Australian Rainfall & Runoff

Revision Projects

PROJECT 5

Regional Flood Methods

STAGE 3 REPORT

P5/S3/025

MARCH 2015

Australian Government

ENGINEERS AUSTRALIA
Water Engineering

AUSTRALIAN RAINFALL AND RUNOFF
PROJECT 5: REGIONAL FLOOD METHODS: STAGE 3 REPORT

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FOREWORD

ARR Revision Process

Since its first publication in 1958, Australian Rainfall and Runoff (ARR) has remained one of the most influential and widely used guidelines published by Engineers Australia (EA). The current edition, published in 1987, retained the same level of national and international acclaim as its predecessors.

With nationwide applicability, balancing the varied climates of Australia, the information and the approaches presented in Australian Rainfall and Runoff are essential for policy decisions and projects involving:

- infrastructure such as roads, rail, airports, bridges, dams, stormwater and sewer systems;
- town planning;
- mining;
- developing flood management plans for urban and rural communities;
- flood warnings and flood emergency management;
- operation of regulated river systems; and
- estimation of extreme flood levels.

However, many of the practices recommended in the 1987 edition of ARR are now becoming outdated, no longer representing the accepted views of professionals, both in terms of technique and approach to water management. This fact, coupled with greater understanding of climate and climatic influences makes the securing of current and complete rainfall and streamflow data and expansion of focus from flood events to the full spectrum of flows and rainfall events, crucial to maintaining an adequate knowledge of the processes that govern Australian rainfall and streamflow in the broadest sense, allowing better management, policy and planning decisions to be made.

One of the major responsibilities of the National Committee on Water Engineering of Engineers Australia is the periodic revision of ARR. A recent and significant development has been that the revision of ARR has been identified as a priority in the Council of Australian Governments endorsed National Adaptation Framework for Climate Change.

The update will be completed in three stages. Twenty one revision projects have been identified and will be undertaken with the aim of filling knowledge gaps. Of these 21 projects, ten projects commenced in Stage 1 and an additional 9 projects commenced in Stage 2. The remaining two projects will commence in Stage 3. The outcomes of the projects will assist the ARR Editorial Team with the compiling and writing of chapters in the revised ARR.

Steering and Technical Committees have been established to assist the ARR Editorial Team in guiding the projects to achieve desired outcomes. Funding for Stages 1 and 2 of the ARR revision projects has been provided by the Federal Department of Climate Change and Energy Efficiency. Funding for Stages 2 and 3 of Project 1 (Development of Intensity-Frequency-Duration information across Australia) has been provided by the Bureau of Meteorology.

Project 5: Regional Flood Methods

The most commonly encountered hydrological problem associated with estimating flood flows is that of estimating the flood flow of a given Annual Exceedence Probability (AEP) at a location where no historical monitored information exists. Numerous alternative techniques have been developed in the different regions (primarily, the states) of Australia to provide flow estimates in ungauged catchments. The current diversity of approaches has resulted in predicted flows varying significantly at the interfaces between regions. There is a need to develop generic techniques that can be applied across the country, to test these techniques, and to develop appropriate guidance in their usage.

The aim of Project 5 is to collate techniques and guidelines for peak flow estimation at ungauged sites across Australia.

Mark Babister
Chair Technical Committee for ARR Research Projects

Dr James Ball
ARR Editor

ARR REVISION PROJECTS

The 21 ARR revision projects are listed below:

ARR Project No.	Project Title	Starting Stage
1	Development of intensity-frequency-duration information across Australia	1
2	Spatial patterns of rainfall	2
3	Temporal pattern of rainfall	2
4	Continuous rainfall sequences at a point	1
5	**Regional flood methods**	**1**
6	Loss models for catchment simulation	2
7	Baseflow for catchment simulation	1
8	Use of continuous simulation for design flow determination	2
9	Urban drainage system hydraulics	1
10	Appropriate safety criteria for people	1
11	Blockage of hydraulic structures	1
12	Selection of an approach	2
13	Rational Method developments	1
14	Large to extreme floods in urban areas	3
15	Two-dimensional (2D) modelling in urban areas.	1
16	Storm patterns for use in design events	2
17	Channel loss models	2
18	Interaction of coastal processes and severe weather events	1
19	Selection of climate change boundary conditions	3
20	Risk assessment and design life	2
21	IT Delivery and Communication Strategies	2

