Characterisation of Flow in Regulated and Unregulated Streams in Eastern Australia

Jane Growns Murray–Darling Freshwater Research Centre

Nick Marsh Centre for Environmental Applied Hydrology

Cooperative Research Centre for Freshwater Ecology
Technical Report 3/2000
September 2000

Centre for Environmental Applied Hydrology

The Cooperative Research Centre for Freshwater Ecology improves the health of Australia’s rivers, lakes and wetlands through research, education and knowledge exchange. It was established in 1993 under the Australian Government’s Cooperative Research Centre Program.

The Cooperative Research Centre for Freshwater Ecology is a collaborative venture between:

- ACTEW Corporation
- CSIRO Land and Water
- Department of Land and Water Conservation, NSW
- Department of Natural Resources, Queensland
- Department of Natural Resources and Environment, Victoria
- Environment ACT
- Environment Protection Authority, NSW
- Environment Protection Authority, Victoria
- Goulburn–Murray Rural Water Authority
- Griffith University
- La Trobe University
- Lower Murray Water
- Melbourne Water
- Monash University
- Murray-Darling Basin Commission
- Murray-Darling Freshwater Research Centre
- Sunraysia Rural Water Authority
- Sydney Catchment Authority
- University of Canberra

Ph: 02 6201 5168
Fax: 02 6201 5038
Email: pa@lake.canberra.edu.au
http://freshwater.canberra.edu.au

Printed in September 2000

Growns, Jane.
Characterisation of flow in regulated and unregulated streams
in eastern Australia.

Bibliography.
ISBN 1 876810 06 8

Streamflow – Australia, Eastern. I. Cooperative Research Centre
for Freshwater Ecology (Australia). II. Title. (Series : Technical report
(Cooperative Research Centre for Freshwater Ecology) ; 2000/3).

551.483/0994

Editing and layout: Science Text Processors Canberra, scientex@actonline.com.au
Printing and binding: Elect Printing, Fyshwick, ACT

CONTENTS

List of tables and figures

EXECUTIVE SUMMARY

An understanding of the hydrologic characteristics of Australian rivers will help guide the responsible management of water resources, particularly the provision of environmental flows. This report describes a new method of assessing the hydrology of rivers in a way that is relevant to the ecology of the rivers. It summarises the hydrological characteristics calculated for 107 regulated and unregulated streams and rivers in south-eastern Australia using 20 years of daily discharge data.

The aims of this project were:

1) to develop a comprehensive and ecologically relevant list of statistics that describe a river's flow regime;
2) to characterise rivers by their flow regimes over a 20-year period; and
3) to answer questions such as
    - How has water resource development altered the flow regimes of Australian rivers?
    - Do distinct regions or climates produce characteristic flow regimes?
    - Do different forms of water resource development (irrigation, hydro-electricity, urban supply) impose characteristic changes on flow regimes?

The project used 333 hydrological variables in seven main categories to characterise the flow measured at 107 stream gauging locations in south-east Australia. The seven major categories analysed were:

1. long-term variables, such as mean daily flow, base flow index, maximum and minimum flow;
2. high-flow variables, i.e. number, duration and magnitude of events above a threshold flow;
3. low-flow variables, i.e. number, duration and magnitude of events below a threshold flow;
4. moving-average variables, i.e. 1-, 30- and 90-day moving averages;
5. cessation-of-flow variables, i.e. duration of periods with zero discharge;
6. variables concerned with the rise and fall of the hydrograph, i.e. durations of rising and falling limbs and comparison of differences in consecutive daily flow; and
7. monthly-flow variables, i.e. distribution of flow between months, and annual variability in monthly flow.

The variables for all 107 stream gauges were calculated from records consisting of 20 years of data, from 1/1/1973 to 31/12/1992. Of the 107 data sets, 42 were collected downstream of a regulating structure and 55 were collected from unregulated stations; also, data were simulated for five regulated and five unregulated stations. Stream gauges were classified as regulated if they were located downstream (regardless of distance downstream) of a structure that was likely to alter the stream hydrology. The status of those classified as unregulated was confirmed by checking with the relevant stream gauge management authorities.

The gauging stations were located in three climate types: arid (BS) and two types of warm temperate (Cfa and Cfb). The Cfa stations occurred in non-arid inland areas and coastal areas from Sydney north; Cfb stations occurred in mostly upland areas in south-eastern Victoria and NSW and in northern NSW and southern Queensland.

A cross correlation analysis of output data compared the mean and median values as measures of central tendency. Mean and median values appeared to be highly correlated ($r > 0.8$) for measures of duration (i.e. the duration of events above a certain threshold) and measures of number (i.e. the number of events above a certain threshold). Mean and median values were not highly correlated ($r < 0.8$) for measures of flow (i.e. the peak magnitude of events above a certain threshold). Highly correlated variables were removed, reducing the number of hydrological descriptors to 91 prior to multivariate analysis.

Multivariate analyses showed that the main gradient in the entire data set was that of intermittent-flow gauging stations versus permanent-flow gauging stations. Within the permanent group, stations from the BS and Cf climate groupings could be clearly distinguished from each other. Regulated and unregulated stations could not be compared, either within the BS and Cfb climate groupings or among the various types of water resources development, because of the small number of stations in many of the categories. However, within the Cfa group, the irrigation stations were significantly different from the unregulated stations, and many hydrological variables differed significantly between the two groups. The differences included much higher long-term maximum flows, 90th percentile flows and mean daily flows, and longer return intervals for the 2-year flood for regulated stations. Seasonality of flows was also different and several of the flow descriptors were less variable at regulated stations.

If the method developed in this study were applied to more stations within each of the categories, it would be possible to test differences within the other climate groupings and between various types of water resource development, and the variables that best categorise these groupings could be assessed. All of Australia’s river systems should be compared. If greater use were made of modelled data, regulated and unregulated hydrologies could be compared more directly.

It would be extremely useful if better information could be obtained about how and to what extent water is extracted from the rivers. Direct abstraction volumes should also be assessed; rivers where the volumes are found to be large should then be considered ‘regulated’ or at least part of a separate grouping.

The flow statistics derived in this study are only ecologically significant if they are correlated with patterns in stream biota, spatially or temporally. It is important to identify appropriate biological data sets and to test the correlations between flow variables and biota.

This work has important implications for management. As most water managers are aware, it will be a complex task to determine release strategies for ‘environmental flows’ for rehabilitating rivers. To develop a set of flow statistics that can characterise flow regimes, regionally or perhaps nationally, is a high priority. The results presented in this report suggest that each river would need to be considered in the context of (i) the natural flow regimes of nearby rivers, (ii) the climatic zone in which it occurs, and (iii) the main purpose for which it is regulated. However, the method described here needs further development to determine whether fewer flow statistics can achieve acceptable levels of flow characterisation.

Based on the results of this report, it should now be possible to talk with managers and engineers and discuss how water can be released from dams in ways that minimise both the hydrological differences between regulated and comparable unregulated rivers and the effects on consumptive use.

Acknowledgements

This has been a collaborative project of the Centre for Environmental Applied Hydrology (CEAH) and the Cooperative Research Centre for Freshwater Ecology (CRCFE). We gratefully acknowledge the help of the following individuals and organisations:

- staff of the NSW Department of Land and Water Conservation, particularly Derek Everson, for verification of stream gauge status for New South Wales stream gauges;
- staff of Thiess Environmental Services, particularly Mark Pickles, for verification of stream gauge status for Victorian stream gauges;
- Sharyn RossRakesh for her help in manipulating HYDSYS™ data files;
- the Environmental Flows team from CRCFE, namely Ben Gawne, Peter Gehrke, John Harris, Barry Hart, Terry Hillman, Paul Humphries and Martin Thoms, for their input and enthusiasm;
- Rob Argent, Christopher Gippel, Tony Ladson, Tom McMahon, and Michael Stewardson of CEAH at the Department of Civil and Environmental Engineering at the University of Melbourne, for their advice and input into this project;
- staff of the Cooperative Research Centre for Catchment Hydrology for allowing access to their HYDSYS™ data archives;
- Dr Ivor Growns for reviewing early drafts of the report.

Nick Marsh wrote the computer code to calculate each of the hydrologic variables.

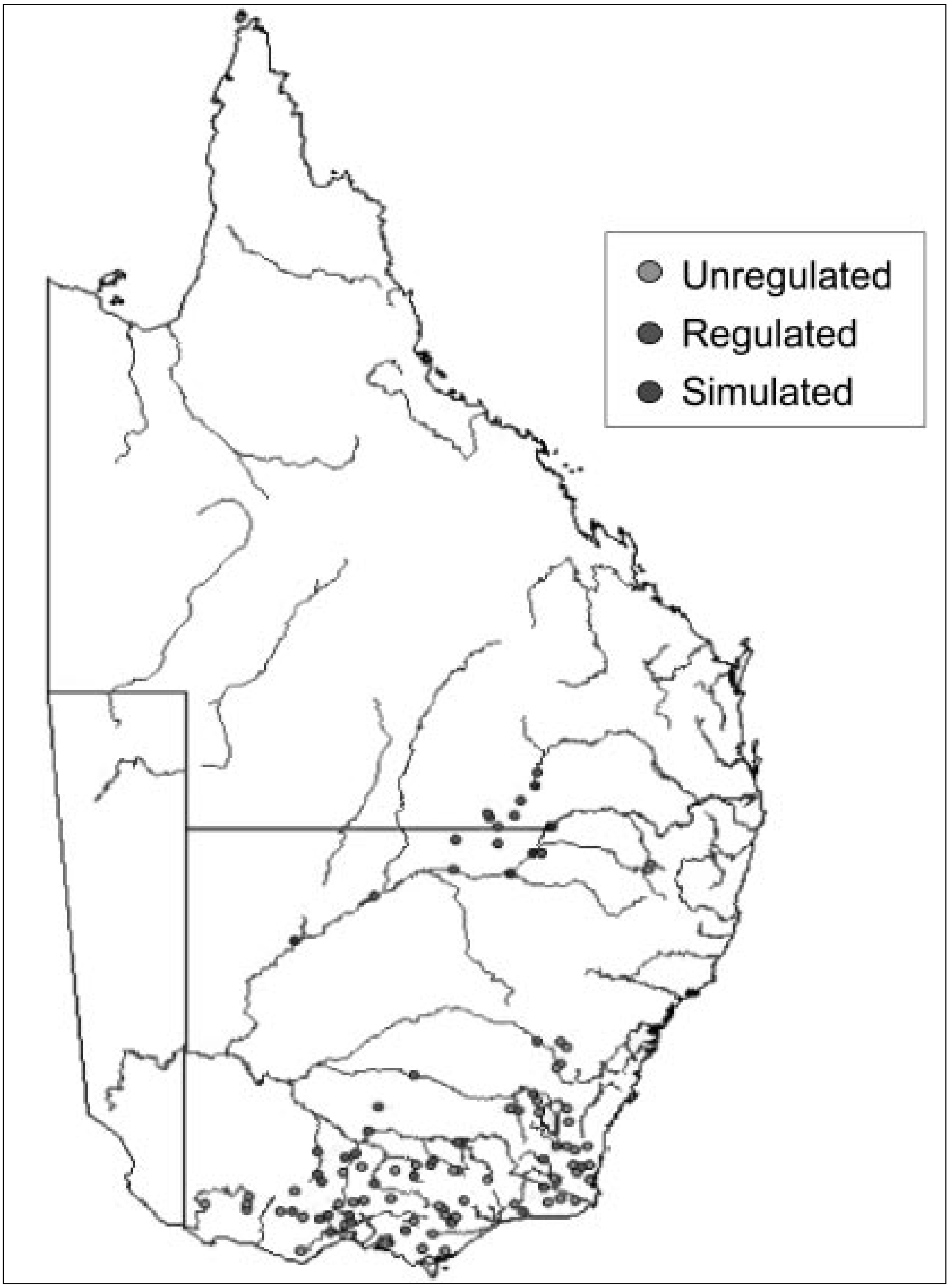

Figure 1. Locations of the 107 gauging stations

1. INTRODUCTION

1.1 Background

The hydrological regime of a stream is an important factor determining the distribution and structure of communities of stream biota (Beumer 1980; Jowet & Duncan 1990; Poff & Allan 1995; Clausen & Biggs 1997). Impoundments have modified the hydrological regimes of many Australian streams, disadvantaging the stream biota. Water released from impoundments in order to benefit stream biota is termed an ‘environmental flow’. Environmental flow allocation is concerned primarily with the maintenance of appropriate hydrological regimes downstream of regulation structures, so as to sustain natural populations of stream biota and physical and chemical processes.

Several models are used for deciding on environmental flow requirements: for example, the Instream Flow Incremental Methodology (IFIM) developed by the United States Fish and Wildlife Service (Bovee 1982), the physical habitat component of IFIM (PHABSIM) (Jowet 1982), and the ‘Holistic’ approach advocated by Arthington (1994). Alternative environmental flow models differ considerably although they all share the basic premise of maintaining a hydrologic regime that sustains ecosystems.

To determine a suitable flow regime we must first be able to characterise the manageable aspects of the stream hydrology. Poff *et al*. (1997) and Richter *et al*. (1996) define a flow regime in terms of five elements: 1) magnitude of discharge; 2) frequency of occurrence, such as the frequency of floods of certain magnitude; 3) duration, or the period of time a specified flow condition is sustained; 4) timing, or predictability of flows of a defined magnitude; 5) rate of change, or the speed at which flow changes from one magnitude to another. There are many ways of incorporating these five elements into variables that characterise the flow regime, as can be seen from the large number of hydrological variables used in recent studies, (e.g. Hughes & James 1989; Arthington 1994; Richter *et al*. 1996; Clausen & Biggs 1997; Puckridge *et al*. 1998; Toner & Keddy 1998).

It is not the intention of this report to suggest that there is a complete and correct list of variables by which flow should be characterised. However, it is important to consider hydrological variables that are essentially independent. This project includes many of the variables used in previous studies, as well as a measure of the variation of most variables. If a large number of hydrologic variables are considered for many streams, it should be possible to note those variables that are highly correlated and to identify those variables that are responsible for a considerable portion of the variation between hydrological regimes. The result should be a list of relatively independent variables that are suitable for characterising the differing hydrological regimes of a range of stream types.

Further, if the database of streams is divided into regulated and unregulated sites, it should be possible to determine the hydrologic variables that discriminate between natural and altered hydrological conditions. The future challenge is to further link these ‘discriminating’ variables to extensive biological data, to further enhance the models for environmental flow allocation.

1.2 Purpose

The purpose of this project was to characterise the flow regimes of both natural and regulated streams across a range of climatic regions in eastern Australia. The aims of this study were:

- to develop a comprehensive but ecologically relevant list of statistics to describe a river’s flow regime;
- to characterise rivers by their flow regimes over a 20-year period; and
- to answer questions such as

- How has water resource development altered the flow regimes of Australian rivers?
- Do distinct regions or climates produce characteristic flow regimes?
- Do different forms of water resource development (e.g. for irrigation, hydro-electricity, urban supply) impose characteristic changes on flow regimes?

1.3 Approach

For this project, stream gauging data from several sources were accumulated, interpreted and processed. There were four major phases to the project:

1) identification and selection of appropriate stream gauge data;
2) selection of appropriate hydrological variables;
3) calculation of hydrological variables from stream gauge data; and
4) statistical analysis of hydrological variables.

Each of the four phases is described in the next section.

2. METHODS

2.1 Selection of stream gauges, and quality control

Strict criteria were set for the selection of stream gauges and analysis of stream gauge data. For this project, data sources were restricted to:

- Pinneena, a database of stream gauging data produced by the NSW Department of Land and Water Conservation. Pinneena supplied data for all New South Wales gauging stations and for some Queensland gauges in the Border Rivers between Queensland and New South Wales.
- CRCCH HYDSYS™ archives, an extensive database archive of stream gauging information collected from past and current hydrological research and held by the CRC for Catchment Hydrology (CRCCH). These archives were searched to find suitable Victorian stream gauges;
- personal files of data available to, or held by, a participant in this project.

These sources produced an initial pool of approximately 3000 potential stream gauges. We sorted the gauges' data according to our criteria, and reduced the number to a final list of 107 stations; see Appendix 1 and Figure 1.

Limited time was available for this project. In a more detailed study it should be possible to include more gauging stations because there would be more time to track down high quality stream gauging data.

2.1.1. Continuous 20-year period

The initial criterion for gauge selection was that all data had to be concurrent for the 20 years from 1 January 1973 to 31 December 1992. Data files were checked using the HYDSYS™ station summary report to identify stations that suited these criteria. However, for some stations the start or finish dates had been entered incorrectly, so the list of suitable gauges was further refined by running the HYDSYS™ program 'GAP report' on the databases of stations to produce a summary list.

The output from the GAP report is a list of variables, their start and finish dates and any gaps in the data. The GAP report looks only at the quality codes and not at the actual data. Where gaps in the data are not reflected in the quality codes the GAP report does not record a period of missing data; hence poor quality code information limits the usefulness of the GAP report. Due to the shortcomings of the GAP report, the summary list could not be finalised until gauge data were extracted from the databases.

2.1.2. Rating table continuity

The stations on the summary list were extracted from the relevant database to generate a directory of discharge files. Many potential sites on the summary list were unable to be extracted because rating table information was unavailable (i.e. it was not possible to convert a water level into a discharge).

2.1.3. Missing data, and details recorded

Gauging stations were not included if their data had a gap at a time when the flow had probably peaked above the mean daily flow (or if the magnitude of a missing flow peak could not be estimated by linear interpolation). To check this, the flow records for nearby and/or upstream stations were examined to see if significant flow events had been recorded for the relevant period.

For each of the suitable records the following details were recorded:

- gauge number;
- gauge location, i.e. the latitude and longitude of each stream gauge were extracted from summary tables of gauge parameters;
- catchment area, derived from database information or state gauge summaries (catchment area was not available for some gauges, particularly those on rivers that had an anabranch);
- rainfall range, derived from Anon. (1984);
- regulated or unregulated, identified by the presence or absence of upstream reservoirs on catchment-scale maps;
- for regulated streams, the name and storage volume of the regulating structure;
- for regulated streams, the down-valley distance from the regulating structure, as measured on catchment-scale maps; and
- for regulated streams, the catchment area upstream of the regulating structure, where this information was easily accessible.

The status of gauges that appeared to be unregulated was confirmed using information provided by the relevant authority from each state, and by comparison with an earlier study (Brooks & Lake 1995).

2.1.4. Incomplete variable record

Even after this process of finding suitable gauges and extracting and cleaning the data, not all variables could be calculated for some gauges. The most common reason was that the long-term median flow was zero. Variables that were normalised by dividing by the long-term median could not be calculated when the long-term median was zero. Another limiting condition for variable calculation was when flow did not exceed the thresholds set in the spell analysis. For example, if the long-term median flow was 10 ML/d and the flow was never less than 5 ML/d, a low-flow spell analysis with a threshold of 1/3 median could not yield a result because the flow simply did not fall below that threshold.

It was not always possible to record the slope of the flow duration curve, which was taken between the 20th and 80th percentile flow values. If r^2 for the values used to describe the flow duration curve (percentage of time flow was exceeded and corresponding discharge) was less than 0.9 then this section of the flow duration curve was not deemed to be suitably linear, and hence the slope of the flow duration curve was recorded as missing data.

2.2. Selection of hydrological variables

The hydrological variables used by Clausen & Biggs (1997), Poff *et al*. (1997), Richter *et al*. (1996) and Puckridge *et al*. (1998) formed the basis for the selection of hydrological variables for this project. Hydrological variables were selected if they were useful measures of some aspects of stream hydrology (as illustrated by the literature) and if the project panel considered them to be potentially valuable to stream biota. The list of hydrological variables is therefore a combination of those that are known to be successful indicators and those that are potentially valuable biological variables.

A series of brief summary tables and descriptions of the variables are provided in the following sections. The algorithms used to calculate the variables are detailed in Appendix 2 and a complete list of the hydrological variables calculated for each gauge is given in the sample output in Appendix Table A3.1.

