option allows the monthly distributions of total natural flow, separated natural baseflows and the three main IFR components

(maintenance low and total flows, drought low flows) to be graphically displayed using either a log or linear axis.

Setting the assurance rules :

At this stage in the program the only output options are to print the assurance rule table or write it to a text file with a default extension of ***.rul**. The data can be output as mean monthly discharges in $m^3 s^{-1}$, or as monthly flow volumes in $m^3 * 10^6$, for 10 percentage points (10, 20, 30, 40, 50, 60, 70, 80, 90, 99%) for each month of the year.

Generating the modified time series :

This section of the program graphically displays the natural and modified time series in a way which allows the user to zoom in and out on specific parts of the series and display the flow axis as linear or log values. Part of the screen display includes the mean annual volume, in $m^3 * 10^6$ and % natural MAR, of the modified flows. There are also options to save either the total modified time series or the remainder flows (natural flows - IFR) to a WR90 format text file.

Determining an estimate of the reduction in yield :

This option allows the user to load up a text data file of the parameters of the relationships between yield and storage which are based on the diagrams provided in WR90 for each hydrological zone. The shapes of the curves have been generalised by van Rooyen and de Jager (1998) into 3 parameters of non-linear equations expressing yield (as % natural MAR) as a function of storage (also as % natural MAR) for various return periods :

$$Yield = [(Storage - C) / A]^{1/B} \quad \text{.......... Eq. 8.1}$$

which can also be represented :

$$Storage = A\,(Yield)^{B} + C \quad \text{.......... Eq. 8.2}$$

The procedure adopted is that the user loads up the required data file (currently ***YIELDCF.DAT***) and sets the storage and return period required. If the original time series of natural flow data have been accessed from the ***WR90*** database table, a default hydrological zone is specified, otherwise the user has to enter this as a combination of the WR90 volume number (1 to 6) and the hydrological zone letter (A to X - either upper or lower case) because this information is not included in the normal text data files.

The required storage (S in % MAR) is used to estimate the equivalent yield value (Y in % MAR $year^{-1}$) and the critical length (in years) of the drought period that determines the yield is then estimated from the derivative of equation 8.2 :

$$dS/dY = A\,B\,Y^{(B-1)} \quad \text{.......... Eq. 8.3}$$

Where dS/dY is the slope of the storage-yield relationship at Y and is therefore a length of time in years. This duration is then used with the time series of Ecological Reserve requirements to find the minimum requirement (by comparing all possible running sums) over that critical duration. The minimum requirement is then reduced to an annual equivalent (dividing by the period) and expressed as a percentage of the natural mean annual runoff for the site. This value can be considered an estimate of the reduction in yield that can be expected if the estimated reserve requirements are met and not considered part of the exploitable component of the natural flow regime.

Some comparisons have been made with the results of applying the residual flow (natural flows less reserve requirements) time series with a monthly reservoir simulation program.. The yield reductions given by the two methods are broadly comparable.

The yield derived from Equation 8.1 (i.e. based on the total natural flows with no allowance for the Reserve) is also printed to the screen for comparison purposes and to put the reduction value into context.

8.2 Program *SARES*

For this program the annual values for both the natural flows and the IFR modified flows are provided in the database table, while the detail (monthly distributions, assurance rules and modified time series) are stored in BLOB (Binary Large Objects) fields. The main summary facilities are therefore designed to allow the data in these BLOBs to be displayed or output to file.

Monthly distribution of IFR :

These data can be listed on the screen for a specific quaternary catchment outlet, once a database record has been selected (click on the required record in the table).

Assurance rules :

The assurance rules can be saved to a text file in the same way, and using the same format as in *RESDSS.*

IFR modified time series :

There are three options for saving IFR modified time series data to text files (WR90 format); the user chooses between saving only the low flow, or only the high flow components, or the total IFR.

Output of WR90 or WR90RES field data as text files :

There are several options to output the quaternary catchment names together with some of the database field data as text files. Examples include the region number, information on the baseflow contribution of quaternary catchments and the CVB index values.

Yield reduction estimates :

The method of estimating the mean annual water supply yield reduction consequent upon the implementation of the IFR modified flow time series as the Reserve (see section 8.1) has been added to ***SARES*** in the form of an output table of yield reduction values for several storage values (given a 1:50 year drought) and for EMCs A, B, C and D. The yield reduction estimates are divided up into those due to the low-flow requirement and those due to the high-flow requirements. The method seems to work quite well for storages of 20% of natural MAR and greater, but may not be very precise when using low storage values and is not suitable for no storage, i.e. run-of-river abstraction schemes. At present yield reductions under different return periods for run-of-river abstractions are based on a critical drought duration of 3 months instead of the value given by Equation 8.3.

8.3 Proposed future options

There are several options that are planned to be included within the programs in the near future.

Use of MapObjects (or similar) to access Arc View coverages and select catchment areas or regional parameter data directly :

At present the ArcView coverages of various items of spatial information can be distributed with the software, and an option is included to display these as bitmap images. However, it is also planned to make use of a spatial coverage analysis option that is available for DELPHI (such as MapObjects). This type of software allows the spatial coverages (and associated relational databases) to be accessed and analysed within a DELPHI program. While the required software is somewhat expensive at present, its use would extend the functionality of the various programs and will certainly be considered in the future.

Incorporation of modifications to the annual estimates and the seasonal distributions based on physical and biological factors :

Münster and Hughes (1999) describe an approach for using information on the physical and biological characteristics of river cross-sections to estimate correction factors to some of the IFR values derived by ***RESDSS***. At present these procedures have been incorporated into a separate program (***ECSCORE***) that allows scores to be estimated for annual maintenance and drought low-flow requirement totals, distributions of low flows and annual high-flow requirement totals. The concept is that these scores will then be used to adjust the purely hydrological estimates that are given by ***RESDSS***. Münster and Hughes (1999) is currently being circulated for comment, after which further modifications will be made and the procedures incorporated into ***RESDSS***.

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Instream Flow
Requirement

HYDROLOGICAL EXTRAPOLATION OF PAST IFR RESULTS A CONTRIBUTION TO THE PRELIMINARY RESERVE METHODOLOGY FOR SOUTH AFRICAN RIVERS

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November 1998

1. INTRODUCTION

It had already been recognised in 1996 that the volume of water (expressed as a percentage of mean annual runoff - MAR) that was required for the environmental reserve, generally decreased as the desired future state (now referred to as the Management Class) moved from category A down towards category D. However, there exists a large amount of scatter of values within each management class which could be related to :

- The subjectivity inherent in setting any IFRs due to the complex processes involved and the lack of any monitored information to confirm the results after a development has taken place.
- Differences in the flow regimes of the rivers concerned.
- Regional differences in riverine ecological processes or the specific ecological significance of a river reach or cross section.
- Differences in geomorphological characteristics of the channels.