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- Department of Primary Industries, Parks, Water and Environment, Tasmania
- Department of Transport and Main Roads, Queensland
- Department of Water, WA
- Hydro Tasmania, Tasmania
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Executive Summary

To upgrade the Regional Flood Frequency Estimation (RFFE) method in Australian Rainfall and Runoff (ARR) as a part of ARR *Project 5 Regional Flood Methods*, a project team undertook extensive data collation and modelling tasks during 2006 to 2014. The principal objectives of ARR Project 5 were to collate a quality controlled national database and to develop a new RFFE technique based on the collated database for the new ARR (4th edition). ARR Project 5 has been completed in three stages. Stage 1 and Stage 2 reports (Rahman et al., 2009; 2012) contained details of initial investigations in relation to the development of a national database and testing of different regional flood estimation methods to select a method for inclusion in the ARR (4th edition). This report summarises the analyses and outcomes from Project 5 Stage 3 (final stage), which forms the basis of a new RFFE technique for Australia known as 'RFFE Technique 2015'.

The data from 853 gauged catchments in Australia have been used in Stage 3 to develop and test RFFE Technique 2015. Australia has been divided into data-rich and arid (data-poor) areas. There are 798 gauged catchments in the data-rich areas and 55 gauged catchments in the data-poor areas.

In flood frequency analysis, the newly developed Multiple Grubbs-Beck (MGB) test has been adopted to detect Potentially Influential Low Flows (PILFs). It has been found that the MGB test identifies a greater number of PILFs than the original Grubbs-Beck test. The outcome from the MGB test is found to be consistent with the judgement of experienced hydrologists who often adopt an interactive censoring in flood frequency analysis.

For each of the selected gauged catchments, flood quantiles are estimated for 6 annual exceedance probabilities (AEPs), which are 50%, 20%, 10%, 5%, 2% and 1%. For the data-rich areas, flood quantiles are estimated from the annual maximum flood series data using FLIKE software adopting an LP3 distribution and Bayesian parameter estimation procedure. For the data-poor areas, partial duration series data (considering average number of events per year = 0.5) is used to estimate flood quantiles by a Generalised Pareto distribution and L moments procedure.

In the application of RFFE Technique 2015, the data-rich areas of Australia have been divided into five different regions. The data-poor areas have been divided into two different regions. The boundaries between the data-rich and data-poor regions are drawn approximately based on the 500 mm mean annual rainfall contour line. To reduce the effects of sharp variation in quantile estimates for the ungauged catchments located close to these regional boundaries, six fringe zones have been delineated.

For the data-rich regions, a region-of-influence approach has been adopted to define a sub-region for each of the 798 gauged sites. A Bayesian generalised least squares (GLS) regression approach has been adopted to develop prediction equations for three parameters/moments of the LP3 distribution (parameter regression technique). These prediction equations require two to three predictor variables (catchment area, design rainfall intensity (Bureau of Meteorology 2013 design rainfall data at catchment centroid) and shape factor). These prediction equations largely satisfy the assumptions of the regression analysis.

For the two arid regions, an index type approach has been applied where 10% AEP flood quantile has been used as the index variable. The prediction equation for the index variable has been developed based on a fixed-region approach using an ordinary least squares regression. These prediction equations require two predictor variables (catchment area and design rainfall intensity).

A leave-one-out validation approach has been adopted to assess the performance of the RFFE Technique 2015. Based on this, it has been found that for AEPs of 50% to 1%, the median relative error values (with respect to at-site flood frequency analysis results) for the RFFE Technique 2015 range from 33% to 69% for the data-rich regions and 35% to 67% for the arid regions. The distributions of median relative error values for small and medium catchment sizes (in the model dataset) have been found to be similar. Also, no relationship has been found between relative error and catchment size. However, the applicability of the RFFE Technique to very small catchments (beyond the lower limit of the model catchments) could not be checked due to unavailability of gauged streamflow data for these catchments.