2.2.1. Summary of hydrological variables

The general approach was to consider both mean and median values for most variables, as well as two measures of variability (see Appendix Table A3.1). Mean values such as the mean daily flow (MDF) are simple to calculate and are commonly used in water resource management, but can be heavily affected by extreme flows, particularly flood flows. The median value is an alternative measure of central tendency that is not skewed by high flows. In this study, both the median and the mean value were calculated for most flow variables to allow the two measures to be compared as hydrological indices in conjunction with detailed biological data.

Before flow magnitude variables (values in ML/d) could be compared between streams they had to be normalised by dividing by a measure of the long-term daily flow. If the variable was a median, the divisor was the median daily flow for the record under analysis; if the variable was a mean, the divisor was the mean daily flow for the record.

Puckridge *et al*. (1998) have emphasised the importance of flow variability. Therefore this study included measures of the variability of the data that had been used to calculate each mean and median. The two measures of variability used are referred to in this report as *variability* and *coefficient of variation* (CV). The variability characteristic is given as the range between the 90th and 10th percentile values divided by the median (Q10 – Q90 / median) (Puckridge *et al*. 1998). The 10th percentile flow value is labelled Q90 and is the flow that is equalled or exceeded 90% of the time. The CV values are the standard deviation of values divided by the mean value. Hence, the variability characteristic is essentially related to median values, and the CV is related to mean values.

Therefore, four characteristics were defined for most hydrological variables: the mean, median, variability, and CV. In total, 333 flow characteristics were calculated for each record of stream gauge data (Appendix Table A3.1). Of these values, four were intended to provide some context to the raw data and were not intended to be used as descriptors of the flow regime. The next sections briefly describe the hydrological characteristics calculated for each gauge record.

2.2.2. Long-term variables

The long-term variables (Table 1) use the entire 20-year record as a single series of daily flow values without breaking them into annual or monthly values. The minimum flow and Q90 are low-flow values, and the maximum flow and Q10 values are high-flow values, included mainly to illustrate the range of flows in ML/d. Likewise, the mean and median values are actual values (ML/d) of discharge for the 20-year period under consideration. The skewness of flow is a ratio of the long-term mean to median flow. A high value for the skewness indicates a large fluctuation in discharge (i.e. mean flow is large relative to the median flow).

A partial duration series determined the magnitude of the 1.58-, 2- and 5-year average return interval (ARI) floods. The partial duration series is based on 60 flood events in the 20-year record. Independence criteria for each event are set according to the catchment area; that is, each event above a threshold flow must be separated from the previous and subsequent events by a minimum period to ensure the floods are actually independent events and not different peaks of the same flood event. For larger catchments the independence criterion (period between events) was larger than for small catchments. The results of a flood frequency analysis using a partial duration series are more accurate than those generated using annual series data for average return intervals up to 10 years (Institution of Engineers, Australia 1987), although they are more difficult to calculate. The 1.58-year ARI from a partial duration series relates to approximately the 2-year ARI using an annual series (Institution of Engineers, Australia 1987); the 2- and 5-year ARI were selected to provide a further indication of how regulation may affect high frequency floods.

Table 1. Long-term variables

Variable	Value	Median	Mean	Variability	CV
Minimum flow for entire period	X				
Maximum flow for entire period	X				
Q90 for entire period	X				
Q10 for entire period	X				
Median daily flow	X				
Mean daily flow	X				
Skewness of flow for entire record	X				
1.58 ARI — Annual series (1.0 ARI partial series)	X				
2.0 ARI — Annual Series (1.443 ARI partial series)	X				
5.0 ARI — Annual Series (4.481 ARI partial series)	X				
Base flow index	X				
Flood flow index	X				
Slope of flow duration curve	X				
r^2 of flow duration curve	X				

The base flow index is the volume of base flow divided by the total discharge using the method described in the *Low Flow Atlas for Victorian Streams* (Nathan & Weinmann 1993). The flood flow index is the volume of flood flow (i.e. total flow minus base flow) divided by the base flow.

The flow duration curve graphs percentile values against discharge values: it illustrates the percentage of time during which flows exceed a given magnitude. When plotted on linear axes, the curve is usually S shaped, with a relatively smooth central portion and curved extremities that relate to the frequencies of low- and high-flow frequencies.

The slope of the flow duration curve for the 20–80th percentile flow range was recorded as a hydrological variable. A low gradient on the flood frequency curve indicates a flow regime with a relatively small range of discharges, while a steep gradient indicates a flow regime with a greater range of discharges. The regime of some streams is not well represented by a straight line through this central portion of the curve. To identify streams that might be unsuitable for this type of analysis, $r^2 = 0.9$ was set as a minimum for the points on this range of the curve. For streams in which $r^2 < 0.9$, the flow duration curve was not considered to be suitably linear and its slope was not recorded. The r^2 value for this portion of the curve is included in the list in Table 2 although it was not used as a hydrological variable in subsequent statistical analysis.

2.2.3. Variables for high-flow spell analysis

The variables for high-flow spell analysis (Table 2) relate to flows above a defined threshold flow. Variables were calculated for six thresholds: the long-term median flow and flows that were 3, 5, 7 or 9 times the long-term median flow or 2 times the long-term mean flow. Three variables were determined for each of the six flow thresholds:

1. the number of times the high-flow threshold was exceeded; that is, the number of flow events per year that exceeded the pre-determined threshold. The median and mean number of times the threshold was exceeded each year were calculated as well as the variability and CV of these annual values.
2. the duration of events that exceeded the high-flow thresholds. The median and mean of the duration of events that exceeded the threshold were calculated as well as the variability and CV of the duration of the events.

Table 2. High-flow variables

Variable	Value	Median	Mean	Variability	CV
Number of 'above-threshold' flows					
Threshold = 1 x median		X	X	X	X
Threshold = 3 x median		X	X	X	X
Threshold = 5 x median		X	X	X	X
Threshold = 7 x median		X	X	X	X
Threshold = 9 x median		X	X	X	X
Threshold = 2 x mean		X	X	X	X
Peak magnitude of 'above-threshold' flow					
Threshold = 1 x median		X	X	X	X
Threshold = 3 x median		X	X	X	X
Threshold = 5 x median		X	X	X	X
Threshold = 7 x median		X	X	X	X
Threshold = 9 x median		X	X	X	X
Threshold = 2 x mean			X		X
Duration of 'above-threshold' flows					
Threshold = 1 x median		X	X	X	X
Threshold = 3 x median		X	X	X	X
Threshold = 5 x median		X	X	X	X
Threshold = 7 x median		X	X	X	X
Threshold = 9 x median		X	X	X	X
Threshold = 2 x mean			X		X
Seasonal variation of 'above-threshold' flows					
Season with most flows >3 x median	X				
Proportion of high flows in above season	X				
Number of summer high flows		X	X	X	X
Number of autumn high flows		X	X	X	X
Number of winter high flows		X	X	X	X
Number of spring high flows		X	X	X	X
Season with most flows >9 x median	X				
Proportion of high flows in above season	X				
Number of summer high-flow days		X	X	X	X
Number of autumn high-flow days		X	X	X	X
Number of winter high-flow days		X	X	X	X
Number of spring high-flow days		X	X	X	X

3. the magnitudes of the peak flow for events that exceeded the threshold. The median, mean, variability and CV of these peak flows were calculated. The median and mean peak flow values were normalised by dividing them by the long-term median and mean values, respectively.

For thresholds that were 3 and 9 times the long-term median, the seasonality of 'above-threshold flows' was also analysed. The season with the greatest number of above-threshold flows beginning in that season was recorded, and the proportion of above-threshold flows during that season. The median, mean, variability and CV of the annual number of above-threshold flows for each of four seasons were also calculated.

Table 3. Low-flow variables

Variable	Value	Median	Mean	Variability	CV
Number of 'below-threshold' flows					
Threshold = 1/2 x median		X	X	X	X
Threshold = 1/3 x median		X	X	X	X
Threshold = 1/9 x median		X	X	X	X
Threshold = 10% x mean			X		X
Magnitude of 'below-threshold' flows					
Threshold = 1/2 x median		X	X	X	X
Threshold = 1/3 x median		X	X	X	X
Threshold = 1/9 x median		X	X	X	X
Threshold = 10% x mean			X		X
Duration of 'below-threshold' flows					
Threshold = 1/2 x median		X	X	X	X
Threshold = 1/3 x median		X	X	X	X
Threshold = 1/9 x median		X	X	X	X
Threshold = 10% x mean			X		X
Seasonal variation of 'below-threshold' flows					
Season with most flows <1/3 median	X				
Proportion of low flows in above season	X				
Number of summer low-flow days		X	X	X	X
Number of autumn low-flow days		X	X	X	X
Number of winter low-flow days		X	X	X	X
Number of spring low-flow days		X	X	X	X
Season with most flows <1/9 x median	X				
Proportion of low flows in above season	X				
Number of summer low-flow days		X	X	X	X
Number of autumn low-flow days		X	X	X	X
Number of winter low-flow days		X	X	X	X
Number of spring low-flow days		X	X	X	X

2.2.4. Variables for low-flow spell analysis

The low-flow spell analysis (Table 3) was similar to the high-flow spell analysis. A low-flow event was smaller than a pre-defined low-flow threshold. Four low-flow thresholds were selected: 1/2 x, 1/3 x, and 1/9 x long-term median flow and 10% of the mean daily flow. The median, mean, variability and CV were calculated for the number, magnitude and duration of 'below-threshold' events for each of the four threshold values. The seasonality of low flows was assessed for the thresholds that were 1/3 and 1/9 of long-term median flow. The season in which the greatest number of below-threshold events began, and proportion of below-threshold events that began in that season were recorded for both thresholds. The mean, median, variability and CV of the annual number of below-threshold flow values were also calculated for each of four seasons.

2.2.5. Moving-average variables

Maximum and minimum flows were recorded (presented as median, mean, variability, CV) for moving averages of 1, 30 and 90 days (Table 4). The one-day moving average is simply a comparison of mean daily flow values. The annual maximum and minimum daily flow values were recorded for each year of the 20-year record. The 30-day moving average is calculated by averaging the flow values for days 1–30 (say Jan 1–Jan 30), then for days 2–31 (say Jan 2–Jan 31), then for days 3–32 (say Jan 3–Feb 1), and so on. In this way, the maximum and minimum 30-day moving average was calculated for each year of the 20-year record. Likewise, the maximum and minimum values for the 90-day moving average were recorded. From the annual values of maximum and minimum moving-average values, the overall median, mean, variability and CV were calculated.

The moving-average values indicated the continuity of flow. In a highly regulated stream, the maximum daily flows are likely to be considerably lower than in the unregulated condition, but the 30- or 90-day moving-average value could be higher than before, because of smoothing of the flood peak by a regulating structure.

Table 4. Moving-average variables

Variable	Value	Median	Mean	Variability	CV
Maximum annual moving average					
Annual maximum daily flow		X	X	X	X
Annual maximum 30 day flow		X	X	X	X
Annual maximum 90 day flow		X	X	X	X
Minimum annual moving average					
Annual minimum daily flow		X	X	X	X
Annual minimum 30 day flow		X	X	X	X
Annual minimum 90 day flow		X	X	X	X

2.2.6. *Cessation-of-flow variables*

The cessation of flow is considered a biologically important aspect of the hydrological regime (Puckridge *et al*. 1998). Zero flow days are those on which a zero value has been entered in the data record; they do not include days for which the record is missing. The cessation of flow statistics (Table 5) consisted of the total number of zero flow days in the entire record. Then an array of the number of zero flow days for each year of the record was used to calculate the annual median, mean variability and CV of zero flow days. To check for clumping of the zero flow days, the proportion of months in the entire 20-year record that had at least one zero flow day was also noted.

Table 5. Cessation-of-flow variables

Variable	Value	Median	Mean	Variability	CV
Zero flows					
Total number of zero flow days of record	X				
Number of days per year having zero flow		X	X	X	X
Proportion of all months that have a zero flow day	X				

2.2.7. *Variables concerned with the rise and fall of the hydrograph*

Stream flow can vary quite considerably from day to day. Periods of continuously increasing or decreasing flow are recorded and referred to on the hydrograph as rising limbs or falling limbs, respectively (Table 6). The annual number (median, mean, variability and CV) of rising and falling limbs was calculated. When each limb occurred, the duration was measured in days from start to end; the shortest period possible would be two days, and the maximum period possible would be the entire record, if the discharge continuously increased or decreased for every consecutive day over the entire 20-year period. The median, mean, variability and CV of the duration of rising and falling limbs commencing in any given year were also noted.

A series of other variables were calculated, based on consecutive daily flow. A positive daily difference between consecutive daily flows indicates an increase in flow, or part of a rising limb of the hydrograph; similarly a negative daily difference indicates a decrease in flow, or part of a falling limb of the hydrograph. Median, mean, variability and CV were calculated for the following variables:

- magnitude of the positive and negative daily differences in flow, recorded as a continuous record over the flow record (i.e. no separation into annual, seasonal or monthly values);
- magnitude of the mean annual positive and negative daily differences in flow;
- magnitude of the annual maximum positive and negative daily difference in flow;
- the annual number of positive and negative daily differences in flow.

Table 6. Variables concerned with the rise and fall of the hydrograph

Variable	Value	Median	Mean	Variability	CV
Number of rises and falls of the hydrograph					
Total number of rising limbs per year		X	X	X	X
Duration of individual rising limbs for entire record		X	X	X	X
Total number of falling limbs per year		X	X	X	X
Duration of individual falling limbs for entire record		X	X	X	X
Magnitude of daily change in flow					
Positive daily differences in flow for entire record		X	X	X	X
Mean annual positive daily differences in flow		X	X	X	X
Annual maximum positive daily differences in flow		X	X	X	X
Annual number of positive daily differences		X	X	X	X
Negative daily differences in flow for entire record		X	X	X	X
Mean annual negative daily differences in flow		X	X	X	X
Median of annual minimum negative daily differences in flow		X	X	X	X
Median of the annual number of negative daily differences in flow		X	X	X	X

2.2.8. Monthly flow variables

The 20-year record was broken into monthly units (Table 7). A mean daily flow was calculated for each month, so there were 20 annual records of mean daily flow for each of 12 months. For each month the median, mean, variability and CV of mean daily flow values were calculated.

For each station, the ‘driest month’ was the month in which the minimum monthly value for mean daily flow most commonly occurred during the whole 20-year record. We also noted the ‘month in which the maximum mean daily flow most frequently occurs’.

Two measures of variability of monthly flow were included. The first was the year-to-year variability between months. There is already an inter-annual variability for each of the 12 months. The ‘variability of inter-annual monthly variability’ simply calculates the variability between the 12 monthly values, to provide some form of overall variability of monthly flow, as

$$\frac{\text{90th percentile for month} - \text{10th percentile for month}}{\text{median of mean daily flow for month}},$$

for each of the 12 months. The second overall measure of monthly flow variability was a year-to-year comparison. For this, the variability between the 12 monthly flow values was calculated for each of the 20 years, and from this collection of 20 annual variability values, the variability was calculated to give the inter-annual monthly variability.

Table 7. Monthly flow variables

Variable	Value	Median	Mean	Variability	CV
Monthly flows					
January: daily flow for entire period		X	X	X	X
February: daily flow for entire period		X	X	X	X
March: daily flow for entire period		X	X	X	X
April: daily flow for entire period		X	X	X	X
May: daily flow for entire period		X	X	X	X
June: daily flow for entire period		X	X	X	X
July: daily flow for entire period		X	X	X	X
August: daily flow for entire period		X	X	X	X
September: daily flow for entire period		X	X	X	X
October: daily flow for entire period		X	X	X	X
November: daily flow for entire period		X	X	X	X
December: daily flow for entire period		X	X	X	X
Month in which the minimum ‘mean daily flow’ most frequently occurs	X				
Month in which the maximum ‘mean daily flow’ most frequently occurs	X				
Inter-month variability					
Variability of inter-annual monthly variability		X	X	X	X
Inter-annual monthly variability					
Annual values of inter-month variability		X	X	X	X

2.3. Calculation of hydrologic variables

The computer code for calculating each of the variables was written in Visual Basic for Applications (VBA) and is available by contacting the CRCFE. This language can use Microsoft® Excel functions within the body of the code; hence, the number of specific coding algorithms needed is reduced. An example would be the calculation of a median value. Normally a sorting routine would have to be written and the central value selected, but in VBA the Microsoft® Excel function MEDIAN( ) can simply be used. There is no need to use specific compiler software to produce an executable file from the VBA source code. The code can be run (and edited if necessary) on any computer with Microsoft® Excel 5 for Windows® 95. This allows the code to be manipulated for future analysis of stream gauge data. Appendix 2 describes each of the subroutines used to calculate the hydrological variables.

Appendix 3 gives a sample of the calculated output of hydrological variables. Appendix 4 lists the variables used in this study that are also used in other published studies.

2.4. Statistical analysis

Mean and medians and associated measures of variance were calculated for most variables as discussed above. For this study, mean and median values were included for the first stage of statistical analysis (cross correlation).

2.4.1. Cross correlation

There was a large number of variables and many of them were interdependent, so the first phase of the data analysis was a cross correlation of all variables, using the software package SYSTAT®. For analysing the cross correlation matrix, a series of threshold correlation coefficients were chosen and the number of pairs of variables with cross correlation coefficients above the threshold coefficient were noted. Figure 2 shows a logarithmic response of the number of cross correlation pairs above a given threshold correlation value. An appropriate cut-off or threshold correlation coefficient value of 0.8 was selected so that variables could be removed if they were measuring essentially similar aspects of the hydrologic regime.

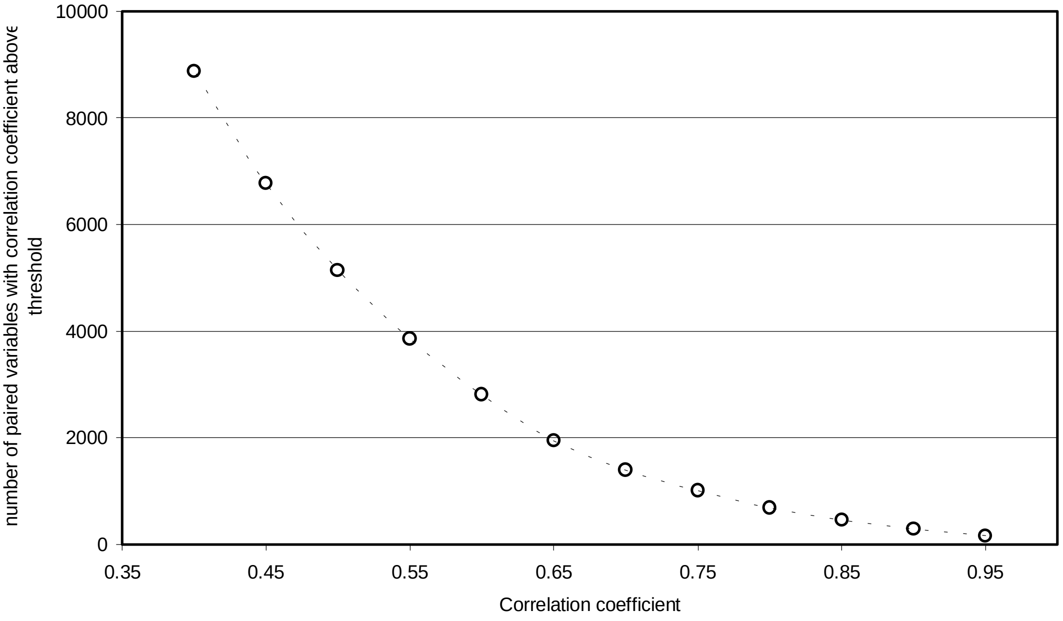

Figure 2. Cross correlation for varying threshold values of the correlation coefficient

All median and related variability values were removed before subsequent analysis. Of the remaining variables, when pairs of variables had a correlation coefficient of 0.8 or greater, one of the variables was removed before subsequent analysis. The criteria for selecting variables was hierarchical, using the following conditions:

- more commonly used hydrological variables were selected in preference to variables that are less frequently used;
- for spell analysis characteristics that were highly correlated, variables related to low thresholds (such as 1 times the median flow) and high thresholds (such as 9 times the median flow) were retained in preference to those with intermediate thresholds;
- where variables were related to seasons, those variables that related to either summer or winter were retained in preference to those relating to spring or autumn.