The first point is difficult to handle in any scientific study and can only be minimised at this stage of the development of the BBM by selecting those IFR results in which a reasonably high degree of confidence has been expressed by the specialists involved. The last two are difficult to address without more detailed analysis of eco-hydrological relationships. While the second and third points are considered by the present authors to be not independent, but neither are they considered to be totally dependent. This initial document only addresses the differences that might be due to differences in the flow regime characteristics of the rivers.

This component of the preliminary reserve programme is concerned only with attempting to derive relationships between the past IFR results and the natural hydrological (or flow) regime of the rivers. It was therefore necessary to accept at the start of the project that no precise relationships would be found because other factors had to be initially ignored. A purely numerical statistical approach would have been unlikely to yield any useful results and therefore a more 'conceptual' approach had to be adopted. This 'conceptual' approach has largely involved identifying those components of the flow regime that can logically be considered to have some bearing on the flows that would be required to maintain the ecological functioning of a river system. The main hypothesis is that rivers which have more variable regimes (in several senses) are likely to require less water to function ecologically at a specified level, than those which have more regular regimes and therefore more constant and reliable habitats.

2. CONSTRAINTS

2.1 Information available from past IFRs

The study was constrained to be able to evaluate any relationships based on the information that could be readily obtained from past IFRs in which a reasonable degree of confidence has been expressed in the results. The following relevant information was generally available :

- Total flow volume for the four building block components (i.e. maintenance low flows, maintenance high flows and freshes, drought low flows and drought higher flows and freshes).
- Monthly distributions of the four building block components.
- Present ecological state (A to F) and future management category (A to D).

In many cases time series of daily flow data that were used in the IFR workshop to check the range of flows set for the IFR were available, but not in all cases. This was because the authors were not involved in all past IFR's and it would have been impossible in the time frame of the project to contact the relevant specialists and obtain all the data. In some cases, only monthly data were used in the workshops. It should therefore be recognised that for some sites, the comparisons between the results and indices of the natural hydrology were not really possible as no daily time series were available. In such cases, some indices based on natural (or naturalised) monthly time series were used coupled with other indices based on daily time series from nearby flow gauges that do not necessarily represent natural conditions. This issue will be referred to later.

2.2 Constraints related to future extrapolation

If any method developed is to have value in terms of the preliminary reserve project, it must be based on indices of flow regime characteristics which can be quantified using readily available information for the whole of South Africa. The most widely available source of information is the WR90 publications (or electronic data) which contain data at the quaternary scale and with a monthly time resolution. If this project makes use of any indices that are based on daily time series data (from whatever source), it must also provide a solution to estimating their value at sites where daily data are not readily available. A parallel study (being conducted largely by the fourth author) is therefore investigating the regionalisation of some indices (or flow regime characteristics) that have to be currently estimated from daily data.

One of the problems that will always be present is the fact that the information that is widely available, nationwide, is based on quaternary catchments. It is extremely difficult to extrapolate WR90 data to smaller catchments due to the complexities of hydrological processes that affect scale variations and the fact that gauged data for smaller catchments are not widely available.

3. POSSIBLE HYDROLOGICAL INDICES

The following hydrological indices were extracted from the daily data that were available for each IFR site that had formed part of a previous workshop. In each case an explanation of the reasons for considering them important is given.

- Annual coefficient of variation (standard deviation of annual flow volume / MAR). This represents the annual variation in total volume of runoff, can be considered a coarse representative of flow reliability and it might be expected that rivers with high annual CV's would have lower IFR requirements. It is also readily estimated (for catchments at the quaternary scale) from data contained within WR90.

- Seasonal monthly coefficients of variation based on the main summer months (JFM-CV; January, February and March) and the main winter months (JJA-CV; June, July and August). These are readily estimated from WR90 data but might be expected to have different effects in the different rainfall regions (i.e. the main summer rainfall region, winter rainfall region and all-year rainfall region). The JJA-CV, for example, may be useful in the context of lowflows (maintenance and/or droughts) in summer rainfall region rivers, where the requirements might decrease with increasing CV. However, lower wet-season CV's might suggest higher (as well as more reliable) baseflow contributions, which could also have a bearing on the lowflow IFR. Wet season CV's could also be the only readily available index which has a bearing on the variations in high flow requirements.

- Daily CV's for winter and summer seasons have also been extracted from the daily data available. These indices could be more useful than monthly based CV's, particularly in the wet season and in relation to the setting of the high flow requirement of the reserve. However, these are not likely to be generally available, unless they can be regionalised.

- The authors of this document consider that the separation of total flow into baseflow and higher flow components based on traditional hydrograph separation procedures could yield an important hydrological index. This is based on the assumption that if the natural regime has a high baseflow component, it might be expected that this would be reflected in the ecological functioning of the river and consequently, the IFR results. However, an index of baseflow contribution (BFI) really requires daily data to derive (and is generally different between natural and impacted regimes). Therefore, while a conventionally derived BFI has been used, it has also been necessary to investigate methods of regionalising the index using relationships with monthly WR90 data.

4. HYDROLOGICAL DATA (daily time series) USED IN THIS STUDY

Wherever possible, the same daily time series that were used during the workshops were used in this study (a mixture of observed, simulated and patched or extrapolated data), in other cases the best available data to represent natural conditions were used. Unfortunately, in some cases these data were from gauges located on rivers with large scale upstream impacts and could not be considered to be representative of natural conditions. Table 1 provides some more details about the source of the daily time series used and it is clear that for some sites the data can be considered more reliably representative of natural conditions than others.

Table 1 Source of daily time series of flows

IFR Site or River	Source of data & comments
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Letaba River sites	Data available from B8H010 (IFR1), B8H017 (IFR2) and B8H008 (IFR3), all records being patched to the same length of 36 years. All records appear to be impacted by abstractions.
Mogalakwena sites	Data available from gauge A6H009 (near confluence with Limpopo). 16 years of data that are unlikely to be very natural.
Bivane River sites	Data available from gauge W4H004 on the Bivane River close to IFR1&2. Some 20 years of data that appear to be close to natural conditions.
Mvoti River sites	Data available from U4H002 (30 years) which is located upstream of IFR1 and is affected by afforestation and irrigation abstractions. These data are not very suitable for the downstream IFR sites.
Berg River sites	Data available from G1H036 (18 years) which lies between the two IFR sites. The records are affected by afforestation and irrigation abstractions.