The coefficients of the developed regression equations at each of the 798 gauged locations and for the two arid regions are estimated, stored and embedded in a computer-based application tool (called RFFE Model 2015). The user is required to enter simple input data like latitude, longitude, catchment area and design rainfall intensity for the ungauged catchment of interest. The RFFE Model 2015 then generates design flood estimates and 90% confidence limits for AEPs of 50%, 20%, 10%, 5%, 2% and 1%. The output also includes a set of the nearest gauged catchments (which have been used to develop RFFE Model 2015) so that the user can compare the characteristics of the ungauged catchment of interest with the nearest gauged catchments used in the model development.

Despite the best possible efforts in data collation, some errors in the data might have remained undetected. Given the high variability of Australian hydrology and the current density and streamflow record lengths of the gauged stations used to develop the RFFE Technique 2015, the degree of uncertainty associated with the RFFE technique is considered acceptable. To enhance the accuracy of the RFFE Technique 2015, a greater number of stations with longer period of streamflow records should be used when these become available.

The development of the RFFE Technique 2015 is based on the assumption that the catchment characteristics represented in the regression equation (e.g. catchment area, design rainfall intensity and shape factor) account for the important differences in flood characteristics between sites in a region. It should be recognised that flood estimates generated by the RFFE Model 2015 for a catchment with flood characteristics that are distinctly different from typical gauged catchments in the region may not only be associated with larger error margins but also significant bias. In such situations hydrological judgment must be used to assess if any adjustment of the regional flood frequency estimate is required (based on comparison of other relevant catchment characteristics). To support such an assessment, the RFFE Model 2015 output describes the set of gauged catchments used in developing the RFFE Model, which are located closest to the ungauged catchment of interest.

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1. Introduction

1.1 Background

To upgrade the Regional Flood Frequency Estimation (RFFE) method in Australian Rainfall and Runoff (ARR) as a part of ARR *Project 5 Regional Flood Methods*, a project team undertook extensive data collation and modelling tasks during 2006 to 2014. The principal objectives of ARR Project 5 were to collate a quality controlled national database and to develop a new RFFE technique based on the collated database for the new ARR (4th edition). ARR Project 5 has been completed in three stages. Stage 1 and Stage 2 reports (Rahman et al., 2009; 2012) contained details of initial investigations in relation to the development of a national database and testing of different regional flood estimation methods to select a method for inclusion in the ARR (4th edition).

This report contains information on the final national database that has been used in the development of the RFFE Technique 2015 and results related to the development and testing of the RFFE Technique 2015.

1.2 Scope of the report

The report provides information on the selected catchments and database used in the development of the RFFE Technique 2015.

The report also presents the adopted methodology in forming the regions and developing the regional prediction equations. This also presents results on the development and testing of the RFFE Technique 2015.

1.3 Outline of the report

There are 8 chapters and three appendices in the report, as follows.

Chapter 1 provides the background, scope and outline of the report.

Chapter 2 provides details of the database that has been used in the development and testing of the RFFE Technique 2015. This covers selection of catchments and preparation of streamflow and catchment characteristics data.

Chapter 3 describes the adopted statistical methods in the development of the RFFE Technique 2015 i.e. region-of-influence approach, parameter regression technique (PRT) and generalised least squares (GLS) regression.

Chapter 4 presents results on the formation of regions in the data-rich and data-poor areas of Australia.

Chapter 5 presents the development and validation of prediction equations for the data-rich areas by applying region-of-influence approach and GLS regression.

Chapter 6 presents the development and validation of prediction equations for the data-poor (arid) areas.

Chapter 7 provides information on the development of the application tool (known as RFFE Model 2015), which is a computer-based tool that incorporates the model coefficients derived in this study. This enables the user to estimate flood quantiles at the ungauged catchment location with simple input data.

Chapter 8 provides a summary of the results and findings from this study.

Appendix A contains the list of the selected catchments, river name, gauge location, area of the catchments and streamflow record lengths used to develop the RFFE Technique 2015. This also provides summary statistics of the relevant catchment characteristics data for different regions.

Appendix B provides additional results from the data-rich regions in relation to the development and testing of the prediction equations for the RFFE Technique 2015.

Appendix C provides additional results from the arid regions in relation to the development and testing of the prediction equations for the RFFE Technique 2015.

Appendix D provides list of publications originated from Project 5.