This approach means that only linear correlations were examined: no measure of non-linear correlation was considered in this analysis.

The 91 variables remaining after the cross-correlation analysis (Appendix Table A3.2) were used in the multivariate analyses.

2.4.2. Multivariate analyses

The PATN software package was used for all multivariate analyses. Association matrices were calculated using the Gower Metric for continuous data, as recommended by Belbin (1991b). Data were not standardised or transformed before the Gower Metric was applied. Semi-strong hybrid multi-dimensional scaling (SSH; Belbin 1991a) was used to ordinate the gauging stations in two dimensions. Stress values of <0.30 were considered acceptable, where stress measures the inverse of fit between dissimilarities between stations and distances on the ordination plot. Note that this value of stress differs from the normally accepted value (Clarke 1993) because PATN software uses a non-standard algorithm to calculate stress (L. Belbin, pers. comm.).

All sites were classified into climatic groups using the Köppen system (Gentilli 1986; McMahon et al. 1992), which defines four major climatic zones: A = tropical; B = arid; C = warm temperate; and D = snow. Within each zone there are subsidiary groupings based on variation in temperature, seasonality and amount of rainfall. Four climatic groups were included within this study: BSh (arid, steppe, mean annual temperature >18°C), BSk (arid, steppe, mean annual temperature <18°C), Cfa (warm temperate, sufficient precipitation in all months, warmest month >22°C) and Cfb (warm temperate, sufficient precipitation in all months, warmest month >22°C, at least 4 months >10°C).

Stations were grouped using information on regulation status, the main type of water resource development affecting flows at a station, and Köppen climate class (Appendix 1). 'Intermittent' stations were defined arbitrarily as those with more than 1000 days of zero flow (ZEN) within the 20-year record (Figure 3). The remaining stations are hereafter referred to as 'permanent'. The 93 permanent stations were then reanalysed, to allow patterns within this group to be seen more clearly.

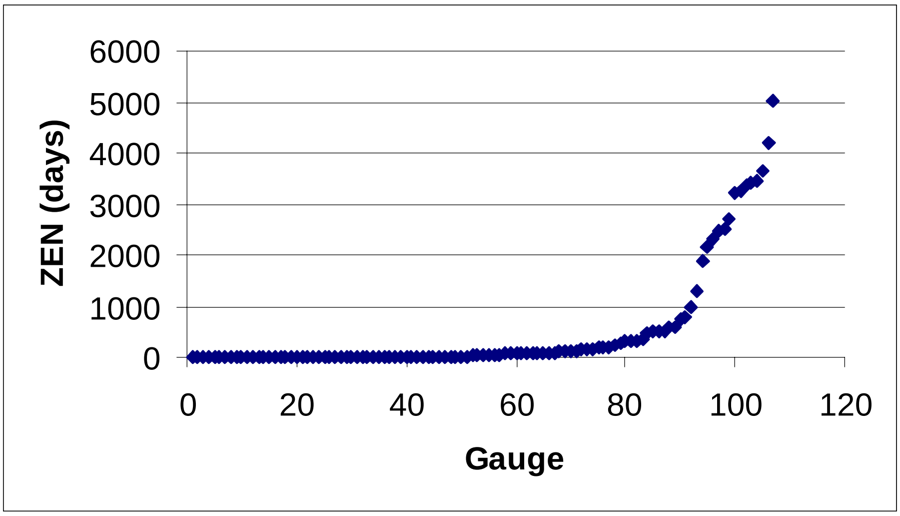

Figure 3. The number of days of zero flow (ZEN) in relation to the quantity of gauging stations

Differences in the suite of hydrological variables were compared for several pairs of groups*:*

- intermittent versus permanent stations;
- BS versus Cf permanent stations; and
- regulated versus unregulated Cfa stations.

One-way ANOSIM (Analysis of Similarities; Clarke 1993) was used to determine whether differences in the suite of hydrological variables were significantly different between groups of gauging stations. The Principal Axis Correlation (PCC) and Monte-Carlo Attributes and Ordination (MCAO) routines were used to determine which of the hydrological descriptors were significantly correlated with each ordination. Levels of significance (P values) were obtained from 500 randomisations. The Group Statistics (GSTA) routine was then used to determine which of the significantly correlated variables differed between groups of stations defined *a priori*. This routine produces tables of minimum, maximum, mean and standard deviation for each variable for the defined groups, and the Kruskal–Wallis (non-parametric) statistic indicates those variables that show significant discrimination between groups.

The numbers of days with zero flow for the stations for which simulated data were available were assessed, to determine whether existing regulation patterns have increased or decreased the intermittency of flow.

3. RESULTS AND INTERPRETATION

3.1. Gauges selection

At the completion of the data sorting process outlined above, 107 records of stream flow had been selected as suitable for analysis. A summary list of the records is presented in Appendix 1. Of this list, 47 records were classified as regulated (five of them were simulated) and 60 as unregulated (five of them were simulated). The 10 records of simulated data consisted of two alternative scenarios from each of five locations in the Darling River system for which real data were available: 1) flow under the current level of regulation (i.e. removing the effects of gradually increasing water resource development), and 2) flow under unregulated conditions.

Figure 1 shows the distribution and classification of gauges (regulated, unregulated, simulated). There were no suitable unregulated records in the lowland sections of the Murray-Darling system, which is indicative of the highly regulated nature of this system.

Six of the records had median daily flow values of zero. Therefore, it was not possible to calculate variables relying on division by the median daily flow for these six gauges. Four of the six gauges were in the lower anabranching channels of the Balonne River in western Queensland. The remaining two sites were classified as unregulated, one in the upper reaches of the Warrego River, the other in Wanalta Creek in Victoria.

3.1.1 Measures of central tendency

The correlation coefficients for mean and median values show whether or not these two measures of central tendency are independent for hydrologic data. Table 8 summarises the cross correlation between mean and median values for a threshold correlation coefficient of 0.8. From Table 8 it appears that the mean and median are highly correlated when the value under consideration is a duration of flow (such as the duration of above-threshold flows) or the number of events (such as the number of above-threshold flows). Mean and median are not highly correlated when values are measures of flow or flow magnitude (such as the peak flow above a threshold flow), with the exception of the long-term mean and median flows which are highly correlated.

3.1.2 Variables used in multivariate analysis

The number of variables was reduced to remove bias produced by using a large number of variables that are related. First, all median values and the associated measures of variance were removed. In most cases above, the mean was shown to be a suitable measure. In deciding whether to retain the mean or median measure of those variables where $r < 0.8$, the mean was considered to be a more useful variable. Consistently, the median measure was highly correlated with more other variables than the equivalent mean.

3.2 Multivariate analysis

3.2.1 All 107 stations

Ordination of the 107 gauging stations clearly grouped the intermittent-flow stations separately from the permanent-flow stations (Figure 4a). The 14 intermittent stations comprised nine stations on the Border Rivers (inland, near the border between NSW and Queensland), one on the Darling River at Louth, two in north-central Victoria and two in coastal rivers in southern Victoria (Figure 1).

Table 8. Cross correlation of mean and median values

Category	**Variable**	**Mean and median correlation coefficient >0.8**	**Mean and median correlation coefficient <0.8**
Long term		$r > 0.8$ for long-term mean and median values	
High-flow spell analysis	Number of ‘above-threshold’ flows	Consistently $r > 0.8$	
	Peak magnitude of ‘above-threshold’ flow		Consistently $r < 0.8$
	Duration of ‘above-threshold’ flows	Consistently $r > 0.8$	
	Seasonal variation of ‘above-threshold’ flows	Consistently $r > 0.8$	
Low-flow spell analysis	Number of ‘below-threshold’ flows	Consistently $r > 0.8$	
	Magnitude of ‘below-threshold’ flow		Consistently $r < 0.8$
	Duration of ‘below-threshold’ flows	Consistently $r > 0.8$	
	Seasonal variation of ‘below-threshold’ flows	Consistently $r > 0.8$	
Moving average	Maximum annual moving average		Consistently $r < 0.8$
	Minimum annual moving average		Consistently $r < 0.8$
Zero flows	Number of zero flow days per year	$r > 0.8$	
Rise and fall of the hydrograph	Number of rises and falls of the hydrograph	$r > 0.8$	
	Magnitude of daily change in flow	The number of positive and negative differences in daily flow $r > 0.8$	Both positive and negative differences in daily flow $r < 0.8$
Monthly flows	Magnitude of monthly flow		Monthly flow values, consistently $r < 0.8$
Inter-month variability			$r < 0.8$
Inter-annual monthly variability			$r < 0.8$

Seventy-eight of the hydrological descriptors were significantly correlated with the ordination ($P < 0.01$; Appendix Table A5.1). The variables with the strongest correlations using PCC ($r > 0.8$) are shown in Figure 4b. Of the 78 variables, 54 contributed significantly to the separation between permanent and intermittent stations using GSTA (Appendix Table A6.1). Some of these variables related simply to the intermittency: all LTQ90 values were zero for intermittent streams; the base flow index (BFI) was lower; and the number of zero flow days (ZEN) was greater for intermittent streams.

However, several of the variables indicated that the intermittent stations were hydrologically more variable than the permanent stations: the slope of the flow duration curve (LTSFD) was greater, and the mean numbers of flows above 1x, 3x and 9x median flow (HFME1, HFNME3, HFNME9) were lower for intermittent streams; the peak magnitudes were greater at intermittent stations than at permanent stations for flows above median flow (HFPME1) but lower for flows above 9x median flow (HFPME9), and flows above median flow (HFDME1) had longer mean duration than at permanent stations.

The seasonality of permanent and intermittent stations also varied: the greatest number of high-flow events occurred in winter–spring at permanent stations but in autumn at intermittent stations (HFSS3, HFSS9), but permanent stations showed more variation in the season with most high flows (HFSC3, HSFC9); the mean number of summer high flows (HFSME9) was larger at intermittent stations.

Intermittent stations had fewer low-flow events (LFNME1) than permanent stations, according to the low-flow spell analysis variables, but the number of low flows per year was more variable (LFNC10). However, the discharges during low-flow events (LFPME10) were lower at intermittent stations. The most low-flow days (LFSS3, LFSS9) occurred in winter at intermittent stations but in autumn at permanent stations. The proportion of low-flow days that occurred during this season (LFSSP3, LFSSP9) was greater at permanent stations. This again shows that intermittent stations are more variable. In each season there were more low-flow days at intermittent stations than at permanent stations (LFSME3, LFAME3, LFWME3, LFSPME3) and the number of low-flow days was less variable at intermittent stations in winter and spring (LFWC3, LFSPC3).

At intermittent stations, the moving average for the annual maximum 90-day flows (MAHME90) was larger than at permanent stations; for the annual minimum 90-day flows (MALOME1) the moving average was smaller than at permanent stations. This indicates greater continuity of flow at intermittent stations. However, the moving average of minimum flows annually and for 90 days (MALC1, MALC90) were much more variable at intermittent stations.

At intermittent stations there were fewer rising (RFNRME) and falling (RFNFME) limbs per year, but the number of rising limbs (RFNRC) was more variable than at permanent stations. The rising (RFDRME) and falling (RFDFME) limbs lasted longer at intermittent stations, and the duration of falling limbs (RFDFC) was more variable.

Flows at intermittent stations were more variable in January (MFJANC), March (MFMARC), November (MFNOVC), and December (MFDECC), and there was greater variability in the mean variability of inter-annual monthly coefficient of variation (MFAVME). However, there was less variation in the interannual monthly coefficient of variability (MFAVC). The annual values of inter-month coefficient of variability (MFMVME) were greater at intermittent stations.

3.2.2 Permanent stations

Ordination of the 93 permanent stations did not clearly separate regulated and unregulated stations (Figure 5). The ANOSIM indicated that the two groups were significantly different, probably due to the slightly greater spread of regulated stations rather than because of directional differences. However, if climate type is also superimposed (Figure 6a) some patterns emerge. Stations in BS clearly differed from stations in Cfa and Cfb (ANOSIM, $P < 0.05$), although there was no separation of regulated and unregulated BS stations. The Cfa and Cfb stations overlapped considerably, and Cfb stations showed no difference between regulated and unregulated stations (ANOSIM, $P > 0.05$). However, regulated and unregulated Cfa stations were significantly different (ANOSIM, $P < 0.001$). The regulated Cfa stations consisted of one hydroelectric and nine irrigation stations.

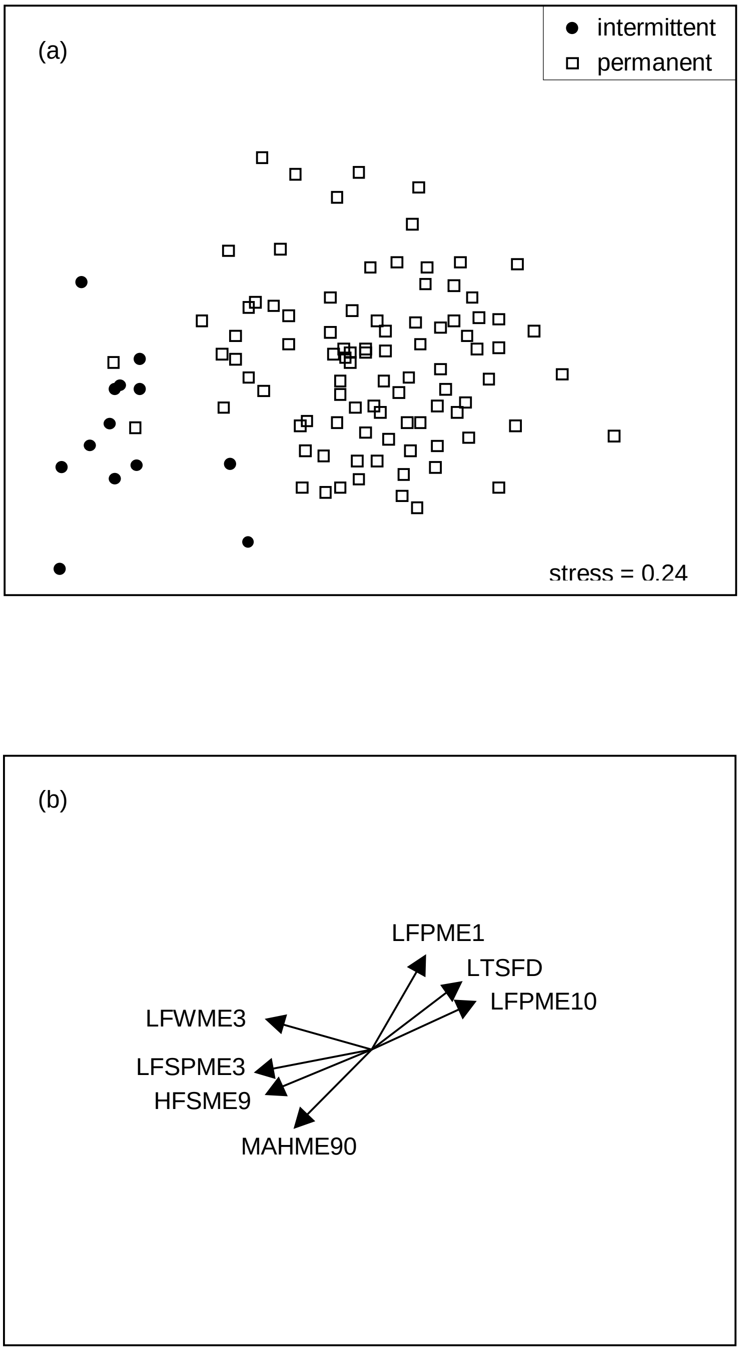

Figure 4. Two-dimensional ordination of all 107 gauging stations showing (a) permanent and intermittent stations, and (b) hydrological descriptors with correlations >0.8

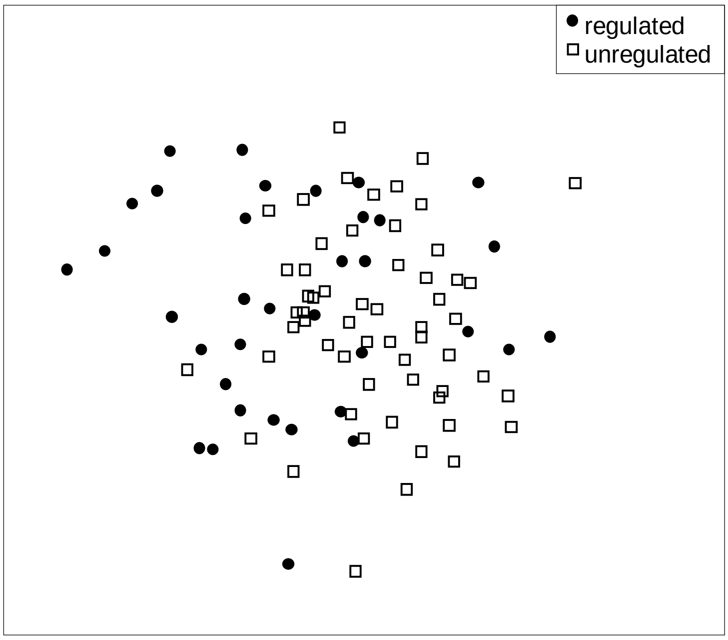

Figure 5. Ordination of the 93 permanent stations with regulation superimposed

Seventy-seven of the hydrological descriptors were significantly correlated with the ordination ($P < 0.01$; Appendix Table A5.2). The variables with the strongest correlations using PCC ($r > 0.8$) are shown in Figure 6b. Of the 77 significantly correlated descriptors, 47 contributed to the separation between BS and Cf stations (Appendix Table A6.2).

Of the 77 hydrological descriptors that were significantly correlated with the ordination, 38 contributed significantly to the separation between irrigation and unregulated Cfa stations using GSTA (Appendix Table A6.3). The regulated stations tended to have higher long-term maximum flows (LTMAX), Q90s, mean flows and base flow indices (LTBFI), the latter indicating more constant discharge. However, regulated stations had longer return intervals for the 2-year flood (LT2ARI). Irrigation stations had fewer high flows (HFNME3, HFNME9) but more variability in the number of high-flow events (HFNC3, HFNC5), greater variability in the duration of high-flow events (HFDC3) and greater variability in the number of high-flow events in summer (HFSC3) and winter (HFWC3). Irrigation stations had more high-flow events in spring (HFSSP9) and greater variability in the number of winter high-flow days (HFWC9).

Low-flow descriptors showed that unregulated stations had most low-flow days during summer and autumn, whereas irrigation stations had most low-flow days during autumn and winter (LFSS3, LFSS9). Irrigation stations had, on average, about half the number of low-flow days in summer, but 2.5 times the number of low-flow days in winter, compared to unregulated stations.

Irrigation stations had lower mean annual maximum 90 day flows (MAHME90) and less variability in the mean of the annual minimum daily flow (MALC1). Irrigation stations had fewer days of zero flow (ZEN) compared to unregulated stations. They had more rising and falling limbs per year (RFNRME, FRNFME), greater mean durations of rising limbs but shorter mean durations of falling limbs (RFDFME) and smaller positive daily differences in discharge (RFDPME). Irrigation stations had greater mean daily flow than unregulated stations for January (MFJANME), May (MFMAYME), August (MFAUGME), September (MFSEPME), October (MFOCTME) and December (MFDECME). Irrigation stations had lower variability in mean daily flow for March and November (MFMARC, MRNOVC). The mean and coefficient of variability of the inter-annual monthly coefficient of variation (MFAVME, MFAVC) and the mean of the annual values of intermonth coefficients of variation (MFMVME) were all lower at irrigation stations than at unregulated stations.

3.2.3. Simulated data

Of the five stations for which simulated data were available, two had no zero flow days under either unregulated or existing levels of regulation. For the other three stations, the number of days of zero flow under regulated conditions was higher by 2 to 5 times.