5. INITIAL RELATIONSHIPS BETWEEN THE BBM COMPONENTS AND THE HYDROLOGICAL INDICES.

In general terms the procedures followed during this study have involved attempts to identify suitable hydrological indices to relate to the four components of the BBM (maintenance/drought, lowflows/highflows), expressed either in volumetric terms, as a percentage of natural MAR or as a percentage of another component. The next step was then to attempt an approach that allows the monthly distribution of the component to be defined. Parallel steps have necessarily involved trying to explain some of the anomalies, making use of site specific information related to known differences in the ecological functioning of the systems, or special circumstances that prevail at individual sites or river reaches.

Figures 1 and 2 illustrate the general relationships between management category and the total requirements set for maintenance and drought years, expressed as a percentage of natural MAR. Given that the requirements are expected to generally decrease with an increasing value (A → D or 1 → 7) of the management category, four sites are immediately noticeable as anomalies (Sabie 6 and 8, Berg 1 and 2). As far as the drought requirements are concerned, the main anomalies are the two Berg sites.

The following sub-sections discuss the results of the attempts to account for the variation within each management category

5.1 Maintenance low flows

These are expected to *INCREASE* with increasing values of the baseflow index (BFI - always less than 1), but *DECREASE* with increasing values of flow variability. It therefore follows that if indices of variability and baseflow response are to be combined they would have to have opposite effects. Figure 3 illustrates the best results obtained in the study thus far and uses a combined index of the sum of the maximum monthly CV's for the summer (JFM) and winter (JJA) periods, divided by the BFI. Non-linear estimation equations have been derived that fit through many of the points and that appear to be sensible from a purely hydrological point of view (figure 4).

The A/B line is difficult (!!) to locate as there is only one example of this category. The B line passes successfully through, or close to, four of the 5 high confidence sites, while Sabie 8 lies above the line, Bivane 1&2 falls lower and Luvuvhu 3 (low confidence) is way off the line. It is possible to suggest that the lowflow IFR for Sabie 8 (Sand River) was set quite high to ensure that this sand bed river remains perennial, while the Bivane site lies within a gorge and requires less water. The B/C line passes close to four of the sites, but Sabie 6 lies a long way above (high requirement) and Tugela 2 quite far below. The Sabie site (Mutlumuvi) is probably high to account for the need to rehabilitate this site after the collapse of Zoegnog Dam.

There are eleven sites falling into category C, four of which are on the Mogalakwena River, where the lowflow requirement is negligible (it is a temporary river). The line has been drawn more-or-less parallel to the other lines and apart from the two Mvoti sites, most of the others fall quite far above. Three of these are the Letaba sites where the CV data have been drawn from the naturalised monthly data used in the workshop, while the BFI data have been based on the observed records. The latter are therefore expected to be too low, and if corrected would bring down the value of the combined index used in the graph, making the points fall closer to the C line.

A C/D line has been drawn in, but does not pass close to the only C/D category site. The line is therefore positioned on the basis of extrapolation from the other lines. It should be noted that the only Western Cape river represented (Berg) has requirements that are far greater than these extrapolations suggest. The flow data used to evaluate the hydrological indices for the Mvoti 3 site is a long way upstream and it is possible that the flow regime at site 3 would be less variable with a higher baseflow contribution. This point would then move vertically downward toward the C line and could be illustrative of scaling variations between large and small catchments or rivers. Problems have also been identified with the hydraulics at this site.

5.2 Drought low flows

Attempts were made to relate drought low flows in a similar way to maintenance low flows, but there were less clear relationships. A second attempt related drought lowflows, expressed as a % of maintenance lowflows, to the sum of the monthly CV's for winter and summer. The relationship was far from clear and did not really provide a very useful method. Subsequently, discussions with various ecological specialists suggested that it does not really make sense to define different drought low flows for different management classes (i.e. there is really only one drought condition that applies to all management classes). Until a better approach can be proposed, drought flows are therefore taken as equivalent to the 'D' class flows (as shown in figure 4)..

5.3 Maintenance high flows

There is a relatively narrow range of values of maintenance highflow requirements (expressed as % MAR) but there does not seem to be any relationship with the available hydrological variables within the various management classes. This result could have been anticipated given the high degree of variability in site specific circumstances surrounding the setting of high flows (related to the channel size and shape, riparian vegetation needs and geomorphological needs in terms of sediment transport, amongst others).

In an attempt to obtain at least an initial estimation approach for high flows, the total IFR requirement was plotted against the same variable used in figure 3 (i.e. the sum of the monthly CV's for winter and summer divided by the BFI). The result (figure 6) is a set of relationships (for each management category) with a relatively high degree of scatter (outliers due to low flows and due to high flows are combined) but which could be of value. The lines for each management category follow the same approximate pattern as those in figure 4 (repeated as bold lines in figure 6), but are straighter and of course above the lowflow lines. If these lines are used in conjunction with figure 4 the result is values for the total maintenance IFR and the lowflow component, from which the high flow component can be derived. Because one set of lines is straighter than the others, applying these relationships gives variable highflow contributions for each management category of between 5 and 8 for C sites, 5 and 10 for B/C sites, 5 and 10 for B sites and approximately 8 to 15 for A/B sites (all values given as % MAR). In general terms, these figures do correspond to the experience from past IFR's, although there are quite a few outliers. The main outliers are Sabie 6 and 8 (related to the movement of sediement and rehabilitation), the Berg River sites (already identified under the lowflow section) and the Luvuvhu sites (low confidence results in general).

5.4 Drought high flows

The drought high flow requirements range from very small % MAR values to less than 3% and while it has not been possible to discover a suitable estimation relationship, this component is not of great importance.

6. MONTHLY DISTRIBUTIONS

Mean seasonal distributions of total flows and separated baseflows have been compiled for all of the IFR sites using the available data referred to in Table 1 and compared with the seasonal distributions of IFR lowflow and highflow requirements (where available). Some general observations could be made.

- The largest differences between the natural and modified (i.e. IFR) lowflow regimes occur in the wet season, regardless of the IFR requirement. This is effectively the same as stating that the environmental reserve requires a higher proportion of the natural flows in the dry season than in the wet season.

- As the IFR requirement decreases relative to the natural flows, a greater proportion of the wet season flows can be released for other uses, relative to the dry season. If the proportions remained similar, there is the possibility that dry season flows would almost disappear for rivers with very low requirements.