2. Selection of catchments and preparation of streamflow and catchment characteristics data

2.1 Overview

This chapter provides information on the selection of catchments and the preparation of streamflow and catchment characteristics data used to develop and test the RFFE Technique 2015. The selection of catchments from the data-rich areas of Australia is presented first, followed by the selection of catchments from the arid areas and a summary of all the selected catchments. The selection of climatic and catchment characteristics data is provided next. Thereafter, the streamflow data preparation and at-site flood frequency analysis are presented. Finally, the method of data archiving is described.

2.2 Selection of catchments from data-rich areas

The following six criteria were considered in making the initial selection of the study catchments:

Catchment area: The primary objective here is to develop prediction equations for flood estimation in small to medium sized ungauged catchments. The flood frequency behaviour of large catchments has been shown to significantly differ from smaller catchments. ARR (I.E Aust., 1987) suggested an upper limit of 1000 km^2 for small to medium sized catchments, a criterion adopted in this study. However, for a few states (e.g. the Northern Territory and Tasmania), the upper limit was relaxed to increase the number of catchments, as too small a number of catchments may not able to capture the variability in flood characteristics within a region.

Record length: The streamflow record at a stream gauging location should be long enough to characterise the underlying flood probability distribution with reasonable accuracy. In most practical situations, streamflow records at many gauging stations in a given study area are not long enough and hence a balance is required between obtaining a sufficient number of stations (which captures greater spatial information) and a reasonably long record length (which enhances accuracy of at-site flood quantile estimates). The cut-off record length was selected to maximise the potential number of stations with the expectation that further culling will reduce that number. The cut off record length was set to be 20 years; however, for Tasmania and the Northern Territory, it was taken to be 19 years.

Regulation: Ideally, the selected streams should be unregulated, since major regulation affects the rainfall-runoff relationship significantly (e.g., storage effects). Streams with minor regulation, such as small farm dams and diversion weirs, may be included because this type of regulation is unlikely to have a significant effect on annual floods. Gauging stations on streams subject to major upstream regulation (e.g. a large dam on the stream) were excluded from the data set.

Urbanisation: Urbanisation can affect flood behaviour dramatically (e.g. decreased infiltration losses and increased flow velocity). Therefore catchments with more than 10% of the area affected by urbanisation were excluded from the data set.

Landuse change: Major landuse changes, such as the clearing of forests, changing agricultural practices or urbanisation modify flood generation mechanisms and make streamflow records heterogeneous over the period of record length. Catchments which are known to have undergone major landuse changes over the period of streamflow records were excluded from the data set.

Quality of data: Most statistical analyses of flood data assume that the available data are error free; however, at some stations it is recognised that this assumption may be grossly violated. Stations graded as ‘poor quality’ or with specific comments by the gauging authority regarding quality of the data were assessed in greater detail; if flood data were deemed ‘low quality’, these stations were excluded.

The annual maximum flood series data may be affected by multi-decadal climate variability and climate change, which are not easy to deal with. The effects of multi-decadal climate variability can be accounted for by increasing the cut-off record length at an individual station; however, the impacts of climate change present a serious problem in terms of the applicability of the past data in predicting future flood frequency, which needs further research (Ishak et al., 2013).

2.2.1 Catchments from New South Wales and ACT (data-rich parts)

A total of 176 catchments have been selected from New South Wales (NSW) and the Australian Capital Territory (ACT) (listed in Appendix Table A1).

The record lengths of annual maximum flood series of these 176 stations range from 20 to 82 years (mean: 35.76 years, median: 34 years and standard deviation: 12.20 years). The distribution of record lengths is shown in Figure 2.1.

The catchment areas of the selected 176 catchments range from 1 km^2 to 1,036 km^2 (mean: 311 km^2 and median: 204 km^2). The geographical distribution of the selected 176 catchments is shown in Figure 2.2. The distribution of catchment areas of these stations is shown in Figure 2.3.