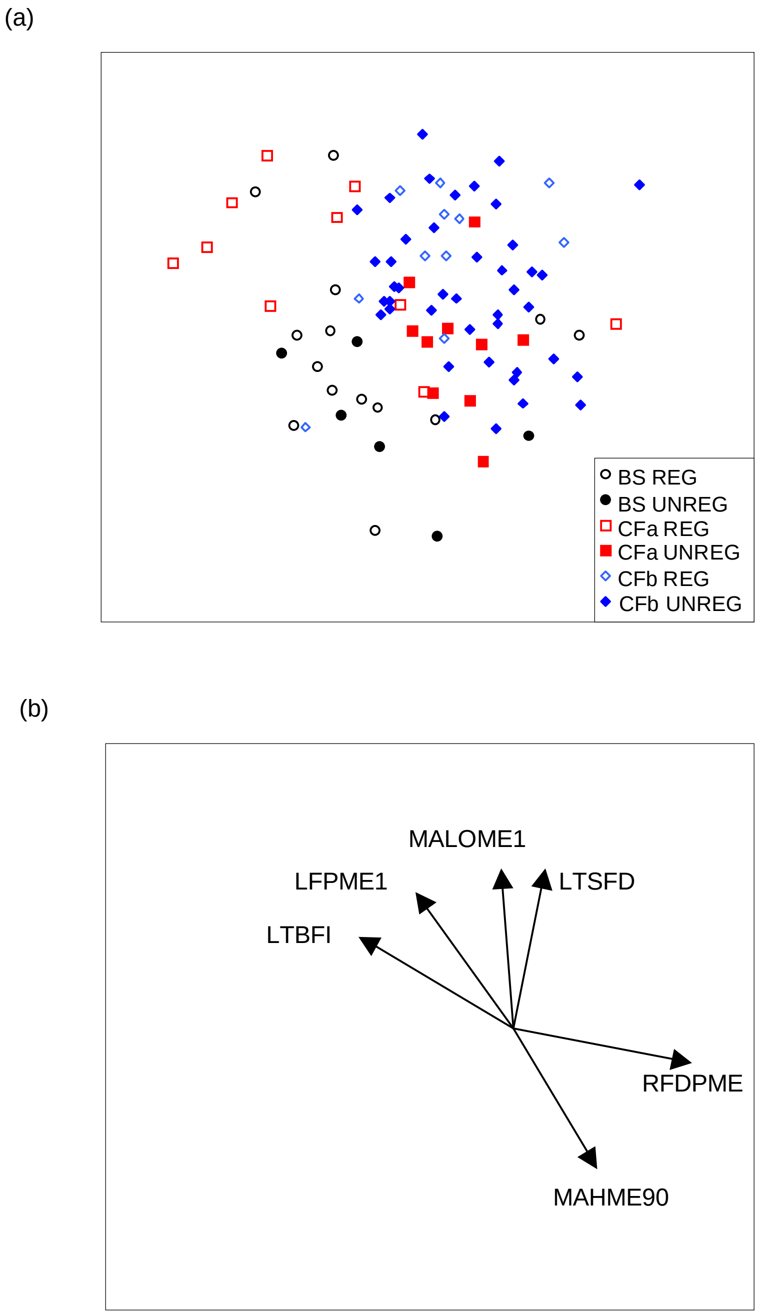

Figure 6. Two-dimensional ordination of the 93 permanent gauging stations showing (a) climate type and regulation and (b) hydrological descriptors with correlations >0.8

4. Discussion

This study has developed a method for looking at the hydrology of Australian rivers by calculating a large number of descriptor variables which are likely to be ecologically meaningful (Richter *et al.* 1996; Clausen and Biggs 1997; Poff *et al.* 1997; Puckridge *et al.* 1998). Australia's rivers are some of the most variable in the world (Puckridge *et al.* 1998) and so a small number of basic descriptors may not be sufficient to characterise their hydrology. In addition, the effects of water resource development are complex and vary with the type of development and the climate of the catchment area. The method enables all these complexities to be assessed. The present study used relatively few gauging stations compared to the geographical area covered, and some of the categories of stations were not well represented. As such, it is a pilot study; it does not answer all the questions.

Some strong patterns are evident. The major gradient in the entire data set is that of permanent to intermittent flows. As well as having descriptors that relate to intermittency, the intermittent stations differ from the permanent stations in their high-flow, low-flow, seasonality, moving average, rising and falling limb and monthly variation descriptors. It is not known to what extent regulation has changed intermittently flowing rivers to permanent rivers but this has certainly happened. For example, the Campaspe River in northern central Victoria used to dry to a series of pools in some summers but now receives either irrigation flows or a minimal passing flow throughout its length from October to April. In the Barwon–Darling system, the simulated data show that the number of zero flow days has decreased by up to 44% for stations that naturally had some zero flow days.

The second major pattern is the separation of permanent stations within the BS (arid) and Cf (warm temperate) climatic zones. Many of the hydrological descriptors differ between these two groups, clearly showing the wide range of hydrological characteristics among Australia's rivers.

The final pattern is the separation between regulated and unregulated stations within the Cfa warm temperate climate group. Although there is no separation between Cfa and Cfb unregulated stations, regulated Cfa stations are separated both from the unregulated Cf stations and from the regulated Cfb stations. The Cfa stations are in inland areas near the Dividing Range and in coastal areas north of Sydney. The regulated Cfa stations are significantly different from the unregulated Cfa stations with many hydrological variables showing significant differences between the two groups. The differences include much higher long-term maximum flows, 90th percentile flows and mean daily flows and longer return intervals for the 2-year flood, for regulated stations. Seasonality of flows is different and regulated stations have lower variability for several of the flow descriptors.

There is considerable further work to be done, building on this study. The first task is to obtain data from more gauging stations for the climate and regulation categories that are not well represented. This is not simply a problem of missing data. Most gauging stations fail at some point, often during extreme wet weather events. This means that the gaps in the flow record need to be filled before the hydrological descriptors are calculated. This is relatively easy using standard modelling techniques (e.g. rainfall run-off models) for unregulated stations, but poses greater problems for regulated stations.

This study has mainly used unregulated rivers as the basis for the comparison with regulated rivers. Another approach would be to use modelled data for regulated and unregulated conditions for each station. This removes the need to find suitable unregulated stations for comparisons, but the modelling would have to provide an accurate estimate of the flows. This approach may be necessary for inland arid zone rivers, where unregulated stations are rare.

The present study has defined regulated stations as those downstream of regulating structures. This is an oversimplification and could be improved upon in future. For stations downstream of regulating structures, the degree of regulation is still not known. For example, some weirs are used to provide a head of water but do not significantly alter the hydrology downstream of the structure. Also, many rivers with no significant regulatory structure are nonetheless affected by water resource development because of direct abstraction. This is much harder to quantify because much of the abstraction is not monitored. Finding detailed information on the regulation levels and types for each station will be a time-consuming task, but would make the interpretation of the information from hydrological studies much easier and more useful.

This method used in this study can now be extended to relate long-term biological data sets to the hydrology. Then a predictive capability can be developed with which to estimate the effects of future water resource development. The linking of hydrology and ecology is of considerable interest at present, both in Australia and elsewhere. Extence *et al*. (1999) correlated an index of macroinvertebrate community health with a large number of flow measures for several rivers in the UK. They found strong relationships that were particularly evident between drought years and years of normal flow. Clausen and Biggs (1997) correlated both periphyton and macroinvertebrate data with hydrological variables and found significant relationships for both groups of taxa. Little work of this type has been attempted for fish (but see Beumer 1980; Bain *et al*. 1988). There are several long-term macroinvertebrate and fish data sets available within Australia for which correlative analyses could be performed, using the hydrological method developed in the present study.

Finally, the geographical range for future work could easily be extended to cover all of Australia. The only limiting factor would be the availability of good quality hydrological data. This would show if there are commonalities in the hydrology of regulated rivers throughout Australia. Alternatively, regions or climatic zones could be identified within which it would be possible to generalise about the hydrological and ecological consequences of water resource development.

There are important management implications from this work. As most water managers are aware, determining release strategies for ‘environmental flows’ to rehabilitate rivers is going to be a complex task. The development of a set of flow statistics that can characterise flow regimes, regionally and perhaps nationally, is a high priority. The results presented in this report suggest that each river might need to be considered in the context of the natural flow regime of nearby rivers, the climatic zone in which it occurs and the main purpose for which it is regulated. However, we can now build on this framework for characterising flow regimes and we need to determine whether a smaller number of flow statistics can achieve this characterisation. It should also be possible to use this information as a starting point from which to talk with managers and engineers about how to release water from dams to minimise both the hydrological differences between regulated and comparable unregulated rivers and the effects on consumptive use.

5. References

Anon. (1984) *The Macquarie Illustrated World Atlas*. McMahons Point NSW, Macquarie Library, Division of Lands Mapping, Canberra, Department of Lands and Survey, Wellington.

Arthington, A. (1994) A holistic approach to water allocation to maintain the environmental values of Australian streams and rivers: a case history. *Mitt. Internat. Limnol*. **24**, 165–177.

Bain, M.B., Finn, J.T. & Booke, H.E. (1988) Streamflow regulation and fish community structure. *Ecology* **69**, 382–392.

Belbin, L. (1991a) *PATN Pattern Analysis Package*. CSIRO, Division of Wildlife and Ecology.

Belbin, L. (1991b) Semi-strong hybrid scaling, a new ordination algorithm. *Journal of Vegetation Science* **2**, 491–496.

Beumer, J.P. (1980) Hydrology and fish diversity of a North Queensland tropical stream. *Australian Journal of Ecology* **5**, 159–186.

Bovee, K. (1982) *A Guide to Stream Habitat Analysis using the Instream Flow Incremental Methodology*. US Fish and Wildlife Service.

Brooks, S. & Lake, P. (1995) *Impacts of Hydrological Disturbance on Stream Communities.* LWRRDC Milestone Report.

Clarke, K.R. (1993) Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**, 117–143.

Clausen, B. & Biggs, B. (1997) Relationships between benthic biota and hydrological indices in New Zealand Streams. *Freshwater Biology* **38**, 327–342.

Extence, C.A., Balbi, D.M. & Chadd, R.P. (1999) River flow indexing using British benthic macroinvertebrates: a framework for setting hydroecological objectives. *Regulated Rivers: Research and Management* **15**, 543–574.

Gentilli, J. (1986) Climate. In *Australia — A Geography. Volume 1 The Natural Environment* (ed. D.N. Jeans) Sydney University Press, pp. 14–48.

Grayson, R.B., Argent, R.M., Nathan, R.J., McMahon, T.A. & Mein, R.G. (1996) *Hydrological Recipes: Estimation Techniques in Australian Hydrology*. Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria.

Growns, I. & Growns, J. (1997) The relationship between biota and hydrology in the Hawkesbury–Nepean River system and their implications for environmental flow allocation. In *Science and Technology in the Environmental Management of the Hawkesbury–Nepean Catchment*. Australian Institute of Engineers, University of Western Sydney, pp. 54–60.

Hughes, J. & James, B. (1989) A hydrological regionalization of streams in Victoria, Australia, with implications for stream ecology. *Australian Journal of Marine and Freshwater Research* **40**, 303–326.

Institution of Engineers Australia (1987) *Australian Rainfall and Runoff: a Guide to Flood Estimation.* Revised edition. Institution of Engineers Australia.

Jowet, I. (1982) The incremental approach to instream flow needs. New Zealand case studies. *River Low Flows: Conflicts of Water Use.* R.S. McColl, Water and Soil Miscellaneous Publications **47**, 9–15.

Jowet, I. & Duncan, M. (1990) Flow variability in New Zealand rivers and its relationship to instream biota. *New Zealand Journal of Marine and Freshwater Research* **24**, 305–317.

McMahon, T.A., Finlayson, B.L., Haines, A.T. & Srikanthan, R. (1992) *Global Runoff-Continental Comparisons of Annual Flows and Peak Discharges*. Catena Verlag, Germany.

Nathan, R. & Weinmann, P. (1993) *Low Flow Atlas for Victorian Streams*. Department of Conservation and Natural Resources, Victoria.

Poff, N. & Allan, J. (1995) Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* **76**, 606–627.

Poff, N., Allan, J., Bain, M., Karr, J., Prestegaard, K., Richter, B., Sparks, R. & Stomberg, J. (1997) The natural flow regime. *Bioscience* **47**, 769–784.

Poff, N. & Ward, J. (1989) Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal for Fisheries and Aquatic Science* **46**, 1805–1818.

Puckridge, J., Sheldon, F., Walker, K. & Boulton, A. (1998) Flow variability and the ecology of large rivers. *Marine and Freshwater Research* **49**, 55–72.

Richter, B., Baumgartner, J., Powell, J. & Braun, D. (1996) A method for assessing hydrological alteration within ecosystems. *Conservation Biology* **10**, 1163–1174.

Richter, B.D., Baumgartner, J.V., Wigington, R. & Braun, D.P. (1997) How much water does a river need? *Freshwater Biology* **37**, 231–249.

Toner, M. & Keddy, P. (1998) River hydrology and riparian wetlands: a predictive model for ecological assembly. *Ecological Applications* **7**, 236–246.

Appendix 1: Summary of suitable stream gauges

In the following table, the column ‘main regulation purpose’ relates to the purpose of the regulating structure: I, Irrigation; H, Hydroelectricity; C, Flood control; N, Navigation; S, Water supply; R, recreation; and Q, water quality control.

Köppen climate classes: BSh, arid, steppe, mean annual temperature >18°C; Bsk, arid, steppe, mean annual temperature <18°C; Cfa, warm temperate, sufficient precipitation in all months, warmest month >22°C; and Cfb, warm temperate, sufficient precipitation in all months, warmest month >22°C, at least 4 months >10°C.

Table A1.1. Regulated gauges

Record no.	Gauge	Name	Catchment area (km^2)	Köppen Climate class	Rainfall (mm)	Regulating structure	Main regulation purpose
1	219003	Bemboka River @ Morans Crossing	316	Cfb	500–800	Cochrane Lake	I
2	222006	Snowy River @ Dalgety	3040	Cfb	500–800	Lake Jindabyne	H
3	409008	Edward River @ offtake	anabranch	BSk	250–500	anabranch regulator, Hume, Yarrawonga	I
4	409016	Murray River @ d/s Hume Weir (Heywoods)	15300	Cfa	250–500	Lake Hume	I
5	409017	Murray River @ Doctors Point	16750	Cfa	250–500	Lake Hume	I
6	410008	Murrumbidgee River @ Burrinjuck Dam	13100	Cfa	500–800	Burrinjuck Res.	I
7	410017	Billabong Creek @ Conargo (Puckawidgee)	anabranch	BSk	250–500	Burrinjuck Res., Blowering Res.	I
8	410021	Murrumbidgee River @ Darlington Point	38850	Cfa	250–500	Blowering Res.	I
9	410033	Murrumbidgee River @ Mittagang Crossing	1891	Cfb	>800	Tantangara	H
10	410073	Tumut River @ Oddys Bridge	1630	Cfa	500–800	Blowering Res.	H
11	412002	Lachlan River @ Cowra	11100	Cfa	500–800	Wyangala Dam	I
12	416001	Barwon River @ Mungindi	44070	BSh	<250	Glenlyon, Pindari, Coolmunda	I
13	422002	Barwon River @ Brewarrina	297850	BSh	350–650	Narran Lake, Beardmore Res.	I
14	422003	Barwon River @ Collarenebri	85500	BSh	<250	Glenlyon, Coolmunda	I
15	422017	Culgoa River @ Weilmoringle	anabranch	BSh	350–650	Beardmore Res., anabranch	I
16	422narra	Narran River @ Narran Plain	anabranch	BSh	350–650	Beardmore Res., anabranch	I
17	422201	Balonne River @ St George	??	BSh	350–651	Beardmore	I
18	422204	Culgoa @ Whyenbah	anabranch	BSh	<250	Beardmore Res., anabranch	I
19	422206	Narran River @ Dirranbandi–Hebel road	anabranch	BSh	<250	Beardmore Res., anabranch	I
20	422207	Ballendool River @ Hebel–Bolon road	anabranch	BSh	<250	Beardmore Res., anabranch	I

Table A1.1 continued

Record no.	Gauge	Name	Catchment area (km^2)	Köppen Climate class	Rainfall (mm)	Regulating structure	Main regulation purpose
21	422208	Culgoa River @ Wollerbilla	anabranch	BSh	<250	Beardmore Res., anabranch	I
22	422209	Bokhara River @ Hebel	anabranch	BSh	<250	Beardmore Res., anabranch	I
23	422212	Balonne River @ Beardmore Dam inflow	??	BSh	350–652	Beardmore	I
24	425004	Darling River @Louth	489300	BSh	<250	Beardmore, Glenlyon, Coolmunda	I
25	222200	Snowy River @ Jarrahmond	13421	Cfb	>800	Lake Jindabyne	H
26	222209	Snowy River @ Mckillop Bridge Basin 22 Snowy	11964	Cfb	>800	Lake Jindabyne	H
27	225204	Macalister River @ Lake Glenmaggie (Tai gauge)	1891	Cfb	>800	Lake Glenmaggie	I
28	228201	Tarago River @ Drouin West	218	Cfb	500–800	Tarago Res.	S
29	231204	Werribee River @ Werribee (diversion weir)	1424	Cfb	500–800	Melton Res.	I
30	231205	Werribee Reservior	1155	Cfb	500–800	Melton Res.	I
31	232204	Moorabool River @ Morrisons	575	Cfb	500–800	Moorabool Res.	S
32	233200	Barwon River @ Pollocksford	2713	Cfb	500–800	West Barwon Dam, Lake Elizabeth, Gong Gong Res., White Swan Res.	S
33	233215	Leigh River @ Mount Mercer	539	Cfb	500–800	Gong Gong Res., White Swan Res.	S
34	236203	Mount Emu Creek @ Skipton	1251	Cfa	500–800	Lake Burrumbee	I
35	403223	King River @ Docker Road bridge	1114	Cfa	500–800	Lake William Hovel	I
36	404220	Broken River @ Lake Nillahcoote (outlet)	??	Cfa	500–800	Lake Mokoan	I
37	405202	Goulburn River @ Seymour	8601	Cfa	250–500	Lake Eildon	I
38	406202	Campaspe River @Rochester	3269		250–500	Lake Eppalock	I
39	407203	Loddon River @ Laanecoorie BSk	4178	BSk	250–500	Laanecoorie Res., Cain Curran Res., Tullaroop Res.	I
40	407210	Loddon River @ Cairn Curran Reservoir	1593	BSk	250–500	Cairn Curran Res.	I
41	407224	Loddon River @ Loddon Weir	5500	BSk	250–500	Laanecoorie Res., Cain Curran Res., Tullaroop Res.	I
42	407253	Piccaninny Creek @ Minto	668	BSk	250–500	Spring Gully Res.	S

Table A1.2. Unregulated gauges

Record number	Gauge	Name	Köppen Climate class	Catchment area (km^2)	Rainfall (mm)
43	218001	Tuross River @ Tuross Vale	Cfb	93	500–800
44	218005	Tuross River @ D/S Wadbilliga River junction	Cfb	900	500–800
45	219001	Rutherford Creek @ Brown Mountain (solid cutting)	Cfb	15.1	500–800
46	219006	Tantawangalo Creek @Tantawangalo Mountain (dam)	Cfb	87	500–800
47	219017	Double Creek @ Near Brogo	Cfb	152	500–800
48	220003	Pambula River @ Lochiel	Cfb	105	>800
49	222004	Little Plains River @ Wellesley (Rowes)	Cfb	604	>800
50	222008	Delegate River @ Quidong	Cfb	1127	>800
51	410024	Goodradigbee River @ Wee Jasper (Kashmir)	Cfb	1165	500–800
52	410061	Adelong Creek @ Batlow road	Cfa	155	500–800
53	410062	Numeralla River @ Numeralla school	Cfb	673	>800
54	410088	Goodradigbee River @ Brindabella(no.2&no.3–cabbans)	Cfb	427	500–800
55	410705	Molonglo River @ Burbong	Cfb	50	500–800
56	410734	Queanbeyan River @ Tinderry	Cfb	50	500–800
57	412028	Abercrombie River @ Abercrombie	Cfb	2770	500–800
58	412050	Crookwell River @ Narrawa North	Cfb	740	500–800
59	412065	Lachlan River @ Narrawa	Cfb	2240	500–800
60	412081	Rocky Bridge Creek @ near Neville	Cfb	145	500–800
61	416016	Macintyre River @ Inverell (Middle Creek)	Cfb	726	650–1200
62	418005	Copes Creek @ Kimberley	Cfb	259	650–1200
63	221201	Cann River (West Branch) @ Weeragua	Cfb	311	>800
64	221207	Errinundra River @ Errinundra	Cfb	162	>800
65	221210	Genoa River @ The Gorge	Cfb	837	>800
66	222206	Buchan River @ Buchan	Cfb	850	>800
67	224206	Wonnangatta River @ Crooked River	Cfb	1103	>800
68	225209	Macalister River @ Licola	Cfb	1233	>800
69	225213	Aberfeldy River @ Beardmore	Cfb	311	>800
70	225219	Macalister River @ Glencairn	Cfb	570	>800
71	225221	Macalister River @ Stringybark Creek	Cfb	1542	>800
72	225224	Avon River @ The Channel	Cfb	554	>800
73	227200	Tarra River @ Yarram	Cfb	218	>800
74	227202	Tarwin River @ Meeniyan	Cfb	1067	500–800
75	227226	Tarwin River East Branch @ Dumbalk North	Cfb	127	500–800
76	230204	Riddells Creek @ Riddells Creek	Cfb	80	>800
77	230208	Deep Creek @ Darraweit Guim	Cfa	350	500–800
78	231213	Lerderderg River @ Sardine Creek, O'Brien Crossing	Cfb	153	>800