- While the shape of the natural flow distribution cannot be neglected, it appears to be of less importance in defining the final lowflow IFR distribution than other factors.

- There are apparently fewer consistent relationships between the monthly distributions of high flows at the various IFR sites than there are for the lowflows.

6.1 Monthly distributions of lowflows

An attempt was made to determine generalised distributions and sets of weighting factors that could be estimated from the total maintenance or drought lowflow requirement and then applied to the distribution of natural baseflows. This was found to be a practical approach and gave reasonable results for most of the sites included in the analysis for both maintenance and drought low flows. The method relies upon having natural baseflow distributions available and the assumption was made that these would be supplied from a regionalisation of natural baseflow characteristics (part of a parallel study to this one). The curves are all based on a single master distribution which is then coupled to a weighting equation for each month of the year which is controlled only by the total value for the year as a whole. The correct curve to use is determined, iteratively, by changing the total value until the total of the monthly IFR lowflows equals the correct value (set in the workshop or extracted from figure 4). Approximate, non-dimensional, monthly distributions of baseflow contribution (as % of mean monthly total runoff) for all the regions of South Africa have now been compiled.

6.2 Monthly distributions of high flows

While there are a number of differences between the results for the various sites, some generalisations can be made. Some of the differences appear to be related to whether or not large flushing flow events were specified in the workshops, or whether the assumption was made that these would occur naturally (i.e. would not be affected by the water resource development) and were therefore not specified.

The estimation approach that was finally adopted initially involved expressing the mean monthly natural high flows (total flows - baseflow) as a percentage of their total for the year. If the IFR high flow volume requirements are similarly expressed as a % of their total for the year, then useful patterns seem to emerge (for the summer rainfall regions).

The IFR % values for October and November are generally very similar to the natural high flow % values.

There are very few sites where high flows have been quantified for April to September.

The March IFR % value varies between 0.5 and 1.0 times the natural high flow % value (and has been generalised as 0.75).

If the natural high flow peak occurs in February, the highest IFR high flow requirement is in February, while the December requirement is approximately twice the January requirement. If the natural high flow peak occurs in January, the highest IFR flow requirement is in January and the December and February requirements are often similar.

The highest requirement (in January or February) can be associated with the natural peak relative to the natural total volume over the three wettest months.

The above 'rules' have been formalised and modified for the other regions of South Africa (winter rainfall, various aseasonal regions and some summer rainfall regions with different flood seasons). They can be considered to reproduce the actual IFR results reasonably well across the range of sites for which data are available. Inevitably, the final volumes for each month are very dependent on the estimation equations for total and lowflow maintenance volumes, from which the total high flow volume is derived.

7. ASSURANCE RULES.

The estimation procedures discussed above provide estimates of the monthly distributions of maintenance and drought lowflows, as well as maintenance high flows. It is also necessary to have procedures available to specify when maintenance (or above) and when drought conditions should apply. This introduces the concept of assurance (i.e. how often are maintenance, or above, flows required). There is very little past experience of the use of this concept within IFR workshops, although recently the IFR model has been used to specify a time series of IFR flows from which the assurance information can be extracted.

In the absence of further information, a regionalised set of monthly rule curves has been generated based on the flow duration curve characteristics of the natural flow regime. Thus, a river with a relatively reliable flow regime would be expected to have rule curves that suggest high assurance (about 70%) of maintenance flows, maximum flows not a great deal higher than maintenance (some 20% higher, for example) and a relatively short duration of time at drought conditions. A more 'flashy' river would be expected to have lower assurance of maintenance, a higher maximum (about 50-100% higher, giving a more variable regime) and a longer time at drought conditions. These rule curves are the equivalent of flow duration curves (in that they are based on plots of % assurance versus flow) and have been based on a generic, smooth curve algorithm with 4 parameters). To generate a time series of monthly IFR flows the following steps are followed.

- Identify the flow value for a specific month in the time series of natural flows.
- Determine the % time equalled or exceeded on the calendar month flow duration curve.
- Use the same % time with the assurance rule curve and determine the total flow requirement of the IFR.

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The A/B line is difficult (!!) to locate as there is only one example of this category. The B line passes successfully through, or close to, four of the 5 high confidence sites, while Sabie 8 lies above the line, Bivane 1&2 falls lower and Luvuvhu 3 (low confidence) is way off the line. It is possible to suggest that the lowflow IFR for Sabie 8 (Sand River) was set quite high to ensure that this sand bed river remains perennial, while the Bivane site lies within a gorge and requires less water. The B/C line passes close to four of the sites, but Sabie 6 lies a long way above (high requirement) and Tugela 2 quite far below. The Sabie site (Mutlumuvi) is probably high to account for the need to rehabilitate this site after the collapse of Zoegnog Dam.

There are eleven sites falling into category C, four of which are on the Mogalakwena River, where the lowflow requirement is negligible (it is a temporary river). The line has been drawn more-or-less parallel to the other lines and apart from the two Mvoti sites, most of the others fall quite far above. Three of these are the Letaba sites where the CV data have been drawn from the naturalised monthly data used in the workshop, while the BFI data have been based on the observed records. The latter are therefore expected to be too low, and if corrected would bring down the value of the combined index used in the graph, making the points fall closer to the C line.

A C/D line has been drawn in, but does not pass close to the only C/D category site. The line is therefore positioned on the basis of extrapolation from the other lines. It should be noted that the only Western Cape river represented (Berg) has requirements that are far greater than these extrapolations suggest. The flow data used to evaluate the hydrological indices for the Mvoti 3 site is a long way upstream and it is possible that the flow regime at site 3 would be less variable with a higher baseflow contribution. This point would then move vertically downward toward the C line and could be illustrative of scaling variations between large and small catchments or rivers. Problems have also been identified with the hydraulics at this site.

5.2 Drought low flows

Attempts were made to relate drought low flows in a similar way to maintenance low flows, but there were less clear relationships. A second attempt related drought lowflows, expressed as a % of maintenance lowflows, to the sum of the monthly CV's for winter and summer. The relationship was far from clear and did not really provide a very useful method. Subsequently, discussions with various ecological specialists suggested that it does not really make sense to define different drought low flows for different management classes (i.e. there is really only one drought condition that applies to all management classes). Until a better approach can be proposed, drought flows are therefore taken as equivalent to the 'D' class flows (as shown in figure 4)..

5.3 Maintenance high flows

There is a relatively narrow range of values of maintenance highflow requirements (expressed as % MAR) but there does not seem to be any relationship with the available hydrological variables within the various management classes. This result could have been anticipated given the high degree of variability in site specific circumstances surrounding the setting of high flows (related to the channel size and shape, riparian vegetation needs and geomorphological needs in terms of sediment transport, amongst others).