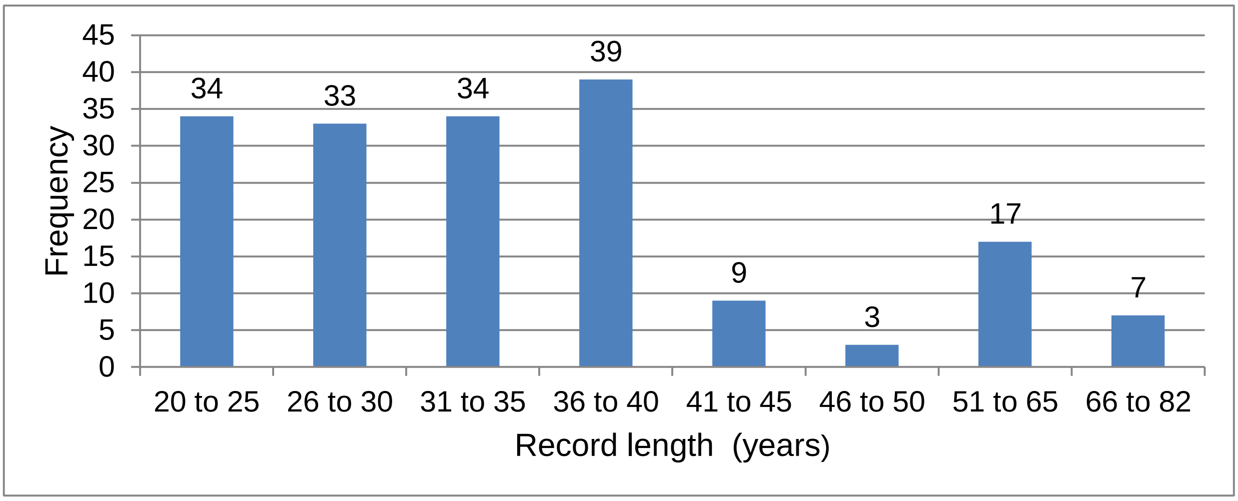

Figure 2.1 Distribution of streamflow record lengths of 176 stations from NSW and ACT