Table A1.2 continued

Record number	Gauge	Name	Köppen Climate class	Catchment area (km^2)	Rainfall (mm)
79	232200	Little River @ Little River	Cfb	417	250–500
80	234200	Woady Yaloak River @ Pitfield	Cfb	324	500–800
81	235210	Lardner Creek @ Gellibrand	Cfb	52	>800
82	236204	Fiery Creek @ Streatham	Cfa	956	500–800
83	238204	Wannon River @ Dunkeld	Cfa	671	500–800
84	238221	Dwyer Creek @ Mirranatwa	Cfa	277	500–800
85	238223	Wando River @ Wando Vale	Cfa	174	500–800
86	238231	Glenelg River @ Big Cord	Cfa	57	500–800
87	401203	Mitta Mitta River @ Hinnomunjie	Cfb	1533	>800
88	403205	Ovens River @ Bright	Cfb	495	500–800
89	403226	Boggy Creek @ Angleside	Cfa	108	500–800
90	403232	Morses Creek @ Wandiligong	Cfb	123	500–800
91	403233	Buckland River @ Harris Lane	Cfb	435	500–800
92	404207	Holland Creek @ Kelfeera	Cfa	451	500–800
93	405217	Yea River @ Devlins Bridge	Cfb	360	500–800
94	405229	Wanalta Creek @ Wanalta	BSk	108.8	250–500
95	405237	Seven Creeks @ Euroa Township	Cfa	332	250–500
96	406214	Axe Creek @ Longlea	BSk	234	250–500
97	408202	Avoca River @ Amphitheatre	Cfa	78	250–500

Table A1.3. Gauges with simulated data

Record number	Gauge	Name	Köppen Climate class	Catchment area (km^2)	Rainfall (mm)	Simulation
98	422001cur	Barwon River @ Dangar Bridge (Walgett)	BSh	132200	350–650	Current level of regulation
99	422001nat	Barwon River @ Dangar Bridge (Walgett)	BSh	132200	350–651	No regulation
100	422003cur	Barwon River @ Collarenebri	BSh	85500	350–650	Current level of regulation
101	422003nat	Barwon River @ Collarenebri	BSh	85500	350–651	No regulation
102	416001cur	Barwon River @ Mungindi	BSh	44070	350–650	Current level of regulation
103	416001nat	Barwon River @ Mungindi	BSh	44070	350–651	No regulation
104	422201cur	Balonne River @ St George	BSh	??	350–650	Current level of regulation
105	422201nat	Balonne River @ St George	BSh	??	350–651	No regulation
106	425008cur	Darling River @ Wilcannia main channel	BSh	569800	<250	Current level of regulation
107	425008nat	Darling River @ Wilcannia main channel	BSh	569800	<251	No regulation

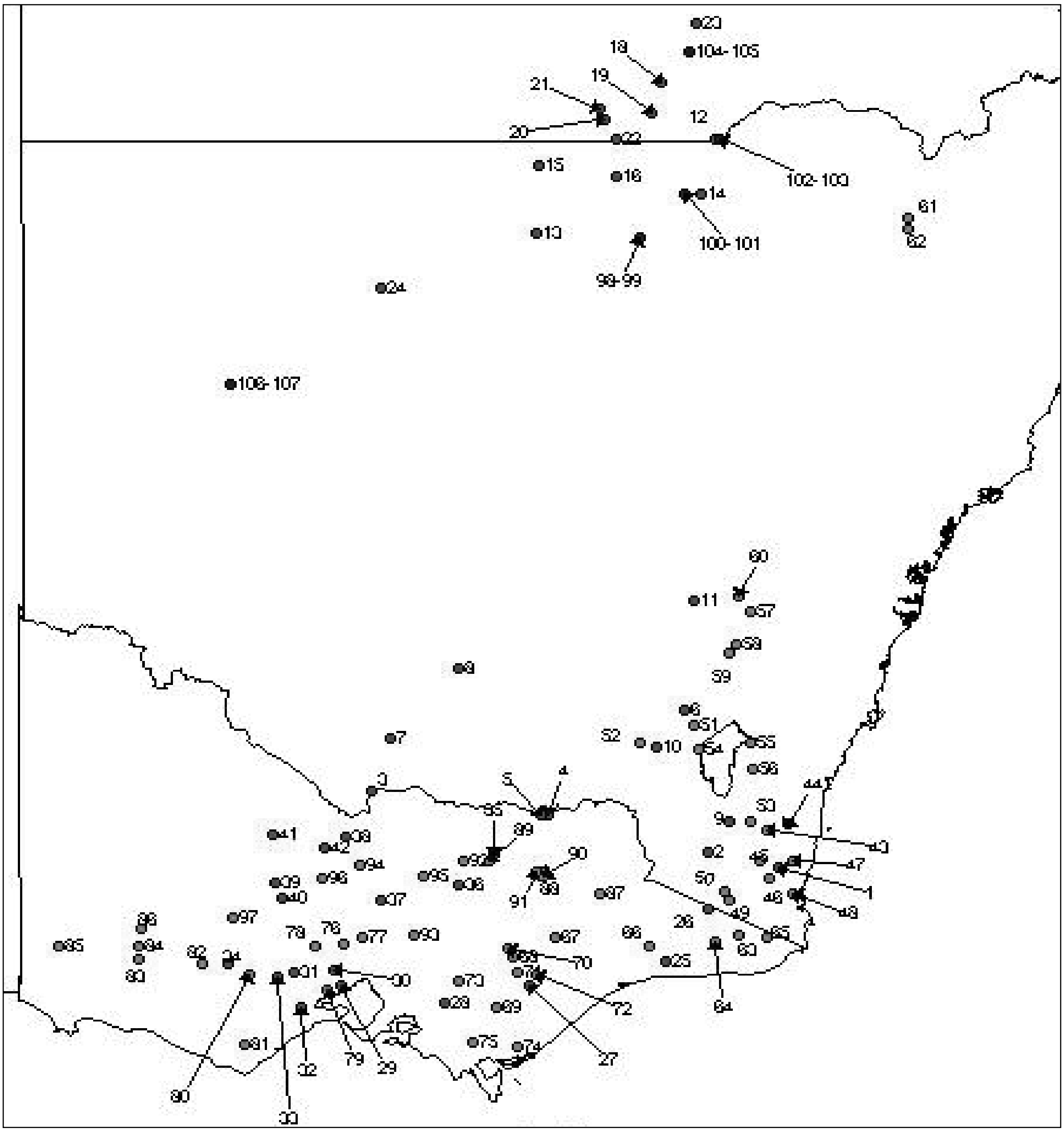

**Figure A1.1. Location of stream gauges
(green = unregulated; red = regulated; blue = simulated)**

Appendix 2: Explanatory notes on the calculation of hydrological variables

The following details are explanatory notes for each of the subroutines used to calculate the hydrological variables. The notes explain both the subroutine and the method of calculation of the variables.

The second level headings below (that start with 'My') relate to a Visual Basic for Applications (VBA) subroutine.

A2.1 Elements of the VBA Code

A2.1.1 Input sheet

To avoid entering each input data file individually, an input worksheet is included with the Excel file containing the VBA code. The input sheet lists the source directory, file name, catchment area and day on which the 20-year record should begin. To enable replication of the process, pre-prepared worksheets are presented that list regulated and unregulated gauges for NSW and Victoria. To recalculate the variables for any of these lists, the relevant worksheet is simply copied to the 'Input' worksheet.

A2.1.2 Report sheet

A report worksheet is also included with the Microsoft® Excel file. Rather than create a new output file and write down all the heading entries, the report sheet is simply copied to a new output file.

A2.1.3 Code modules

The VBA code that actually reads the raw data and calculates the hydrological variables is contained in Module-one of the Excel file. This code can be modified to include additional variables, or to remove variables from the list.

A2.2 Getting the raw data

A2.2.1 MyOpenDataFile

MyOpenDataFile opens a raw data file that is a comma delimited output file from HYDSYS™, where the date is in dd/mm/yy format. The file details are read from the 'Input' worksheet.

A2.2.2 MyFindRange

The MyFindRange subroutine reads the start of the 20-year period from the 'Input' worksheet and calculates the end of the 20-year period. These two dates are then found in the imported data file. The dates and associated flows from the start date to the end date are stored as an array for use in subsequent subroutines.

A2.3 Setting up the reporting sheet

A2.3.1 MyCopyReport

The MyCopyReport subroutine asks if a new output file is needed or whether to add the data to an existing output file.

If a new output sheet is required, the ‘report’ worksheet is copied to a new output file. The default output file is saved under My Documents and is called ‘indices_current-date’. The output file is set up to enter results from subsequent gauges in adjacent columns for easy data interpretation between gauges.

A2.3.2 MyFindNextColumn

The next blank column in the output sheet is selected to enter variables for the current data file.

A2.4 Daily flow summary

A2.4.1 MyBaseFlowIndex

The base flow and flood flow index are calculated using the Lyne and Hollick method as described by Nathan & Weinmann (1993). The digital filter is applied three times to smooth the data, one forward pass, one backward, and then forward again as described by Grayson *et al.* (1996). The equation used is:

$$q_f(i) = \alpha q_f(i-1) + [q(i) - q(i-1)]\frac{1+\alpha}{2} \ ,$$

where

$q_f(i)$ is the filtered quick flow response for the ith sampling instant;

$q(i)$ is the original stream flow for the ith sampling instant; and

α is the filter parameter for which a value of 0.925 is recommended for daily data.

After each pass a new array of base flow values is created. After three passes the base flow array elements are added to give a total base flow for the entire period, the original flow is also added to give a total flow for the entire period.

The base flow index is base flow/total flow.

The flood flow index is the flood flow (i.e. the total flow–base flow)/base flow.

The base flow index and flood flow index are written to the output file.

A2.4.2 MyLongTerm

The MyLongTerm subroutine uses the entire 20-year record as a single array of flow data: i.e. values are calculated from the entire record and not annual series. The output from this subroutine is generated by using Excel spreadsheet functions on the single array of flow data:

Output	**Excel function**
Minimum flow for entire period	MIN( )
Maximum flow for entire period	MAX( )
Q90 for entire period	PERCENTILE( )
Q10 for entire period	PERCENTILE( )
Median daily flow	MEDIAN( )
Mean daily flow	AVERAGE( )

Skewness of flow for entire record: this is the long-term mean divided by the long-term median flow.

A2.4.3 MyFlowDuration

This subroutine calculates the slope of the middle of the flood frequency curve. The Excel function Percentile( ) is used on the array of the total flow record to get the 20th, 30th, 40th, 50th, 60th, 70th and 80th percentile flows. The slope of the flow duration curve is calculated using the Excel function SLOPE( ), and the r^2 value is calculated using the Excel function RSQ( ). If the r^2 value is greater than 0.9 then the flow duration curve is suitably straight for this range of percentiles, and the value of the slope and r^2 are written to the output file. A flow duration curve is usually straight for this range of percentile values, but for higher and lower flows it usually becomes non-linear due to the effect of extreme flows. It is for this reason that only suitably linear central sections of the flow duration curve are considered.

A2.4.4 MyFloodFreq

This subroutine works out the magnitude of the 1.58-, 2-, and 5-year ARI floods. These values are divided by the long-term mean daily flow to normalise the value for comparison between gauges. The flood frequency curve is derived from a partial series of $n \times 3$ where n = number of years in the record (i.e. 60 floods for each gauge). There are two criteria for identifying floods. The first criterion is simply to have a threshold flood level such as for a spell analysis and to count the number of times the flow exceeds this level. The second criterion is that floods have to be independent, and not generated in the same event. The criterion for independence is a minimum time between flood peaks; this minimum time is dependent on the size of the catchment upstream of the gauge. Small catchments are more flashy; hence the independence criterion can be a shorter period of time than for a large catchment. To determine suitable independence criteria, categories of catchment size were developed first, and then a single unregulated gauge within the catchment size category was visually reviewed to identify a suitable period so that peak flows could be considered independent. The catchment size classes, gauges reviewed and independence criteria are shown in the table below.

Catchment size class (km^2)	Gauge reviewed	Gauge catchment size (km^2)	Independence criteria (days)
<50	210068	25	4
50–100	219006	87	5
100–500	201001	213	8
500–1000	206018	894	10
1000–5000	204015	2670	12
5000–10000	208004	6560	15
>10000	423001	60600	20

The catchment size is read from the input file, and the relevant independence criterion is set. A starting flood (threshold) level is set and the array of 20 years of flow data is sorted to find events above the threshold level. When a peak flow above the threshold is found, it is checked to make sure there is no other peak within a period of the independence criterion from the peak. If there is one within the independence criterion, the peaks are compared and the larger one is selected and the other ‘dependent’ peak is discarded. Once the whole record has been stepped through, the number of peaks is checked. If the number of peaks is greater than 60 then the threshold flood is increased and if the number is below 60 the threshold flood is reduced.

After the code has repeated sufficiently to achieve a threshold flow that results in greater than 60 flood events and a threshold that produces less than 60 flood events, the threshold level is adjusted to achieve convergence at 60 flood events over the 20-year period. When the starting flood is too high or too low (i.e. consistently fewer than 60 floods), the starting flood is reset at a different level and the code is allowed to rerun until it converges at 60 flood events.

For some gauges it may not be possible to achieve 60 flood events over the 20-year period. If this is the case the independence criterion is reduced by one day and the code is rerun until 60 floods are recorded. The need to reduce the independence criterion occurs only in a few cases.

After a threshold is selected to produce 60 flood events, the flood peaks of each of the 60 events are sorted and ranked from 1 to 60, and the following plotting position formula is applied to locate their ARI values:

$$YP(m) = \frac{N + 0.2}{m - 0.4},$$

where $YP(m)$ is the ARI of the flood,

N is the number of floods, i.e. 60,

m is the rank of the flood (1 to 60).

Using the values of ARI for the known peaks, the ARI values of 1.58, 2, and 5 years are used to find equivalent floods. The equivalent floods are found by linear interpolation between the flood peaks of known ARIs. The final flood peak values are divided by the long-term mean flow to produce a measure of ARI relative to the long-term mean flow.

A2.5 High-flow spell analysis

A2.5.1 MyFindHighFlowDetails

The MyFindHighFlowDetails subroutine undertakes a spell analysis using a number of threshold flows to find the frequency, duration and magnitude of daily discharges above the threshold levels. The predefined levels are 1, 3, 5, 7, and 9 times the median daily flow (calculated in the MyLongTerm subroutine), and 2 times the mean daily flow (calculated in the MyLongTerm subroutine).

The subroutine steps through one year at a time and considers one threshold at a time. A high-flow period is started when the rising arm of the hydrograph crosses the threshold level, and it finishes when the falling arm crosses back over the threshold limit (Figure A1.2). There is no test for independence of high-flow periods other than this: only one peak value is permitted for each high-flow period.

The subroutine continues to count the duration of all started high-flow periods until the discharge crosses from above to below the threshold level. If a high-flow period starts near the end of a year and continues into the next year, the high-flow period is counted as belonging to the year in which it commenced. Such high-flow periods that overlap years are not double counted; they are simply recorded in the year in which they begin. High flows that occur past the end of the 20-year record are considered to ‘end’ on the last day of the record.

The output is standard for most of the following subroutines, and for each of the main variables the following are calculated:

- the median of (usually 20 annual) values, each of which is the number of high-flow periods for a particular year of the record (or particular month, or season for other subroutines);
- the mean of values, each of which is the number of high-flow periods for a particular year of the record;
- the inter-annual variation in the number of high flows per year: the (90th percentile minus 10th percentile)/median number of exceedances;
- the CV, the standard deviation of annual values or mean number of exceedances.

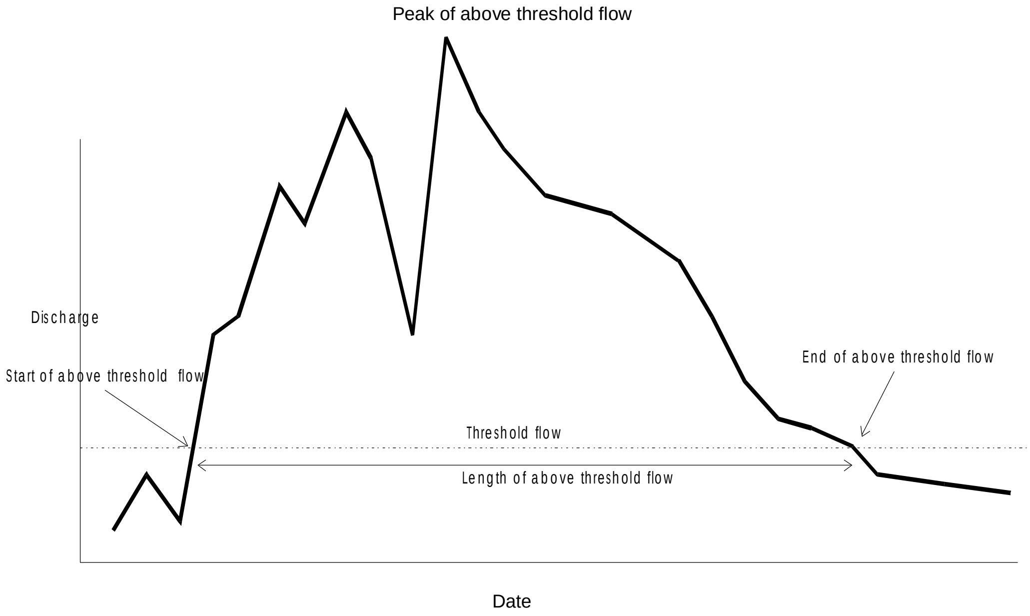

Figure A2.1. Determining above-threshold flows

When the threshold level is a function of the mean, e.g. 2 times mean, then only the mean and CV are returned.

As a generally adopted approach, if the output from a particular variable would be a discharge, the values are normalised to allow comparison between different gauges: that is,

- when the measure is a median or variability, the divisor is the long-term median daily flow;
- when the variable is a mean or CV, the divisor is the long-term mean daily flow.

A2.5.2 MyHighFlowSeasonality

The MyHighFlowSeasonality subroutine uses two threshold values (3 and 9 times the median) to calculate the seasonality of the frequency of high-flow periods. The number of times flow exceeds the threshold for each season is counted and recorded as an annual value for each season. Each season is a standard three- month calendar season, not derived from the flow year. This subroutine is the same as the MyFindHighFlowDetails subroutine with the exception that it searches the records season by season rather than year by year.

A2.5.3 Output

The output for both the high-flow thresholds are as follows:

- the season with the most high-flow periods — proportion of annual high flows that occur in that season;
- for each season, normalised values of median, mean, variability and CV of 20 annual values for that season.

A2.6 Low-flow spell analysis

The low-flow details are calculated using the same method as for the high-flow details explained above, with the exception that an event begins when the flow falls below the threshold level and ends when the flow rises back past the threshold level. The predefined levels are 1/2, 1/3, and 1/9 times the median daily flow, and 10% of mean daily flow. Two subroutines are used: MyFindLowFlowDetails and MyLowFlowSeasonality. These subroutines are equivalent to the MyFindHighFlowDetails and MyHighFlowSeasonality subroutines explained above except that the conditions are for below-threshold flows rather than above-threshold flows. Two thresholds are used for the seasonality of low flows: 1/3 and 1/9 of median flow.