In an attempt to obtain at least an initial estimation approach for high flows, the total IFR requirement was plotted against the same variable used in figure 3 (i.e. the sum of the monthly CV's for winter and summer divided by the BFI). The result (figure 6) is a set of relationships (for each management category) with a relatively high degree of scatter (outliers due to low flows and due to high flows are combined) but which could be of value. The lines for each management category follow the same approximate pattern as those in figure 4 (repeated as bold lines in figure 6), but are straighter and of course above the lowflow lines. If these lines are used in conjunction with figure 4 the result is values for the total maintenance IFR and the lowflow component, from which the high flow component can be derived. Because one set of lines is straighter than the others , applying these relationships gives variable highflow contributions for each management category of between 5 and 8 for C sites, 5 and 10 for B/C sites, 5 and 10 for B sites and approximately 8 to 15 for A/B sites (all values given as % MAR). In general terms, these figures do correspond to the experience from past IFR's, although there are quite a few outliers. The main outliers are Sabie 6 and 8 (related to the movement of sediement and rehabilitation), the Berg River sites (already identified under the lowflow section) and the Luvuvhu sites (low confidence results in general).

5.4 Drought high flows

The drought high flow requirements range from very small % MAR values to less than 3% and while it has not been possible to discover a suitable estimation relationship, this component is not of great importance.

6. MONTHLY DISTRIBUTIONS

Mean seasonal distributions of total flows and separated baseflows have been compiled for all of the IFR sites using the available data referred to in Table 1 and compared with the seasonal distributions of IFR lowflow and highflow requirements (where available). Some general observations could be made.

- The largest differences between the natural and modified (i.e. IFR) lowflow regimes occur in the wet season, regardless of the IFR requirement. This is effectively the same as stating that the environmental reserve requires a higher proportion of the natural flows in the dry season than in the wet season.

- As the IFR requirement decreases relative to the natural flows, a greater proportion of the wet season flows can be released for other uses, relative to the dry season. If the proportions remained similar, there is the possibility that dry season flows would almost disappear for rivers with very low requirements.

- While the shape of the natural flow distribution cannot be neglected, it appears to be of less importance in defining the final lowflow IFR distribution than other factors.

- There are apparently fewer consistent relationships between the monthly distributions of high flows at the various IFR sites than there are for the lowflows.

6.1 Monthly distributions of lowflows

An attempt was made to determine generalised distributions and sets of weighting factors that could be estimated from the total maintenance or drought lowflow requirement and then applied to the distribution of natural baseflows. This was found to be a practical approach and gave reasonable results for most of the sites included in the analysis for both maintenance and drought low flows. The method relies upon having natural baseflow distributions available and the assumption was made that these would be supplied from a regionalisation of natural baseflow characteristics (part of a parallel study to this one). The curves are all based on a single master distribution which is then coupled to a weighting equation for each month of the year which is controlled only by the total value for the year as a whole. The correct curve to use is determined, iteratively, by changing the total value until the total of the monthly IFR lowflows equals the correct value (set in the workshop or extracted from figure 4). Approximate, non-dimensional, monthly distributions of baseflow contribution (as % of mean monthly total runoff) for all the regions of South Africa have now been compiled.

6.2 Monthly distributions of high flows

While there are a number of differences between the results for the various sites, some generalisations can be made. Some of the differences appear to be related to whether or not large flushing flow events were specified in the workshops, or whether the assumption was made that these would occur naturally (i.e. would not be affected by the water resource development) and were therefore not specified.

The estimation approach that was finally adopted initially involved expressing the mean monthly natural high flows (total flows - baseflow) as a percentage of their total for the year. If the IFR high flow volume requirements are similarly expressed as a % of their total for the year, then useful patterns seem to emerge (for the summer rainfall regions).

> The IFR % values for October and November are generally very similar to the natural high flow % values.

There are very few sites where high flows have been quantified for April to September.

The March IFR % value varies between 0.5 and 1.0 times the natural high flow % value (and has been generalised as 0.75).

If the natural high flow peak occurs in February, the highest IFR high flow requirement is in February, while the December requirement is approximately twice the January requirement. If the natural high flow peak occurs in January, the highest IFR flow requirement is in January and the December and February requirements are often similar.

The highest requirement (in January or February) can be associated with the natural peak relative to the natural total volume over the three wettest months.

The above 'rules' have been formalised and modified for the other regions of South Africa (winter rainfall, various aseasonal regions and some summer rainfall regions with different flood seasons). They can be considered to reproduce the actual IFR results reasonably well across the range of sites for which data are available. Inevitably, the final volumes for each month are very dependent on the estimation equations for total and lowflow maintenance volumes, from which the total high flow volume is derived.

7. ASSURANCE RULES.

The estimation procedures discussed above provide estimates of the monthly distributions of maintenance and drought lowflows, as well as maintenance high flows. It is also necessary to have procedures available to specify when maintenance (or above) and when drought conditions should apply. This introduces the concept of assurance (i.e. how often are maintenance, or above, flows required). There is very little past experience of the use of this concept within IFR workshops, although recently the IFR model has been used to specify a time series of IFR flows from which the assurance information can be extracted.

In the absence of further information, a regionalised set of monthly rule curves has been generated based on the flow duration curve characteristics of the natural flow regime. Thus, a river with a relatively reliable flow regime would be expected to have rule curves that suggest high assurance (about 70%) of maintenance flows, maximum flows not a great deal higher than maintenance (some 20% higher, for example) and a relatively short duration of time at drought conditions. A more 'flashy' river would be expected to have lower assurance of maintenance, a higher maximum (about 50-100% higher, giving a more variable regime) and a longer time at drought conditions. These rule curves are the equivalent of flow duration curves (in that they are based on plots of % assurance versus flow) and have been based on a generic, smooth curve algorithm with 4 parameters). To generate a time series of monthly IFR flows the following steps are followed.

- Identify the flow value for a specific month in the time series of natural flows.
- Determine the % time equalled or exceeded on the calendar month flow duration curve.
- Use the same % time with the assurance rule curve and determine the total flow requirement of the IFR.