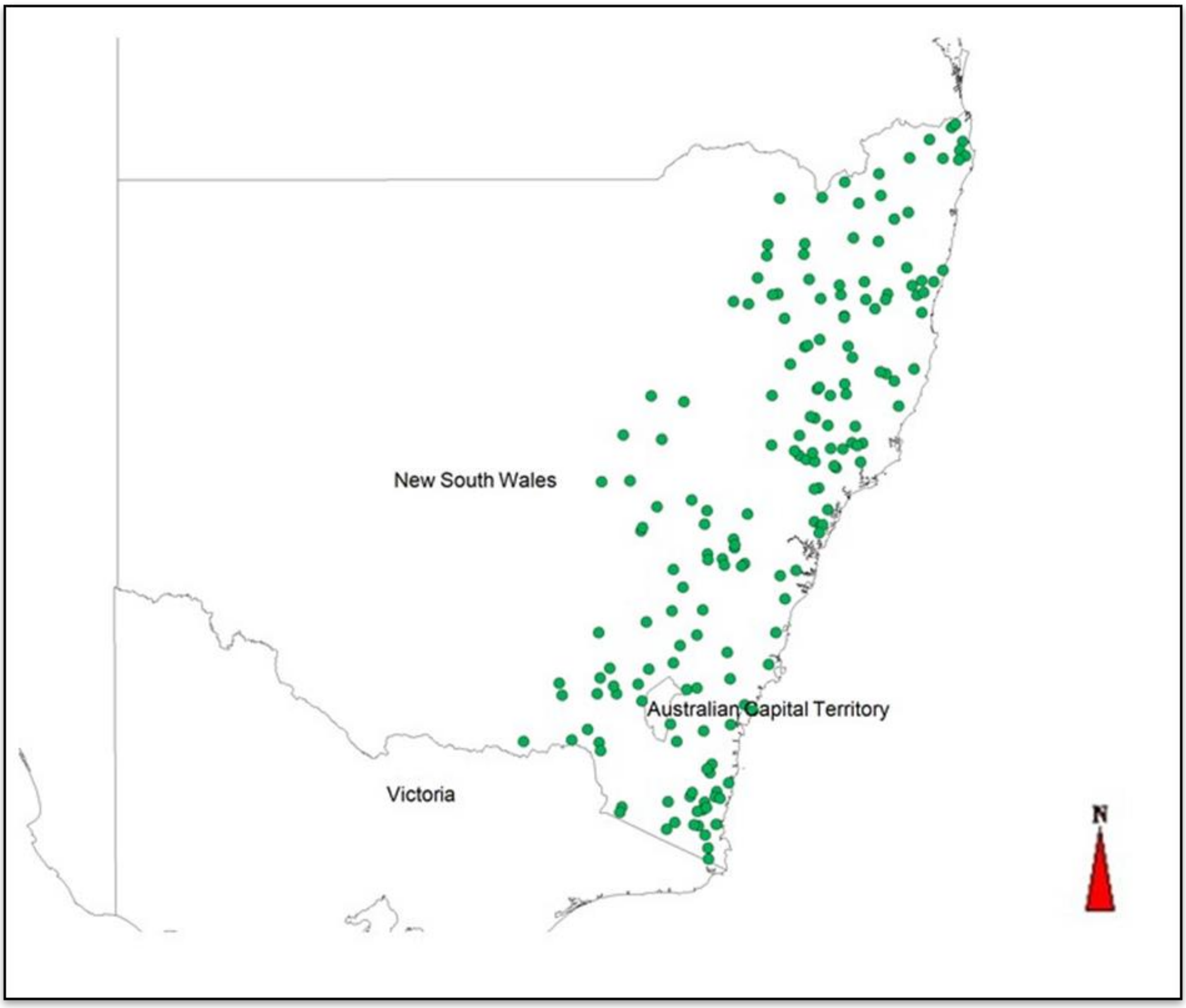

Figure 2.2 Geographical distribution of the selected 176 stations from NSW and ACT

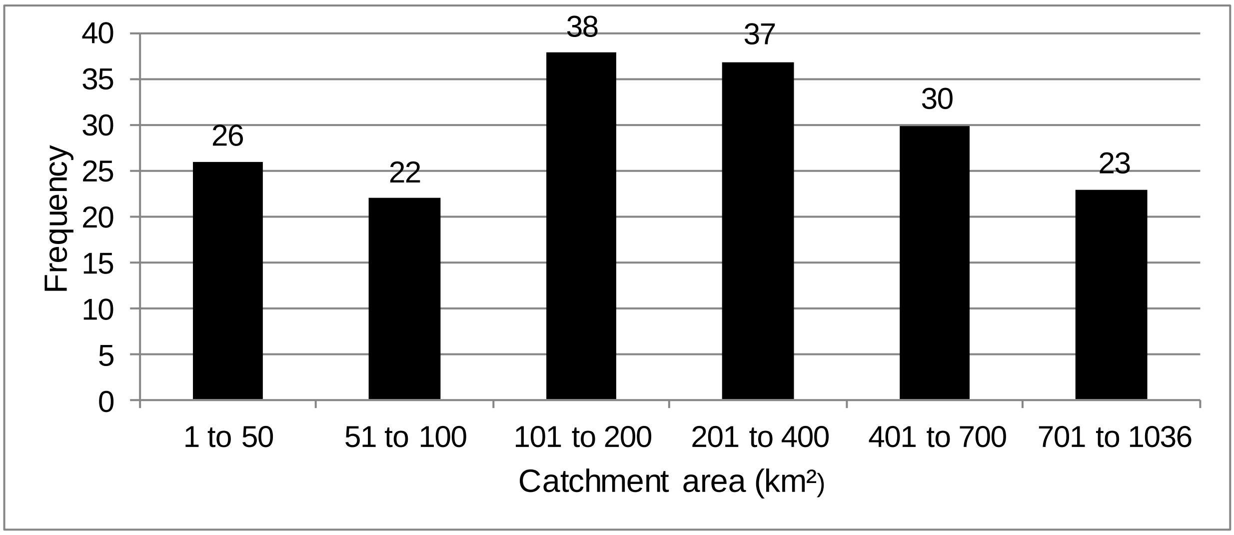

Figure 2.3 Distribution of catchment areas of 176 stations from NSW and ACT

2.2.2 Catchments from Victoria (data-rich parts)

A total of 186 catchments have been selected from Victoria (listed in Appendix Table A2).

The record lengths of annual maximum flood series of these 186 stations range from 20 to 60 years (mean: 37 years, median: 38 years and standard deviation: 7.30 years). The distribution of record lengths is shown in Figure 2.4.

The catchment areas of the selected 186 catchments range from 3 km^2 to 997 km^2 (mean: 271 km^2 and median: 209 km^2). The geographical distribution of the selected 186 catchments is shown in Figure 2.5. The distribution of catchment areas of these stations is shown in Figure 2.6.