A2.7 Moving average

A2.7.1 MyFindAnnualMaximumFlows

The MyFindAnnualMaximumFlows subroutine is used to find the annual, one-day, 30-day, and 90-day maximum values. The subroutine checks each year of the record, noting the maximum of each one-, 30- and 90-day maximum value. There is no overlap between years for 30- and 90-day values. Three arrays are produced: a one-day, 30-day and 90-day array. The one-day array contains 20 values of the largest single discharge for one day in each year of the record. The 30-day array also contains 20 values; each one is the largest of mean 30-day running averages (i.e. sum of 30 flow values/30) for the whole year (i.e. the largest of 365 – 30 running average values for each year of the record). The 90-day array is similar, for 90-day running averages.

For each of the three arrays the median, mean, variability and CV are calculated and normalised by dividing by either the long-term median or mean daily flow as discussed above.

A2.7.2 MyFindAnnualMinimumFlows

The MyFindAnnualMinimumFlows subroutine uses the same technique as the subroutine called MyFindAnnualMaximumFlows to find the minima for one-day, 30-day and 90-day moving averages. The output is the same as for the previous subroutine.

A2.8 Cessation of flow

A2.8.1 MyFindZeroFlow

The array of 20 years of daily flow values is searched to find zero flow values. A count of the number of zero flow days per year is made, and any month which has at least one zero flow day is noted as a ‘zero month’.

The output is a total of the number of zero flow days for the 20-year record, which is calculated by totalling the number of zero flow days for each year of the record.

The inter-annual zero flow statistics — median, mean, variability, CV — are derived from an array which records the number of zero days in each year of the record. If a zero value is recorded for either the mean or median, then there is no result for the variability or CV respectively.

The number of zero months is totalled and divided by the total number of months in the record to give a proportion of zero flow months. This value is the proportion of months in the 20-year record that have at least one zero flow day.

A2.9 Rise and fall of the hydrograph

A2.9.1 MyRisingAndFallingLimbs

This subroutine searches each year of the record and records a rising limb when the next day’s flow is greater than the present day’s flow, and vice versa for falling limbs. An array of the cumulative total ‘rises’ is produced (and another for falls) for each year. An array noting each rise (and another for each fall) in the entire record is also recorded. The duration of rising and falling limbs (i.e. number of consecutive days of rising or falling flows) is noted by an array which has an average value for each year (total duration of rising limbs/number of rising limbs).

From these arrays we have:

- a record of the total number of rises or falls per year; output = median, mean, variability, CV of annual values;

- a measure of length of individual rises and falls — median, mean, variability, CV for rise and fall length.

A2.9.2 MyConsecutiveDailyDifferences

The MyConsecutiveDailyDifferences subroutine looks at the difference between consecutive daily flow values. It searches through the entire record, creating an array of the positive differences and an array of the negative difference between consecutive daily flows. It also searches through each year of the record recording a cumulative total of daily positive and negative differences for each year. It also records the single largest positive and negative differences for each year. As well as absolute values of rises and falls, another array records the number of rises per year and another records the number of falls per year.

The output is (normalised where value is a magnitude) median, mean, variability, and CV from arrays of:

- each positive daily difference for the entire record,
- each negative daily difference for the entire record,
- totalled positive daily differences for each year,
- totalled negative daily differences for each year,
- maximum annual positive daily difference,
- maximum annual negative daily difference,
- annual number of positive daily differences,
- annual number of negative daily differences.

A2.10 Monthly flow analysis

A2.10.1 MyMonthlySummary

For each month of the record, a mean daily flow is calculated; the output from this subroutine is the normalised median, mean, variability and CV for the 20 annual ‘mean daily’ values for each of 12 months.

For each year, the month with the largest mean daily flow and the month with the smallest mean daily flow are recorded in arrays. The output from these arrays is the month (numeric value 1–12) that most frequently has the largest or smallest mean daily flow, respectively.

For each year, the inter-monthly variability is calculated as the (90th percentile minus 10th percentile)/median of mean daily flow for each of 12 months. For these 20 values of inter-monthly variability, the mean, median, variability and CV are calculated to give a feel for the inter-annual variation of inter-month variability.

Twelve values of inter-annual variability are calculated, i.e. inter-annual variability for each month, namely the median, mean, variability and CV for this collection of 12 values. These are calculated to provide an indication of the overall inter-monthly variability.

Appendix 3: Sample output file of hydrological variables

Table A3.1: Sample output file showing variable titles, short names, and the numbers of data points used to calculate the variable (210002 is sample output)

No.			Variable	Data points	Short name	210002
1		Data quality	Number of gaps in data			4
2			Total length of gaps:- days			149
3			Longest single gap in data	7300+		84.00
4	Daily flow	Long-term values	Minimum flow for entire period	7300+	LTMIN	7.64
5	summary		Maximum flow for entire period	7300+	LTMAX	317888
6		Source is a single	Q90 for entire period	7300+	LTQ90	99.15
7		array containing	Q10 for entire period	7300+	LTQ10	1482.05
8		the complete 20 yrs	Median daily flow	7300+	LTMED	340.39
9		of daily flow data	Mean daily flow	7300+	LTMEAN	3893.97
10			Skewness of flow for entire record	7300+	LTSKEW	11.44
11			1.58 ARI:- Annual series (1.0 ARI partial series)	7300+	LT158AR1	3.47
12			2.0 ARI:- Annual Series (1.443 ARI partial series)	7300+	LT2AR1	5.68
13			5.0 ARI:- Annual Series (4.481 ARI partial series)	7300+	LT5ARI	12.04
14			Base flow index	7300+	LTBFI	0.46
15			Flood flow index	7300+	LTFFI	1.18
16			Slope of flow duration curve	7300+	LTSFD	–0.01
17			r^2 of flow duration curve	7300+	LTRFD	0.99
18	High-flow	Number of 'above-	Median of the annual number >1 x median	20	HFNMED1	12
19	spell	threshold' flows	Mean		HFNME1	12.30
20	analysis		Variability		HFNV1	1.10
21		Source data are the	CV		HFNC1	0.44
22		number of 'above-	Median of the annual number >3 x median	20	HFNMED3	6
23		threshold' events	Mean		HFNME3	6.95
24		for each year of	Variability		HFNV3	1.77
25		the record	CV		HFNC3	0.67
26			Median of the annual number >5 x median	20	HFNMED5	4
27			Mean		HFNME5	5.47
28			Variability		HFNV5	2.05
29			CV		HFNC5	0.67
30			Median of the annual number >7 x median	20	HFNMED7	4
31			Mean		HFNME7	5.00
32			Variability		HFNV7	1.90
33			CV		HFNC7	0.65
34			Median of the annual number >9 x median	20	HFNMED9	3
35			Mean		HFNME9	4.47
36			Variability		HFNV9	2.33
37			CV		HFNC9	0.68
38			Mean of the annual number >2 x mean	20	HFNME2M	0
39			CV of annual values		HFNC2M	–9999
40	High-flow	Peak magnitude of	Median peak flow above a threshold >1 x median	20	HFPMED1	1.42
41	spell	'above-threshold'	Mean		HFPME1	0.39
42	analysis	flow	Variability		HFPV1	3.40

Table A3.1 continued

43		Source data are the annual medians of peak magnitude flows for ‘above-threshold’ events	CV		HFPC1	4.27
44			Median peak flow above a threshold >3 x median	20	HFPMED3	5.73
45			Mean		HFPME3	2.35
46			Variability		HFPV3	3.58
47			CV		HFPC3	4.20
48			Median peak flow above a threshold >5 x median	20	HFPMED5	11.99
49			Mean		HFPME5	3.57
50			Variability		HFPV5	4.49
51			CV		HFPC5	3.13
52			Median peak flow above a threshold >7 x median	20	HFPMED7	15.75
53			Mean		HFPME7	4.34
54			Variability		HFPV7	4.09
55			CV		HFPC7	2.75
56			Median peak flow above a threshold >9 x median	20	HFPMED9	18.55
57			Mean		HFPME9	5.17
58			Variability		HFPV9	5.06
59			CV		HFPC9	2.49
60			Mean peak high flows >2 x mean	20	HFPME2M	51.32
61			CV		HFPC2M	1.76
62	High-flow spell analysis	Duration of ‘above-threshold’ flows	Median of duration of events >1 x median	20	HFDMED1	177
63			Mean		HFDME1	181.85
64			Variability		HFDV1	0.00
65		Source data are the durations of ‘above threshold’ events for each year of the record	CV		HFDC1	0.53
66			Median of duration of events >3 x median	20	HFDMED3	24
67			Mean		HFDME3	53
68			Variability		HFDV3	0.00
69			CV		HFDC3	1.10
70			Median of duration of events >5 x median	20	HFDMED5	12
71			Mean		HFDME5	34.68
72			Variability		HFDV5	0.00
73			CV		HFDC5	1.28
74			Median of duration of events >7 x median	20	HFDMED7	10
75			Mean		HFDME7	29.33
76			Variability		HFDV7	0.00
77			CV		HFDC7	1.33
78			Median of duration of events >9 x median	20	HFDMED9	9
79			Mean		HFDME9	26.76
80			Variability		HFDV9	0.00
81			CV		HFDC9	1.42
82			Mean of duration of events >2 x mean	20	HFDMED2M	9.5
83			CV		HFDC2M	1.75
84	High-flow spell analysis	Seasonal variation of ‘above-threshold’ flows	Season with most high-flow periods >3 x median	20	HFSS3	spring
85			Proportion of high flows in above season	20	HFSSP3	0.25
86			Median number of summer high flows	20	HFSMED3	6
87		Source data are the number of ‘above-threshold’ events for each of four seasons	Mean		HFSME3	10.85
88			Variability		HFSV3	3.98
89			CV		HFSC3	1.12
90			Median number of autumn high flows	20	HFAMED3	2.5
91			Mean		HFAME3	11.25
92			Variability		HFAV3	13.84
93			CV		HFAC3	1.52

Table A3.1 continued

94			Median number of winter high flows	20	HFWMED3	7
95			Mean		HFWME3	15.75
96			Variability		HFWV3	5.86
97			CV		HFWC3	1.12
98			Median number of spring high flows	20	HFSPMED3	6
99			Mean		HFSPME3	12.65
100			Variability		HFSPV3	5.33
101			CV		HFSPC3	1.25
102			Season with most high-flow days >9 x median	20	HFSS9	spring
103			Proportion of high flows in above season	20	HFSSP9	0.28
104			Median number of summer high-flow days	20	HFSMED9	1.5
105			Mean		HFSME9	5.75
106			Variability		HFSV9	11.13
107			CV		HFSC9	1.71
108			Median number of autumn high-flow days	20	HFAMED9	0
109			Mean		HFAME9	4.55
110			Variability		HFAV9	–9999
111			CV		HFAC9	1.91
112			Median number of winter high-flow days	20	HFWMED9	3.5
113			Mean		HFWME9	6.15
114			Variability		HFWV9	2.06
115			CV		HFWC9	1.43
116			Median number of spring high-flow days	20	HFSPMED9	2.5
117			Mean		HFSPME9	6.3
118			Variability		HFSPV9	6.04
119			CV		HFSPC9	2.03
120	Low-flow spell analysis	Number of ‘below-threshold' flows	Median of the annual number < 1/2 x median	20	LFNMED1	8
121			Mean		LFNME1	8.2
122			Variability		LFNV1	2.01
123		Source data are the durations of ‘below threshold’ events for each year of the record	CV		LFNC1	0.73
124			Median of the annual number < 1/3 x median	20	LFNMED3	3
125			Mean		LFNME3	5.65
126			Variability		LFNV3	5.47
127			CV		LFNC3	1.23
128			Median of the annual number < 1/9 x median	20	LFNMED9	0
129			Mean		LFNME9	1.75
130			Variability		LFNV9	–9999
131			CV		LFNC9	2.22
132			Mean of the annual number < 10% of mean	20	LFNME10	13.5
133			CV of annual values		LFNC10	0.40
134	Low-flow spell analysis	Magnitude of ‘below-threshold' flows	Median peak flow below a threshold < 1/2 median	20	LFPMED1	0.37
135			Mean		LFPME1	0.03
136			Variability		LFPV1	0.88
137		Source data are the annual medians of peak magnitude flow for ‘below-threshold’ events	CV		LFPC1	0.35
138			Median peak flow below a threshold < 1/3 median	20	LFPMED3	0.23
139			Mean		LFPME3	0.02
140			Variability		LFPV3	0.96
141			CV		LFPC3	0.37
142			Median peak flow below a threshold < 1/9 median	20	LFPMED9	0.08
143			Mean		LFPME9	0.01
144			Variability		LFPV9	0.70
145			CV		LFPC9	0.31
146			Mean peak flow below a threshold < 10% of mean	20	LFPMED10	0.07

Table A3.1 continued

147			CV		LFPC10	0.37
148	Low-flow spell analysis	Duration of ‘below-threshold' flows Source data are the durations of ‘below threshold’ events for each year of the record	Median of duration of events < 1/2 median	20	LFDMED1	45.00
149			Mean		LFDME1	73.90
150			Variability		LFDV1	0.00
151			CV		LFDC1	1.15
152			Median of duration of events < 1/3 median	20	LFDMED3	6.5
153			Mean		LFDME3	44.10
154			Variability		LFDV3	0.01
155			CV		LFDC3	1.62
156			Median of duration of events < 1/9 median	20	LFDMED9	0
157			Mean		LFDME9	5.75
158			Variability		LFDV9	–9999
159			CV		LFDC9	2.36
160			Mean of duration of events < 10% mean	20	LFDMED10	208.45
161			CV		LFDC10	0.44
162	Low-flow spell analysis	Seasonal variation of ‘below-threshold’ flows Source data are the numbers of ‘below-threshold’ events for each of four seasons	Season with most low-flow days <1/3 x median	20	LFSS3	spring
163			Proportion of low flows in above season		LFSSP3	0.25
164			Median number of summer low-flow days	20	LFSMED3	1
165			Mean		LFSME3	6.7
166			Variability		LFSV3	26.10
167			CV		LFSC3	1.75
168			Median number of autumn low-flow days	20	LFAMED3	1
169			Mean		LFAME3	10.15
170			Variability		LFAV3	43.10
171			CV		LFAC3	1.85
172			Median number of winter low-flow days	20	LFWMED3	2
173			Mean		LFWME3	16.15
174			Variability		LFWV3	30.85
175			CV		LFWC3	1.58
176			Median number of spring low-flow days	20	LFSPMED3	2.5
177			Mean		LFSPME3	11.1
178			Variability		LFSPV3	15.60
179			CV		LFSPC3	1.64
180			Season with most low-flow days <1/9 x median	20	LFSS9	winter
181			Proportion of low flows in above season	20	LFSSP9	0.44
182			Median number of summer low-flow days		LFSMED9	0
183			Mean		LFSME9	0.65
184			Variability		LFSV9	–9999
185			CV		LFSC9	2.51
186			Median number of autumn low-flow days	20	LFAMED9	0
187			Mean		LFAME9	1.65
188			Variability		LFAV9	–9999
189			CV		LFAC9	2.80
190			Median number of winter low-flow days	20	LFWMED9	0
191			Mean		LFWME9	2.55
192			Variability		LFWV9	–9999
193			CV		LFWC9	2.35
194			Median number of spring low-flow days	20	LFSPMED9	0
195			Mean		LFSPME9	0.9
196			Variability		LFSPV9	–9999
197			CV		LFSPC9	2.60
198	Moving average	Maximum annual moving average	Median of annual maximum daily flow	20	MAHMED1	39.76
199			Mean		MAHME1	14.76

Table A3.1 continued

200			Variability		MAHV1	12.42
201			CV		MAHC1	1.64
202			Median of annual maximum 30 day flow	20	MAHMED30	11.23
203			Mean		MAHME30	8.02
204			Variability		MAHV30	26.04
205			CV		MAHC30	2.43
206			Median of annual maximum 90 day flow	20	MAHMED90	5.88
207			Mean		MAHME90	4.02
208			Variability		MAHV90	18.03
209			CV		MAHC90	2.53
210		Minimum annual moving average	Median of annual minimum daily flow	20	MALMED1	0.24
211			Mean		MALOME1	0.02
212			Variability		MALV1	2.04
213			CV		MALC1	0.73
214			Median of annual minimum 30 day flow	20	MALMED30	0.47
215			Mean		MALME30	0.04
216			Variability		MALV30	1.45
217			CV		MALC30	0.62
218			Median of annual minimum 90 day flow	20	MALMED90	0.62
219			Mean		MALME90	0.06
220			Variability		MALV90	1.45
221			CV		MALC90	0.53
222	Cessation-of-flow analysis	Zero flows	Total number of zero flow days of record	20	ZEN	0
223			Median number of days per year having zero flow	20	ZENMED	0
224		Source is an array of the number of zero-flow days	Mean		ZENME	0
225			Variability		ZENV	–9999
226			CV		ZENC	–9999
227			Proportion of all months that have a zero flow day	240	ZEP	0
228	Rise and fall of the hydrograph	Number of rises and falls of the hydrograph	Median of total number of rising limbs per year	20	RFNRMED	91.5
229			Mean		RFNRME	93.75
230			Variability		RFNRV	0.33
231			CV		RFNRC	0.15
232			Median duration of individual rising limbs for entire record		RFDRMED	2
233			Mean		RFDRME	2.11
234			Variability		RFDRV	1.50
235			CV		RFDRC	0.62
236			Median of total number of falling limbs per year	20	RFNFMED	137
237			Mean		RFNFME	131.25
238			Variability		RFNFV	0.343796
239			CV		RFNFC	0.280812
240			Median duration of individual falling limbs for entire record	7300+	RFDFMED	2.5
241			Mean		RFDFME	3.75
242			Variability		RFDFV	2.80
243			CV		RFDFC	1.32
244		Magnitude of daily change in flow	Median of +ve daily differences in flow for entire record	7300+	RFDPMED	0.08
245			Mean		RFDPME	0.17
246			Variability		RFDPV	12.93
247			CV		RFDPC	13.30
248			Median of mean annual +ve daily differences in flow	20	RFDPMED2	0.66
249			Mean		RFDPME2	0.19

Table A3.1 continued

250			Variability		RFDPV2	7.98
251			CV		RFDPC2	1.38
252			Median of annual maximum +ve daily differences in flow	20	RFDPMED3	18.38
253			Mean		RFDPME3	12.04
254			Variability		RFDPV3	17.16
255			CV		RFDPC3	1.96
256			Median of the annual number of +ve daily differences	20	RFDPMED4	137
257			Mean		RFDPME4	132.55
258			Variability		RFDPV4	0.30
259			CV		RFDPC4	0.12
260			Median of -ve daily differences in flow for entire record	7300+	RFDNMED	0.06
261			Mean		RFDME	0.10
262			Variability		RFDNV	20.92
263			CV		RFDNC	5.13
264			Median of mean annual -ve daily differences in flow	20	RFDNMED2	0.59
265			Mean		RFDNME2	0.09
266			Variability		RFDNV2	3.45
267			CV		RFDNC2	1.09
268			Median of annual minimum -ve daily differences in flow	20	RFDNMED3	13.31
269			Mean		RFDNME3	3.58
270			Variability		RFDNV3	7.33
271			CV		RFDNC3	1.26
272			Median of the annual number of -ve daily differences	20	RFDNMED4	228
273			Mean		RFDNME4	232.65
274			Variability		RFDNV4	0.18
275			CV		RFDNC4	0.07
276	Monthly flow analysis	Monthly flows	January: Median daily flow for entire period	20	MFJANMED	0.04
277			Mean		MFJANME	0.00
278			Variability		MFJANV	1.32
279			CV		MFJANC	1.03
280			February: Median daily flow for entire period	20	MFFEBMED	0.04
281			Mean		MFFEBME	0.00
282			Variability		MFFEBV	1.53
283			CV		MFFEBV	1.10
284			March: Median daily flow for entire period	20	MFMARMED	0.04
285			Mean		MFMARME	0.13
286			Variability		MFMARV	2.01
287			CV		MFMARC	4.32
288			April: Median daily flow for entire period	20	MFAPRMED	0.04
289			Mean		MFAPRME	0.13
290			Variability		MFAPRV	2.15
291			CV		MFAPRC	4.32
292			May: Median daily flow for entire period	20	MFMAYMED	0.04
293			Mean		MFMAYME	0.12
294			Variability		MFMAYV	1.50
295			CV		MFMAYC	4.33
296			June: Median daily flow for entire period	20	MFJUNMED	0.04
297			Mean		MFJUNME	0.13