8. PROVISION OF INFORMATION REQUIRED TO APPLY THE ESTIMATION PROCEDURES.

As already noted, a parallel study has been carried out to try and derive regional relationships for the natural flow regime variables required by the proposed estimation methods. These variables and the currently available methods of estimating them are as follows :

- The baseflow index (BFI), a value representing the average proportion of total flow that occurs as baseflow. Good relationships have been derived (based on some 70 time series of flow data) between BFI and Q75 taken from the 1-month annual flow duration curve using natural data. WR90 contains monthly time series (1920 to 1989) for all the defined quaternary catchments in South Africa, from which a duration curve can be compiled and the Q75 value estimated. Initial results indicate that the relationship is different for Western Cape rivers than the rivers of aseasonal and summer rainfall regions. There is also a suggestion that the nature of the relationship varies with catchment size.

- Monthly CV's for the main wet and dry season. The values used in the estimations of IFR lowflows and total flows are the maximum CV for the months of January, February and March (JFM) and the maximum CV for the months of June, July and August (JJA). Clearly, the main wet and dry season months are different for the winter rainfall region, but as they are combined in all the estimation methods (figures 4 and 6), the issue is not relevant. Estimates of these values can be obtained from the data provided in WR90.

- Monthly distributions of natural total flow and baseflow. Total flow distributions can be obtained from WR90 data directly, while distributions of baseflow have been regionalised by the fourth author. The results are more than acceptable for several summer rainfall regions and there is a high degree of consistency in the non-dimensional (values expressed as %MAR) shapes of the distributions. The distributions are less consistent for the other regions of the country (winter rainfall and aseasonal regimes).

A Windows95 computer program has been developed that allows all the estimation approaches discussed in this document to be applied. Associated with the program is a data file that includes all the parameters of the estimation equations, as well as the parameters of the regionalised equations and distributions. The program also allows the user to enter the scores for the criteria used to estimate the habitat integrity (according to the method developed by Kemper and Kleynhans as part of the preliminary reserve project) and provides a facility for the initial estimate of the management class. The program therefore represents a Decision Support System for applying the hydrological based estimation procedures of the preliminary reserve approach.

9. GENERAL OBSERVATIONS AND CONCLUSIONS

While some useful results have been achieved at this stage of the project, there are still a number of issues that have to be resolved.

- The amount of IFR workshop data is very limited and this does not make it very easy to determine generalised relationships. Many of the rivers in the sample analysed are within similar hydrological regions and it is difficult to judge whether the derived relationships would hold for other areas. This point is very relevant given that the two Berg River sites are always anomalous.

- The relationships derived thus far are tentative and require further work to check and improve.

- There needs to be a much greater specialist ecological input into checking the usefulness of the relationships and identifying anomalies that need to be accounted for in some way.

- Although the last point referred to 'anomalies', certain sites may only be seen as such because the data set is limited in size. Given more data, the current 'anomalies' may in fact be part of a different group of sites with their own unique characteristics.

- There is a need to investigate or conceptualise the likely effects of river/catchment size on the relationships and to attempt to incorporate more ecological relationships.

- The development of relationships between hydrological characteristics and the environmental reserve requirements should be a continuing process that can accommodate additional information as it becomes available.

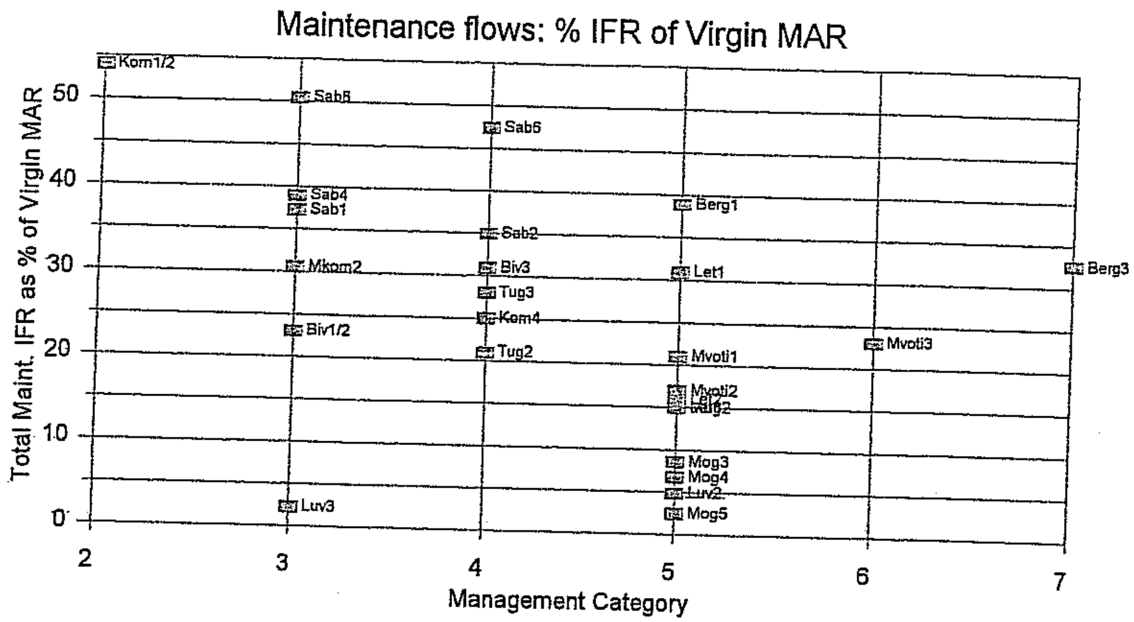

Figure 1 Maintenance flows set for the rivers in different management categories (A/B=2, B=3, B/C=4, C=5, C/D=6, D=7)