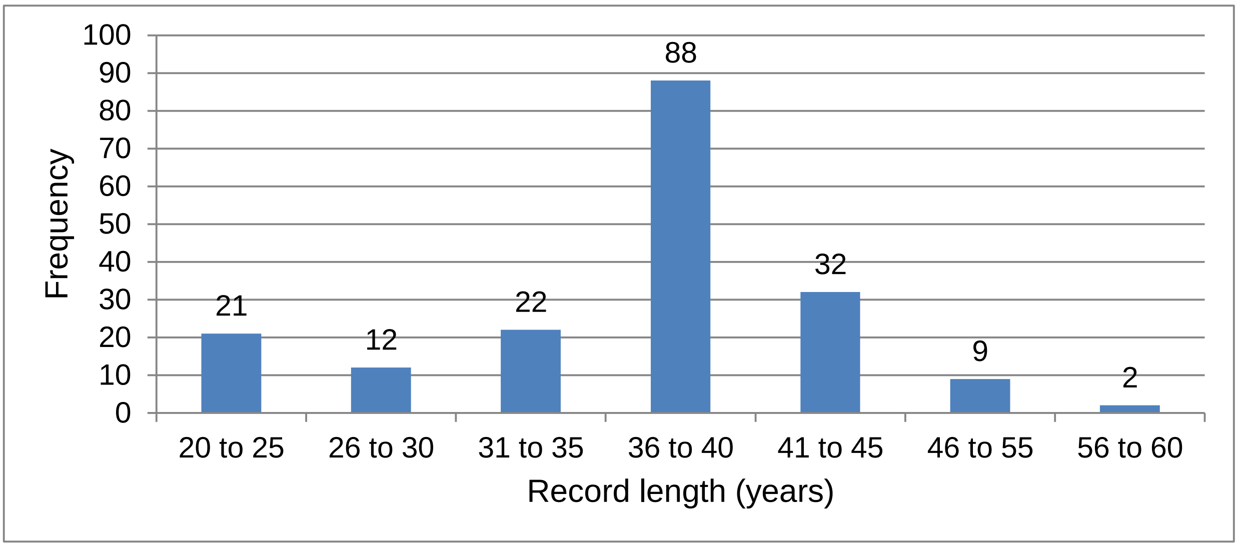

Figure 2.4 Distribution of streamflow record lengths of 186 stations from Victoria