Table A3.1 continued

298		Variability		MFJUNV	6.16
299		CV		MFJUNC	4.25
300		July: Median daily flow for entire period	20	MFJULMED	0.04
301		Mean		MFJULME	0.12
302		Variability		MFJULV	4.55
303		CV		MFJULC	4.30
304		August: Median daily flow for entire period	20	MFAUGMED	0.04
305		Mean		MFAUGME	0.12
306		Variability		MFAUGV	2.66
307		CV		MFAUGC	4.29
308		September: Median daily flow for entire period	20	MFSEPMED	0.04
309		Mean		MFSEPME	0.12
310		Variability		MFSEPV	3.52
311		CV		MFSEPC	4.27
312		October: Median daily flow for entire period	20	MFOCTMED	0.04
313		Mean		MFOCTME	0.11
314		Variability		MFOCTV	2.29
315		CV		MFOCTC	4.31
316		November: Median daily flow for entire period	20	MFNOVMED	0.04
317		Mean		MFNOVME	0.12
318		Variability		MFNOVV	2.89
319		CV		MFNOVC	4.28
320		December: Median daily flow for entire period	20	MFDECMED	0.04
321		Mean		MFDECME	0.07
322		Variability		MFDECV	1.31
323		CV		MFDECC	4.27
324		Month in which the minimum 'mean daily flow' most frequently occurs	12	MFML	1
325		Month in which the maximum 'mean daily flow' most frequently occurs	12	MFMH	2
326	Inter-month variability	Median variability of inter-annual monthly variability	12	MFAVMED	2.22
327		Mean variability of inter-annual monthly CV		MFAVME	4.00
328		Variability of inter-annual monthly variability		MFAVV	1.40
329		CV of inter-annual monthly CV		MFAVC	0.25
330	Inter-annual monthly variability	Median of annual values of inter-month variability	20	MFMVMED	0.67
331		Mean of annual values of inter-month CV		MFMVME	0.40
332		Variability of annual values of inter-month variability		MFMVV	2.30
333		CV of annual values of inter-month CV		MFMVC	0.80

Table A3.2: Variables retained following cross correlation analysis

		Variable	**Data points**	**Short name**	**210002**
Daily flow summary		Maximum flow for entire period	7300+	LTMAX	317888
	Source is a single array containing the complete 20 yrs of daily flow data	Q90 for entire period	7300+	LTQ90	99.15
		Mean daily flow	7300+	LTMEAN	3893.97
		Skewness of flow for entire record	7300+	LTSKEW	11.44
		2.0 ARI:- Annual Series (1.443 ARI partial series)	7300+	LT2ARI	5.68
		Base flow index	7300+	LTBFI	0.46
		Slope of flow duration curve	7300+	LTSFD	–0.01
High flow spell analysis	Number of ‘above-threshold’ flows	Mean of the annual number >1 x median	20	HFNME1	12.30
		CV	20	HFNC1	0.44
	Source data are the ‘threshold’ events for record	Mean of the annual number >3 x median	20	HFNME3	6.95
		CV	20	HFNC3	0.67
		CV of the annual number >5 x median	20	HFNC5	0.67
		Mean of the annual number >9 x median	20	HFNME9	4.47
		CV	20	HFNC9	0.68
		Mean of the annual number >2 x mean	20	HFNME2M	0
		CV of annual values	20	HFNC2M	–9999.00
High flow spell analysis	Peak magnitude of ‘above-threshold’ flow	Mean peak high flows >1 x median	7300+	HFPME1	0.39
		CV	7300+	HFPC1	4.27
	Source data are the magnitudes of flow	Mean peak high flows >3 x median	7300+	HFPME3	2.35
		Mean peak high flows >9 x median	7300+	HFPME9	5.17
		CV	7300+	HFPC9	2.49
		Mean peak high flows >2 x mean	7300+	HFPC2M	51.32
High-flow spell analysis	Duration of ‘above-threshold’ flows	Mean of duration of events >1 x median	7300+	HFDME1	181.85
		CV	7300+	HFDC1	0.53
	Source data are the ‘threshold' events for record	CV of duration of events >3 x median	7300+	HFDC3	1.10
		CV of duration of events >9 x median	7300+	HFDC9	1.42
		Mean of duration of events >2 x mean	7300+	HFDME2M	9.5
High-flow spell analysis	Seasonal variation of ‘above-threshold’ flows	Season with most high-flow periods >3 x median	20	HFSS3	spring
		Proportion of high flows in above season	20	HFSSP3	0.25
	Source data are the ‘above-threshold’ events	CV number of summer high flows >3 x median	20	HFSC3	1.12
		Mean number of winter high flows >3 x median	20	HFWME3	15.75
		CV	20	HFWC3	1.12
		Season with most high-flow days >9 x median	20	HFSS9	spring
		Proportion of high flows in above season	20	HFSSP9	0.28
		Mean no. of summer high flows >9 x median	20	HFSME9	5.75
		CV	20	HFSC9	1.71
		CV number of winter high flows >9 x median	20	HFWC9	1.43
Low-flow spell analysis	Number of ‘below-threshold’ flows	Mean of the annual number < 1/2 x median	20	LFNME1	8.2
		CV of the annual number < 1/3 xmedian	20	LFNC3	1.23
	Source data are the ‘threshold’ events for record	Mean of the annual number < 1/9 x median	20	LFNME9	1.75
		CV	20	LFNC9	2.22
		Mean of the annual number < 10% of mean	20	LFNME10	13.5
		CV of annual values	20	LFNC10	0.40

Table A3.2 continued

Low-flow spell analysis	Magnitude of 'below-threshold' flow	Mean peak flow below a threshold < 1/2 median	7300+	LFPME1	0.03
	Source data are the magnitudes of flow	Mean peak flow below a threshold < 10% of mean	20	LFPME10	0.07
Low-flow spell analysis	Duration of 'below-threshold' flows	Mean of duration of events < 1/2 median	7300+	LFDME1	73.90
	Source data are the 'threshold' events for record	Mean of duration of events < 1/9 median	7300+	LFDME9	5.75
		Mean of duration of events < 10% mean	20	LFDME10	208.45
Low-flow spell analysis	Seasonal variation of 'below-threshold' flows Source data are the 'below-threshold' events	Season with most low-flow days <1/3 x median	20	LFSS3	spring
		Proportion of low flows in above season	20	LFSSP3	0.25
		Mean number of summer low-flow days	20	LFSME3	6.7
		Mean number of autumn low-flow days	20	LFAME3	10.15
		Mean number of winter low-flow days	20	LFWME3	16.15
		CV	20	LFWC3	1.58
		Mean number of spring low-flow days	20	LFSPME3	11.1
		CV	20	LFSPC3	1.64
		Season with most low-flow days <1/9 x median	20	LFSS9	winter
		Proportion of low flows in above season	20	LFSSP9	0.44
Moving average	Maximum annual moving average	CV of annual maximum daily flow	20	MAHC1	1.64
		CV of annual maximum 30 day flow	20	MAHC30	2.43
		Mean of annual maximum 90 day flow	20	MAHME90	4.02
	Minimum annual moving average	Mean of annual minimum daily flow	20	MALOME1	0.02
		CV	20	MALC1	0.73
		CV of annual minimum 90 day flow	20	MALC90	0.53
Cessation-of-flow analysis	Zero flows	Total number of zero flow days of record	20	ZEN	0
Rise and fall of the hydrograph	Number of rises and falls of the hydrograph	Mean of total number of rising limbs per year	20	RFNRME	93.75
		CV	20	RFNRC	0.15
		Mean duration of individual rising limbs for entire record	7300+	RFDRME	2.11
		Mean of total number of falling limbs per year	20	RFNFME	131.25
		Mean duration of individual falling limbs for entire record	7300+	RFDFME	3.75
		CV	7300+	RFDFC	1.32
	Magnitude of daily change in flow	Mean of +ve daily differences in flow for entire record	7300+	RFDPME	0.17
Monthly flow analysis	Monthly flows	January: Mean daily flow for entire period	240	MFJANME	0.00
		CV	240	MFJANC	1.03
		March: Mean daily flow for entire period	240	MFMARME	0.13
		CV	240	MFMARC	4.32
		May: Mean daily flow for entire period	240	MFMAYME	0.12
		June: Mean daily flow for entire period	240	MFJUNME	0.13
		August: Mean daily flow for entire period	240	MFAUGME	0.12
		September: Mean daily flow for entire period	240	MFSEPME	0.12
		October: Mean daily flow for entire period	240	MFOCTME	0.11
		November: Mean daily flow for entire period	240	MFNOVME	0.12
		CV	240	MFNOVC	4.28
		December: Mean daily flow for entire period	240	MFDECME	0.07
		CV	240	MFDECC	4.27

Table A3.2 continued

	Month in which the minimum 'mean daily flow' most frequently occurs	12	MFML	1
	Month in which the maximum 'mean daily flow' most frequently occurs	12	MFMH	2
Inter-month variability	Mean variability of inter-annual monthly CV	12	MFAVME	4.00
	CV of inter-annual monthly CV	12	MFAVC	0.25
Inter-annual monthly variability	Mean of annual values of inter-month CV	20	MFMVME	0.40
	CV of annual values of inter-month CV	20	MFMVC	0.80

Appendix 4: List of hydrological variables used in this study that are identical to those used in other studies

Short name of hydrological variable in present study	Other studies that used this variable	Short name of hydrological variable in present study	Other studies that used this variable
LTMIN	1, 2, 6	ZEN	2, 4, 5
LTMAX	2, 6	ZEP	5
LTQ90	1	RFNRMED	6
LTQ10	1	RFNFMED	6
LTMED	1, 2	RFDFMED	5
LTMEAN	3, 4, 6	RFDPMED	6
LTSKEW	1, 3, 5	RFDNMED	6
LTBFI	2, 3	MFJANME	6
LTFFI	1	MFFEBME	6
HFNMED1	1	MFMARME	6
HFNMED3	1	MFAPRME	6
HFNMED5	1	MFMAYME	6
HFNMED7	1	MFJUNME	6
HFNMED9	1	MFJULME	6
HFPMED1	1	MFAUGME	6
HFPMED3	1	MFSEPME	6
HFPMED5	1	MFOCTME	6
HFPMED7	1	MFNOVME	6
HFPMED9	1	MFDECME	6
HFDMED1	1	MFAVV	5
HFDMED3	1	MFMVV	5
HFDMED5	1		
HFDMED7	1		
HFDMED9	1		
MAHMED1	6		
MAHMED30	6		
MAHMED90	6		
MALMED1	6		
MALME30	6		
MALME90	6		

1. Clausen & Biggs (1997); 2. Growns & Growns (1997); 3. Nathan & Weinmann (1993);
4. Poff & Ward (1989); 5. Puckridge, Sheldon, Walker & Boulton (1998);
6. Richter, Baumgartner, Wigington & Braun (1997).

Appendix 5: Correlations from PCC

Table A5.1: Correlations from PCC for permanent and intermittent stations
(*R* = correlation coefficient; *P* values from 500 Monte Carlo randomisations; ns = not significant)

Descriptor	*R*	*P*	Descriptor	*R*	*P*
LTMAX	0.3818	<0.002	HFWC3	0.4968	<0.002
LTQ90	0.4768	<0.002	HFSS9	0.6158	<0.002
LTMEAN	0.5523	<0.002	HFSSP9	0.4689	<0.002
LTSKEW	0.6087	<0.002	HFSME9	0.8339	<0.002
LT2ARI	0.7346	<0.002	HFSC9	0.6958	<0.002
LTBFI	0.7492	<0.002	HFWC9	0.6202	<0.002
LTSFD	0.8318	<0.002	LFNME1	0.353	0.002
HFNME1	0.378	<0.002	LFNC3	0.6361	<0.002
HFNC1	0.1767	ns	LFNME9	0.0823	ns
HFNME3	0.5752	<0.002	LFNC9	0.6569	<0.002
HFNC3	0.3632	<0.002	LFNME10	0.2524	0.03
HFNC5	0.5199	<0.002	LFNC10	0.3974	<0.002
HFNME9	0.6561	<0.002	LFPME1	0.8563	<0.002
HFNC9	0.5067	<0.002	LFPME10	0.818	<0.002
HFNME2M	0.5653	<0.002	LFDME1	0.1974	ns
HFNC2M	0.1121	ns	LFDME9	0.2487	0.036
HFPME1	0.2987	0.008	LFSS3	0.7902	<0.002
HFPC1	0.4821	<0.002	LFSSP3	0.5591	<0.002
HFPME3	0.3024	0.008	LFSME3	0.7176	<0.002
HFPME9	0.5929	<0.002	LFAME3	0.6543	<0.002
HFPC9	0.5445	<0.002	LFWME3	0.8176	<0.002
HFPC2M	0.57	<0.002	LFWC3	0.5624	<0.002
HFDME1	0.4562	<0.002	LFSPME3	0.8696	<0.002
HFDC1	0.1977	ns	LFSPC3	0.6876	<0.002
HFDC3	0.5244	<0.002	LFSS9	0.7627	<0.002
HFDC9	0.6158	<0.002	LFSSP9	0.5645	<0.002
HFDME2M	0.4344	<0.002	MAHC1	0.246	0.036
HFSS3	0.6263	<0.002	MAHC30	0.3552	<0.002
HFSSP3	0.5099	<0.002	MAHME90	0.8623	<0.002
HFSC3	0.5391	<0.002	MALOME1	0.7227	<0.002
HFWME3	0.7113	<0.002	MALC1	0.7248	<0.002
MALC90	0.764	<0.002	MFJUNME	0.2554	0.028

Table A5.1 continued

Descriptor	*R*	*P*	Descriptor	*R*	*P*
ZEN	0.7602	<0.002	MFAUGME	0.3893	<0.002
RFNRME	0.7108	<0.002	MFSEPME	0.3468	<0.002
RFNRC	0.6542	<0.002	MFOCTME	0.4004	<0.002
RFDRME	0.6397	<0.002	MFNOVME	0.2146	ns
RFNFME	0.6867	<0.002	MFNOVC	0.6979	<0.002
RFDFME	0.5203	<0.002	MFDECME	0.7339	<0.002
RFDFC	0.5741	<0.002	MFDECC	0.7256	<0.002
RFDPME	0.5455	<0.002	MFML	0.3988	<0.002
RFDPC2	0.3676	<0.002	MFMH	0.0874	ns
MFJANME	0.4488	<0.002	MFAVME	0.6936	<0.002
MFJANC	0.5302	<0.002	MFAVC	0.5744	<0.002
MFMARME	0.1244	ns	MFMVME	0.6746	<0.002
MFMARC	0.515	<0.002	MFMVC	0.0674	ns
MFMAYME	0.4845	<0.002			

Table A5.2. Correlations from PCC for permanently flowing stations

(*R* = correlation coefficient; *P* values from 500 Monte Carlo randomisations; ns = not significant)

Descriptor	*R*	*P*	Descriptor	*R*	*P*
LTMAX	0.4253	<0.002	HFWC3	0.496	<0.002
LTQ90	0.5199	<0.002	HFSS9	0.3114	0.006
LTMEAN	0.6427	<0.002	HFSSP9	0.4837	<0.002
LTSKEW	0.6722	<0.002	HFSME9	0.7609	<0.002
LT2ARI	0.7709	<0.002	HFSC9	0.6846	<0.002
LTBFI	0.8988	<0.002	HFWC9	0.6332	<0.002
LTSFD	0.8614	<0.002	LFNME1	0.1345	ns
HFNME1	0.2255	ns	LFNC3	0.6746	<0.002
HFNC1	0.0835	ns	LFNME9	0.5227	<0.002
HFNME3	0.6084	<0.002	LFNC9	0.689	<0.002
HFNC3	0.4787	<0.002	LFNME10	0.5094	<0.002
HFNC5	0.5244	<0.002	LFNC10	0.6853	<0.002
HFNME9	0.7639	<0.002	LFPME1	0.8746	<0.002
HFNC9	0.4404	0.002	LFPME10	0.7539	<0.002
HFNME2M	0.4787	<0.002	LFDME1	0.7997	<0.002
HFNC2M	0.2263	ns	LFDME9	0.7809	<0.002
HFPME1	0.2548	ns	LFSS3	0.7146	<0.002
HFPC1	0.6571	<0.002	LFSSP3	0.4061	<0.002
HFPME3	0.4163	<0.002	LFSME3	0.6433	<0.002
HFPME9	0.5633	<0.002	LFAME3	0.6748	<0.002
HFPC9	0.7959	<0.002	LFWME3	0.7326	<0.002
HFPC2M	0.7263	<0.002	LFWC3	0.6035	<0.002
HFDME1	0.2822	0.02	LFSPME3	0.7775	<0.002
HFDC1	0.2284	ns	LFSPC3	0.6849	<0.002
HFDC3	0.4849	<0.002	LFSS9	0.6106	<0.002
HFDC9	0.5613	<0.002	LFSSP9	0.4622	<0.002
HFDME2M	0.5714	<0.002	MAHC1	0.2005	ns
HFSS3	0.3567	0.002	MAHC30	0.3476	0.004
HFSSP3	0.5158	<0.002	MAHME90	0.83	<0.002
HFSC3	0.5153	<0.002	MALOME1	0.8284	<0.002
HFWME3	0.6132	<0.002	MALC1	0.6968	<0.002
MALC90	0.496	<0.002	MFJUNME	0.2861	0.026
ZEN	0.5865	<0.002	MFAUGME	0.406	<0.002
RFNRME	0.5326	<0.002	MFSEPME	0.3738	0.004
RFNRC	0.4917	<0.002	MFOCTME	0.4078	<0.002

Table A5.2 continued

Descriptor	*R*	*P*	Descriptor	*R*	*P*
RFDRME	0.52	<0.002	MFNOVME	0.2228	ns
RFNFME	0.559	<0.002	MFNOVC	0.7286	<0.002
RFDFME	0.4898	<0.002	MFDECME	0.6575	<0.002
RFDFC	0.4865	<0.002	MFDECC	0.7026	<0.002
RFDPME	0.8015	<0.002	MFML	0.272	0.022
RFDPC2	0.464	<0.002	MFMH	0.2774	0.02
MFJANME	0.4425	<0.002	MFAVME	0.791	<0.002
MFJANC	0.5456	<0.002	MFAVC	0.5321	<0.002
MFMARME	0.1848	ns	MFMVME	0.6995	<0.002
MFMARC	0.5619	<0.002	MFMVC	0.1675	ns
MFMAYME	0.4924	<0.002			

Appendix 6: Group statistics from GSTA

Table A6.1: Group statistics from GSTA for permanent and intermittent stations

(Group 1 = intermittent stations, Group 2 = permanent stations; St. Dev. = standard deviation; *P* values are from the Kruskal–Wallis test and should be used as a guide only)