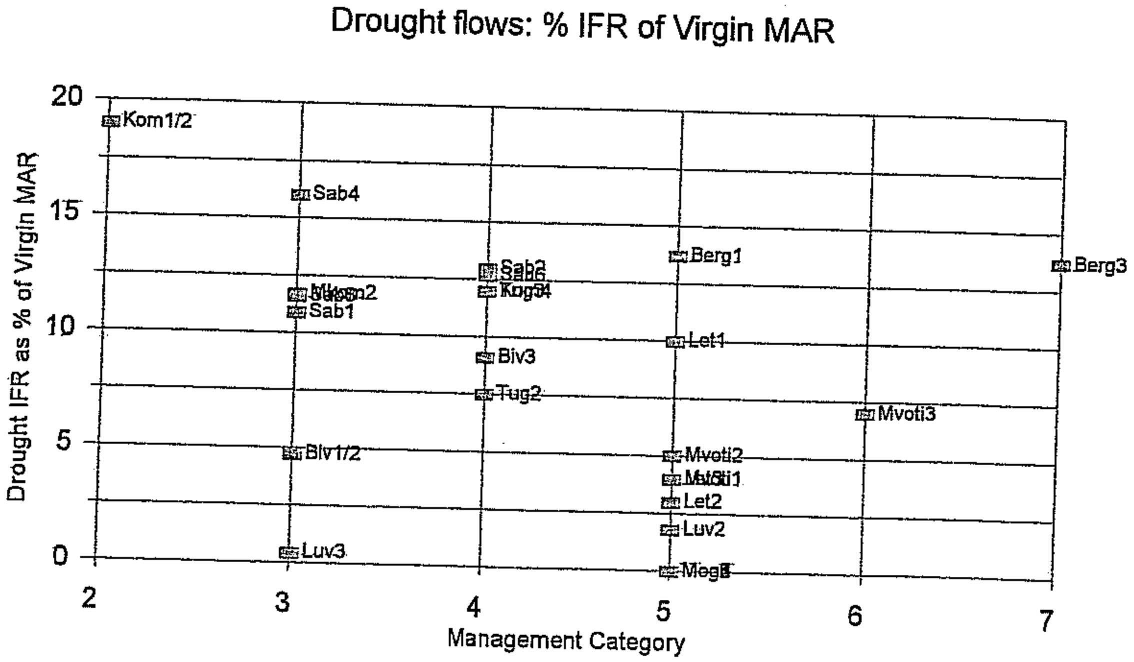

Figure 2 Drought flows set for the rivers in different management categories.

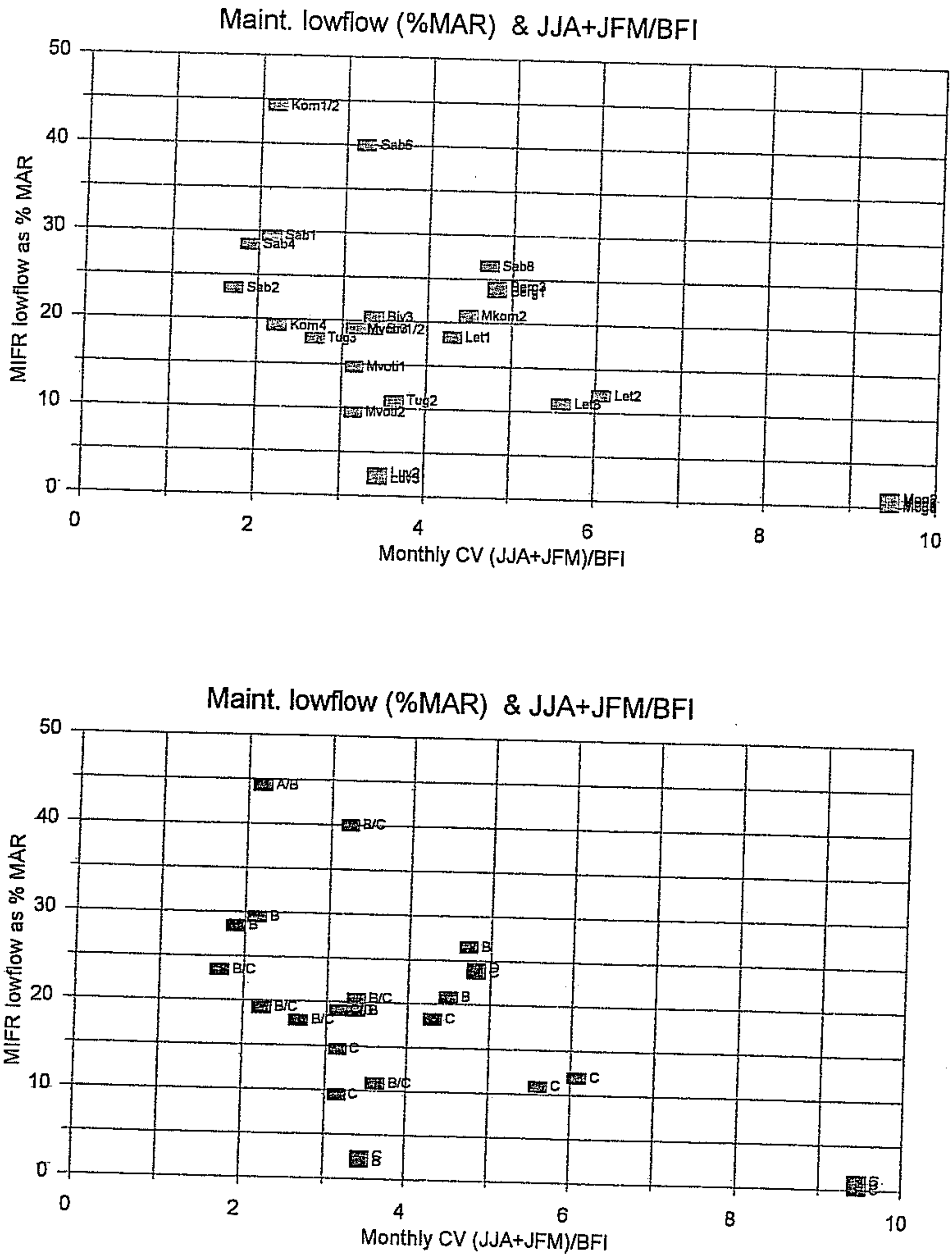

Figure 3 Maintenance lowflow requirement (expressed as % natural MAR) versus the combined CV/BFI index. The top part of the diagram has river name labels, while the lower diagram has management category labels.

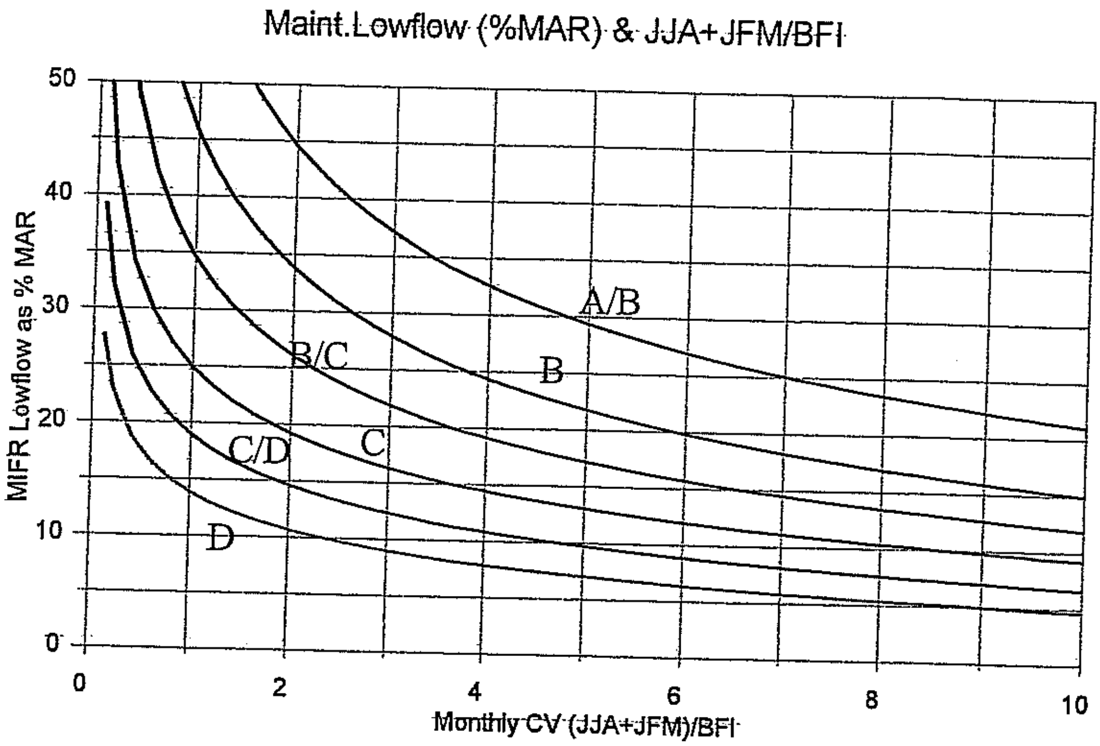

Figure 4 Non-linear estimation relationships for maintenance lowflow volumes based on management category.

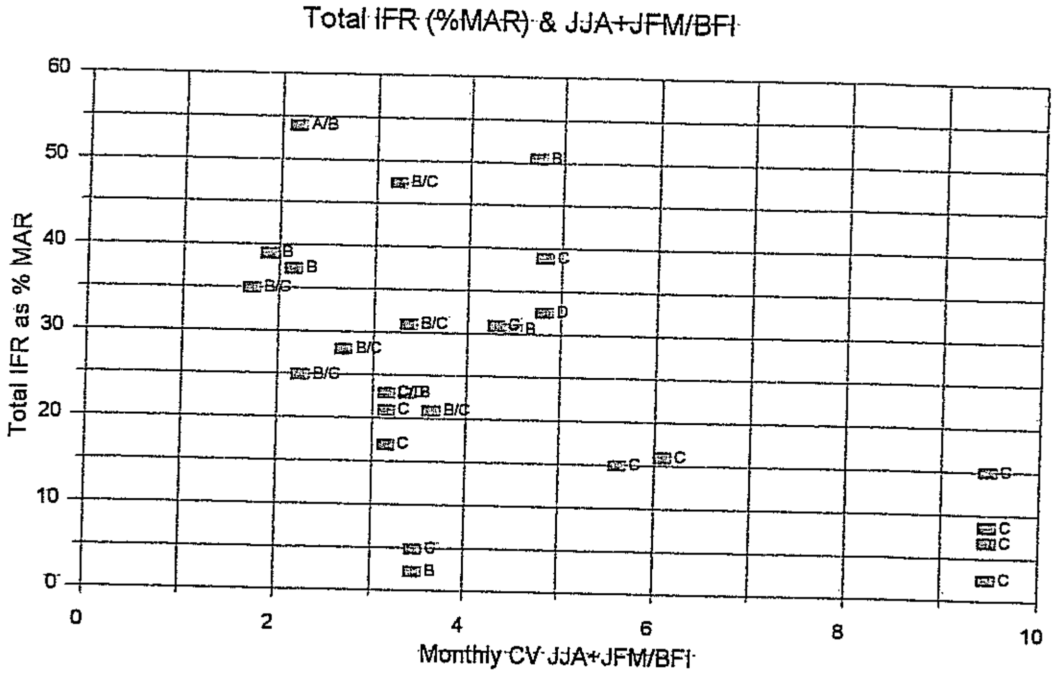

Figure 5 Relationship between combined CV and baseflow index and total maintenance IFR requirement.

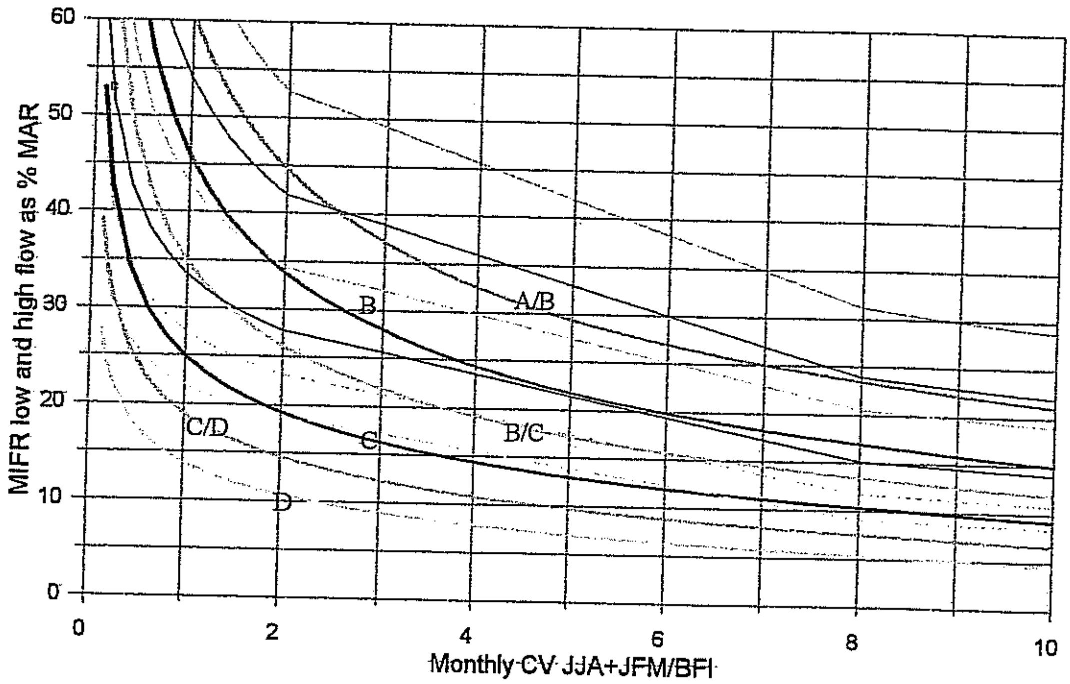

Figure 6 Lines representing the relationships for maintenance lowflows (bold lines - taken from figure 4) and maintenance total flows (thinner lines).