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
LTQ90	1	0.0	0.0	0.0	0.0	0.0000
	2	0.0	2191.0	98.1	295.7	
LTBFI	1	0.10	0.61	0.33	0.12	0.0469
	2	0.13	0.79	0.41	0.14	
LTSFD	1	–0.110	–0.030	–0.058	0.021	0.0000
	2	–0.040	–0.010	–0.019	0.008	
HFNME1	1	0.00	18.60	4.32	4.14	0.0000
	2	2.37	25.05	7.50	3.57	
HFNME3	1	0.00	16.95	4.32	3.70	0.0001
	2	0.00	13.90	6.74	2.72	
HFNME9	1	0.00	12.40	3.98	2.63	0.0094
	2	0.00	11.45	5.18	2.60	
HFNC9	1	0.360	0.680	0.459	0.086	0.0121
	2	0.270	0.910	0.548	0.129	
HFNME2M	1	0.00	7.00	2.86	1.81	0.0001
	2	0.00	12.00	5.67	2.55	
HFPME1	1	0.22	19.49	2.93	4.69	0.0174
	2	0.46	2.25	1.10	0.39	
HFPME3	1	0.22	19.49	3.44	4.66	0.0228
	2	0.87	9.80	3.45	1.44	
HFPME9	1	0.22	19.49	4.25	4.71	0.0000
	2	1.66	25.49	8.82	4.34	
HFPC2M	1	0.0	775.1	190.8	215.6	0.0004
	2	1.8	122.2	23.1	25.0	
HFDME1	1	176.4	231.8	190.6	15.0	0.0007
	2	162.1	194.8	178.5	5.1	
HFDC9	1	0.31	0.65	0.56	0.10	0.0005
	2	0.38	1.40	0.76	0.20	
HFSS3	1	1.00	4.00	2.07	1.28	0.0000
	2	1.00	4.00	3.69	0.72	
HFSSP3	1	0.26	0.41	0.31	0.04	0.0262
	2	0.25	0.80	0.35	0.07	
HFSC3	1	0.35	0.98	0.56	0.17	0.0005
	2	0.38	2.75	0.81	0.33	
HFWME3	1	15.70	49.15	35.30	9.23	0.0334
	2	0.05	50.95	29.38	10.54	

Table A6.1 continued

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
HFSS9	1	1.00	4.00	1.86	1.19	0.0000
	2	1.00	4.00	3.55	0.86	
HFSSP9	1	0.27	0.43	0.32	0.04	0.0339
	2	0.23	1.00	0.36	0.11	
HFSME9	1	15.55	54.00	30.91	11.51	0.0000
	2	0.00	26.30	5.22	5.10	
HFSC9	1	0.35	1.10	0.65	0.21	0.0000
	2	0.50	3.52	1.20	0.48	
HFWC9	1	0.52	1.49	0.89	0.26	0.0229
	2	0.44	2.23	1.12	0.35	
LFNME1	1	0.0	2.3	0.5	0.9	0.0000
	2	1.7	22.4	5.9	3.2	
LFNME9	1	0.0	2.4	0.2	0.6	0.0000
	2	0.0	14.0	2.3	2.1	
LFNME10	1	0.0	5.0	1.1	1.4	0.0000
	2	0.1	17.7	4.8	3.1	
LFNC10	1	0.55	1.78	1.14	0.38	0.0111
	2	0.25	4.47	0.81	0.56	
LFPME10	1	0.010	0.030	0.021	0.008	0.0000
	2	0.030	0.100	0.062	0.015	
LFDME1	1	0.0	162.2	27.7	55.9	0.0000
	2	11.9	156.4	113.5	27.9	
LFDME9	1	0.0	112.9	12.1	31.4	0.0000
	2	0.0	113.4	34.3	29.4	
LFSS3	1	2.00	4.00	3.27	0.96	0.0000
	2	1.00	4.00	1.77	0.78	
LFSSP3	1	0.270	0.410	0.310	0.039	0.0002
	2	0.260	0.530	0.385	0.058	
LFSME3	1	16.7	48.6	34.4	9.2	0.0287
	2	0.6	52.7	26.0	12.2	
LFAME3	1	27.0	62.5	41.5	9.5	0.0010
	2	0.4	52.5	28.0	11.6	
LFWME3	1	28.2	60.6	42.3	7.6	0.0000
	2	0.1	57.1	16.2	12.1	
LFWC3	1	0.21	1.07	0.70	0.21	0.0155
	2	0.31	4.47	1.10	0.60	
LFSPME3	1	18.15	52.50	42.66	9.75	0.0000
	2	0.35	39.05	14.58	7.95	
LFSPC3	1	0.37	0.99	0.65	0.17	0.0001
	2	0.46	2.77	1.17	0.48	
LFSS9	1	2.00	4.00	3.27	0.96	0.0000
	2	1.00	4.00	1.67	0.95	
LFSSP9	1	0.27	0.43	0.31	0.05	0.0000
	2	0.29	1.00	0.46	0.13	

Table A6.1 continued

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
MAHME90	1	2.58	4.64	3.63	0.53	0.0000
	2	1.37	3.91	2.66	0.42	
MALOME1	1	0.000	0.080	0.006	0.021	0.0000
	2	0.000	0.260	0.050	0.053	
MALC1	1	2.02	4.29	3.12	0.72	0.0006
	2	0.30	3.24	1.12	0.66	
MALC90	1	1.55	4.47	2.41	0.85	0.0000
	2	0.23	3.25	0.93	0.48	
ZEN	1	1871	5010	3115	819	0.0000
	2	0	1296	124	234	
RFNRME	1	0.8	67.0	38.9	15.3	0.0000
	2	54.3	116.6	81.9	13.4	
RFNRC	1	0.24	1.93	0.64	0.42	0.0000
	2	0.07	0.38	0.15	0.06	
RFDRME	1	1.9	14.7	5.5	3.1	0.0002
	2	1.7	12.1	2.8	1.7	
RFNFME	1	43.8	119.0	96.0	22.9	0.0000
	2	96.2	162.1	139.7	13.1	
RFDFME	1	3.9	218.0	40.1	51.7	0.0000
	2	2.5	20.4	5.8	3.1	
RFDFC	1	0.89	4.07	1.69	0.72	0.0000
	2	0.72	2.16	0.99	0.21	
MFJANC	1	1.04	4.11	2.24	1.04	0.0014
	2	0.34	3.61	1.36	0.65	
MFMARC	1	1.05	4.13	2.33	1.06	0.0060
	2	0.31	4.30	1.54	0.90	
MFNOVC	1	0.99	4.04	2.66	0.86	0.0006
	2	0.31	4.08	1.73	0.79	
MFDECC	1	0.80	4.23	2.33	1.01	0.0001
	2	0.25	3.48	1.25	0.65	
MFAVME	1	0.99	3.82	2.43	0.84	0.0005
	2	0.32	2.91	1.56	0.61	
MFAVC	1	0.040	0.390	0.197	0.123	0.0081
	2	0.050	0.710	0.311	0.143	
MFMVME	1	0.45	2.04	1.26	0.40	0.0000
	2	0.11	1.76	0.57	0.30	

Table A6.2. Group statistics from GSTA for 73 Cf and 20 BS stations using the Köppen climate classes

(Group 1 = Cf stations, Group 2 = BS stations; St. Dev. = standard deviation; *P* values are from the Kruskal–Wallis test and should be used as a guide only)

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
LTMAX	1	296	44050	67640	369000	0.0008
	2	2847	108100	80390	244000	
LTMEAN	1	2	1155	2674	15550	0.0001
	2	53	2965	2376	8831	
LTSKEW	1	0.85	4.16	2.88	14.69	0.0076
	2	0.92	8.34	7.89	30.54	
LT2ARI	1	2.1	22.8	14.7	72.7	0.0030
	2	1.7	13.6	12.3	49.9	
LTSFD	1	–0.040	–0.018	0.007	–0.010	0.0054
	2	–0.040	–0.025	0.010	–0.010	
HFNME1	1	3.05	7.72	3.46	25.05	0.0346
	2	2.37	6.69	3.84	17.75	
HFNME3	1	0.00	7.14	2.47	12.85	0.0018
	2	0.00	5.25	3.02	13.90	
HFNME9	1	0.00	5.59	2.52	11.45	0.0014
	2	0.00	3.67	2.33	8.35	
HFNME2M	1	0.00	6.28	2.40	12.00	0.0000
	2	0.00	3.43	1.68	8.00	
HFPME3	1	1.29	3.68	1.45	9.80	0.0001
	2	0.87	2.58	0.99	5.92	
HFPME9	1	2.9	9.6	4.3	25.5	0.0000
	2	1.7	5.8	3.0	14.4	
HFDME1	1	162	177	5	195	0.0000
	2	174	183	4	191	
HFDC1	1	0.18	0.47	0.15	1.05	0.0473
	2	0.26	0.56	0.18	0.94	
HFSS3	1	2	3.85	0.49	4	0.0000
	2	1	3.05	1.05	4	
HFSSP3	1	0.260	0.362	0.073	0.800	0.0000
	2	0.250	0.293	0.029	0.360	
HFSS9	1	2.00	3.74	0.65	4.00	0.0001
	2	1.00	2.84	1.14	4.00	
HFSSP9	1	0.23	0.38	0.12	1.00	0.0003
	2	0.25	0.31	0.05	0.41	
HFSME9	1	0.0	3.6	2.6	11.4	0.0000
	2	1.5	11.3	7.1	26.3	
LFNC9	1	0.45	1.48	0.86	4.47	0.0211
	2	0.47	1.09	0.81	4.47	

Table A6.2 continued

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
LFNC10	1	0.36	0.87	0.60	4.47	0.0134
	2	0.25	0.59	0.30	1.65	
LFPME1	1	0.020	0.110	0.061	0.310	0.0031
	2	0.010	0.074	0.076	0.350	
LFPME10	1	0.030	0.066	0.013	0.100	0.0000
	2	0.030	0.049	0.014	0.080	
LFDME1	1	12	111	28	148	0.0485
	2	57	123	26	156	
LFDME9	1	0.00	31.15	28.60	113.40	0.0424
	2	0.35	45.57	29.49	98.00	
LFSS3	1	1	1.63	0.65	3	0.0037
	2	1	2.30	0.95	4	
LFSSP3	1	0.290	0.396	0.051	0.530	0.0012
	2	0.260	0.345	0.063	0.480	
LFWME3	1	0.10	13.95	11.19	54.55	0.0001
	2	5.85	24.36	11.66	57.10	
LFSPME3	1	0.35	12.53	5.91	25.75	0.0000
	2	2.65	22.07	9.74	39.05	
LFSPC3	1	0.46	1.23	0.50	2.77	0.0165
	2	0.49	0.97	0.34	2.05	
LFSS9	1	1	1.46	0.77	4	0.0003
	2	1	2.40	1.16	4	
LFSSP9	1	0.310	0.478	0.139	1.000	0.0031
	2	0.290	0.389	0.084	0.570	
MAHC30	1	0.12	0.69	0.24	1.35	0.0016
	2	0.13	0.88	0.24	1.36	
MAHME90	1	1.7	2.6	0.3	3.3	0.0081
	2	1.4	2.9	0.6	3.9	
MALOME1	1	0.000	0.056	0.053	0.260	0.0013
	2	0.000	0.026	0.043	0.160	
MALC1	1	0.30	1.01	0.59	3.11	0.0006
	2	0.75	1.53	0.74	3.24	
MALC90	1	0.23	0.83	0.39	1.65	0.0003
	2	0.44	1.30	0.61	3.25	
RFNRME	1	57	81	13	117	0.0342
	2	54	85	14	108	
RFNRC	1	0.070	0.136	0.043	0.290	0.0000
	2	0.100	0.204	0.075	0.380	
RFDRME	1	1.65	2.20	0.29	2.96	0.0000
	2	2.08	5.04	2.61	12.14	
RFNFME	1	122	144	10	162	0.0000
	2	96	124	12	151	
RFDFME	1	2.5	5.0	1.2	8.1	0.0004

Table A6.2 continued

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
	2	3.6	9.0	5.2	20.4	
RFDFC	1	0.720	0.973	0.235	2.160	0.0004
	2	0.870	1.046	0.100	1.270	
RFDPME	1	0.070	0.659	0.377	1.620	0.0000
	2	0.040	0.319	0.327	1.280	
MFJUNME	1	0.010	0.035	0.037	0.220	0.0477
	2	0.010	0.021	0.008	0.040	
MFAUGME	1	0.010	0.040	0.031	0.160	0.0027
	2	0.010	0.020	0.007	0.040	
MFSEPME	1	0.010	0.031	0.018	0.110	0.0239
	2	0.000	0.022	0.011	0.050	
MFOCTME	1	0.010	0.025	0.011	0.050	0.0188
	2	0.000	0.019	0.011	0.060	
MFNOVME	1	0.010	0.031	0.026	0.200	0.0070
	2	0.010	0.021	0.013	0.070	
MFML	1	1.0	10.6	3.4	12.0	0.0482
	2	1.0	10.1	3.5	12.0	
MFAVC	1	0.100	0.350	0.127	0.710	0.0000

Table A6.3: Group statistics from GSTA for 9 irrigation and 10 unregulated stations from the Cfa Köppen climate class

(Group 1 = irrigation stations, Group 2 = unregulated stations; St. Dev. = standard deviation; *P* values are from the Kruskal–Wallis test and should be used as a guide only)

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
LTMAX	1	8903	369000	136000	107800	0.0006
	2	668	14780	6404	4307	
LTQ90	1	1	2191	614	747	0.0025
	2	0	20	4	6	
LTMEAN	1	171	15550	5913	5292	0.0004
	2	19	301	115	85	
LT2ARI	1	2.88	19.62	9.42	6.02	0.0055
	2	11.47	42.56	22.63	9.32	
LTBFI	1	0.350	0.700	0.534	0.128	0.0220
	2	0.270	0.510	0.387	0.091	
HFNME3	1	1.89	9.65	5.24	2.53	0.0411
	2	4.58	11.47	7.61	2.29	
HFNC3	1	0.400	0.590	0.514	0.065	0.0032
	2	0.260	0.530	0.387	0.078	
HFNC5	1	0.36	1.00	0.62	0.19	0.0047
	2	0.27	0.48	0.41	0.07	
HFNME9	1	0.00	5.84	2.60	2.44	0.0014
	2	5.21	9.60	7.31	1.65	
HFNME2M	1	2.00	8.00	4.00	1.70	0.0010
	2	6.00	12.00	8.35	1.82	
HFNC2M	1	0.50	0.71	0.56	0.07	0.0245
	2	0.27	0.60	0.46	0.09	
HFDC3	1	0.41	1.40	0.85	0.29	0.0055
	2	0.21	0.68	0.45	0.13	
HFSC3	1	0.57	2.75	1.25	0.68	0.0070
	2	0.39	0.87	0.62	0.11	
HFWC3	1	0.49	2.15	1.23	0.58	0.0037
	2	0.34	0.73	0.48	0.11	
HFSSP9	1	0.33	1.00	0.55	0.26	0.0123
	2	0.23	0.41	0.33	0.05	
HFWC9	1	0.65	1.95	1.32	0.47	0.0227
	2	0.44	1.00	0.72	0.16	
LFSS3	1	1.00	3.00	2.33	0.67	0.0152
	2	1.00	2.00	1.50	0.50	
LFSME3	1	4.95	47.70	18.14	13.92	0.0071
	2	15.70	51.45	37.71	9.33	
LFWME3	1	8.55	50.00	24.69	15.60	0.0222
	2	4.10	15.75	10.33	3.58	

Table A6.3 continued

Variable	Group	Minimum	Maximum	Mean	St. Dev.	*P*
LFSS9	1	1.00	3.00	2.11	0.87	0.0216
	2	1.00	2.00	1.20	0.40	
MAHME90	1	1.65	3.26	2.37	0.51	0.0411
	2	2.20	3.34	2.90	0.35	
MALC1	1	0.37	1.65	0.85	0.36	0.0412
	2	0.74	2.74	1.36	0.61	
ZEN	1	0	88	15	30	0.0096
	2	0	1296	271	409	
RFNRME	1	80	110	99	10	0.0055
	2	68	86	80	6	
RFDRME	1	2.00	2.96	2.53	0.28	0.0029
	2	1.80	2.38	2.07	0.14	
RFNFME	1	123	148	130	7	0.0033
	2	132	148	142	6	
RFDFME	1	2.87	5.27	3.72	0.69	0.0071
	2	4.14	6.55	4.77	0.79	
RFDPME	1	0.07	0.50	0.23	0.14	0.0004
	2	0.45	1.20	0.75	0.25	
MFJANME	1	0.000	0.030	0.022	0.010	0.0392
	2	0.010	0.020	0.014	0.005	
MFMARC	1	0.31	1.99	0.85	0.59	0.0411
	2	0.58	3.13	1.64	0.86	
MFMAYME	1	0.010	0.040	0.023	0.009	0.0494
	2	0.010	0.020	0.015	0.005	
MFAUGME	1	0.010	0.090	0.033	0.023	0.0450
	2	0.010	0.030	0.016	0.007	
MFSEPME	1	0.010	0.110	0.038	0.027	0.0078
	2	0.010	0.020	0.016	0.005	
MFOCTME	1	0.010	0.040	0.028	0.010	0.0209
	2	0.010	0.040	0.016	0.009	
MFNOVC	1	0.31	2.11	1.02	0.58	0.0338
	2	0.86	3.87	1.92	1.00	
MFDECME	1	0.000	0.040	0.024	0.015	0.0136
	2	0.000	0.020	0.007	0.006	
MFML	1	1.00	12.00	6.11	5.09	0.0029
	2	12.00	12.00	12.00	0.00	
MFAVME	1	0.32	1.96	0.95	0.59	0.0336
	2	0.97	2.45	1.50	0.47	
MFAVC	1	0.100	0.650	0.232	0.165	0.0141
	2	0.260	0.580	0.383	0.098	
MFMVME	1	0.14	1.76	0.47	0.47	0.0222
	2	0.39	0.82	0.56	0.13	

OTHER PUBLICATIONS OF

The Cooperative Research Centre for Freshwater Ecology

The Cooperative Research Centre for Freshwater Ecology publishes a range of books, guidelines, newsletters, technical reports and brochures. These publications can be ordered from the Cooperative Research Centre for Freshwater Ecology at its Albury centre, by phoning 02 6058 2310, or by email to enquiries@mdfrc.canberra.edu.au.

Many reports are also available on our web site at http://freshwater.canberra.edu.au

Books

CRC for Freshwater Ecology. 1997. *Living on Floodplains*. Limited copies available.

Brochures

- Billabongs, floodplains and river health
- Chaffey Dam project
- Effects of a drying phase on the ecology of Menindee Lakes
- Environmental flows for the Campaspe River
- Lowland rivers
- Providing an ecological basis for the sustainable management of Menindee Lakes
- Rivers and fish in stress
- Snags: a valuable but scarce resource
- Sustainable rivers: the Cap and environmental flows

Guidelines

Lawrence, I. & Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands.*

Identification Guides

The CRC for Freshwater Ecology sells 31 different Identification Guides to the Invertebrates of Australian Inland waters, including:

Hawking, J. & Smith, F. 1997. *Colour Guide to Invertebrates of Australian Inland Waters.*
ID Guide no. 8. ($24.00)

Technical reports

CRC for Freshwater Ecology. 1996. *Managing Collaboration for Scientific Excellence.*

Cottingham, P. 1999. *Scientific Forum on River Condition and Flow Management of the Moonie, Warrego, Paroo, Bulloo and Nebine River Basins.*

Cottingham P., Whittington J. & Hillman, T. 1999. *Riverine Management and Rehabilitation Scoping Study.*

Cullen, P., Whittington, J. & Fraser, G. 2000. *Likely Ecological Outcomes of the COAG Water Reforms*. Also on the Web at http://freshwater.canberra.edu.au (then click Publications; then click Technical Reports)

Lawrence, I. 2000. *Factors Determining Algal Growth and Composition in Reservoirs*. Available only on the Web at: http://nemp.aus.net

Ransom, G., Morgan, P., Cullen, P., Allen, D., Sinclair, D. & McGregor, D. 1998. *The Effect of Sewage Phosphorus Loads Using Phosphorus-free Laundry Detergent. Thurgoona Case Study*.

Reid, D., Harris, J. & Chapman, D. 1997. *NSW Inland Commercial Fisheries Data Analysis*.

Scholz, O., Gawne, B., Ebner, B., Ellis, I., Betts, F. & Meredith, S. 1999. *The Impact of Drying on the Ecology of Menindee Lakes*.

Sheldon, F. 1999. *Spencer Regions Strategic Water Management Study*.

Thoms, M.C. 1998. *The Condition of the Namoi River System*.

Thorncraft, G. & Harris, J.H. 2000. *Fish Passage and Fishways in New South Wales: A Status Report*. Technical report no. 1/2000.

Whittington, J. 2000. *Technical Review of Elements of the WAMP Process of the Queensland DNR*.