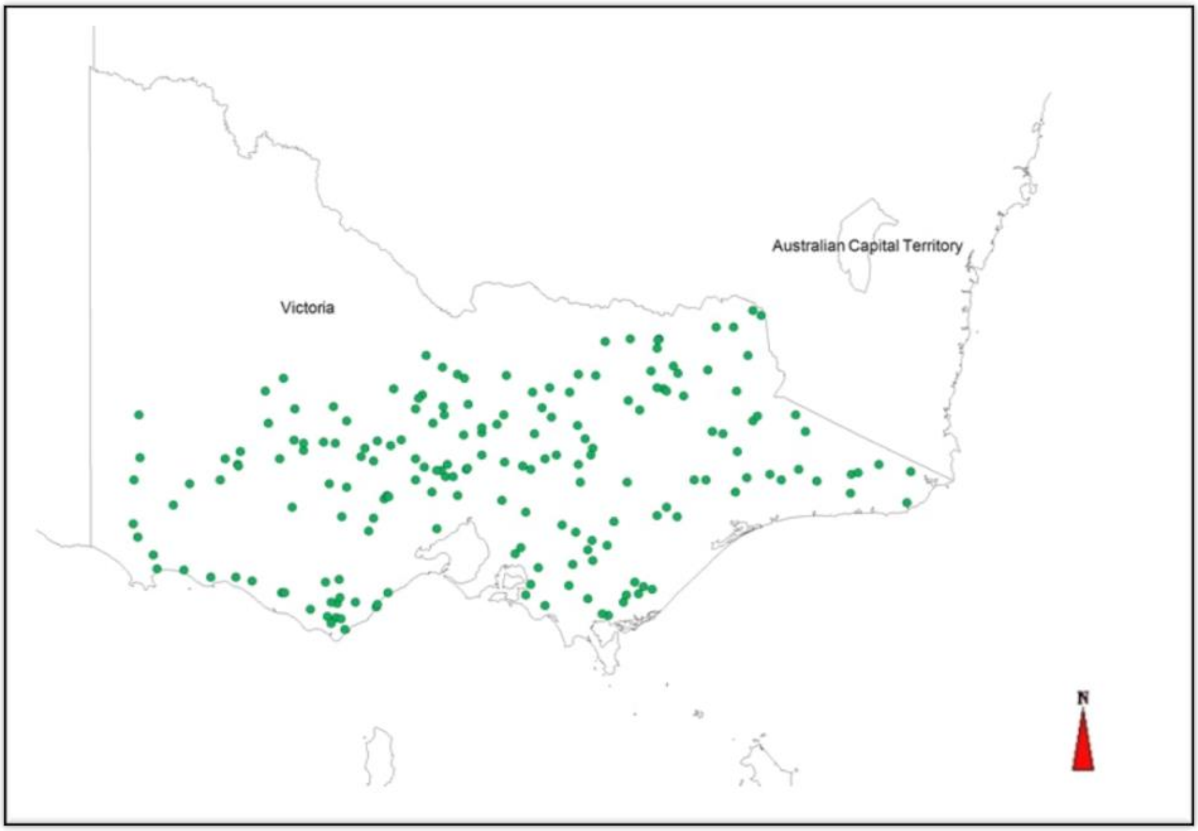

Figure 2.5 Geographical distribution of the selected 186 stations from Victoria

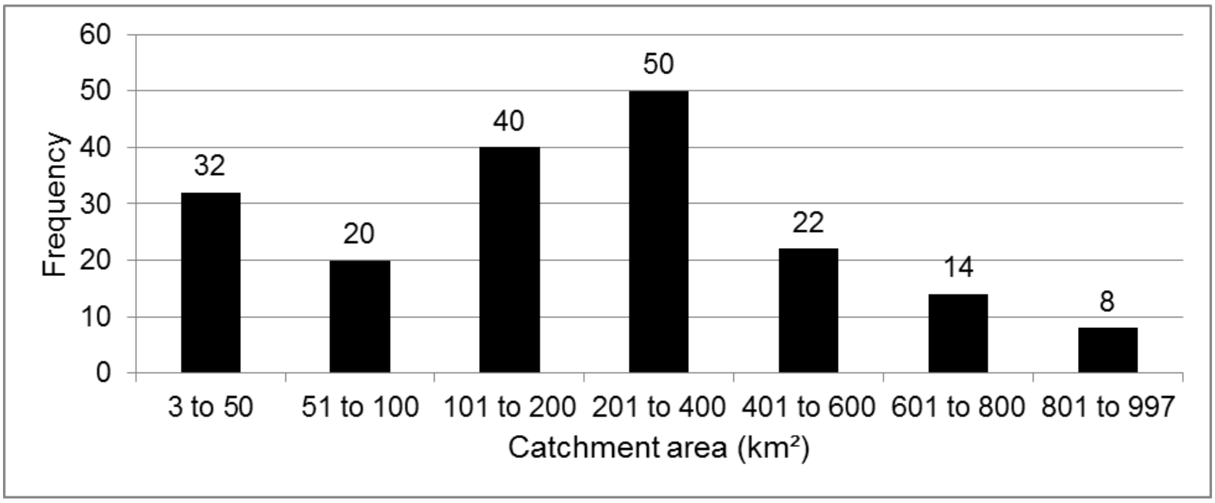

Figure 2.6 Distribution of catchment areas of 186 stations from Victoria

2.2.3 Catchments from South Australia (data-rich parts)

A total of 28 catchments have been selected from South Australia (listed in Appendix Table A3).

The record lengths of annual maximum flood series of these 28 stations range from 20 to 63 years (mean: 36.64 years, median: 37 years and standard deviation: 9.15 years). The distribution of record lengths is shown in Figure 2.7.

The catchment areas of the selected 28 catchments range from 0.6 km^2 to 708 km^2 (mean: 161 km^2 and median: 63 km^2). The geographical distribution of the selected 28 catchments is shown in Figure 2.8. The distribution of catchment areas of these stations is shown in Figure 2.9.

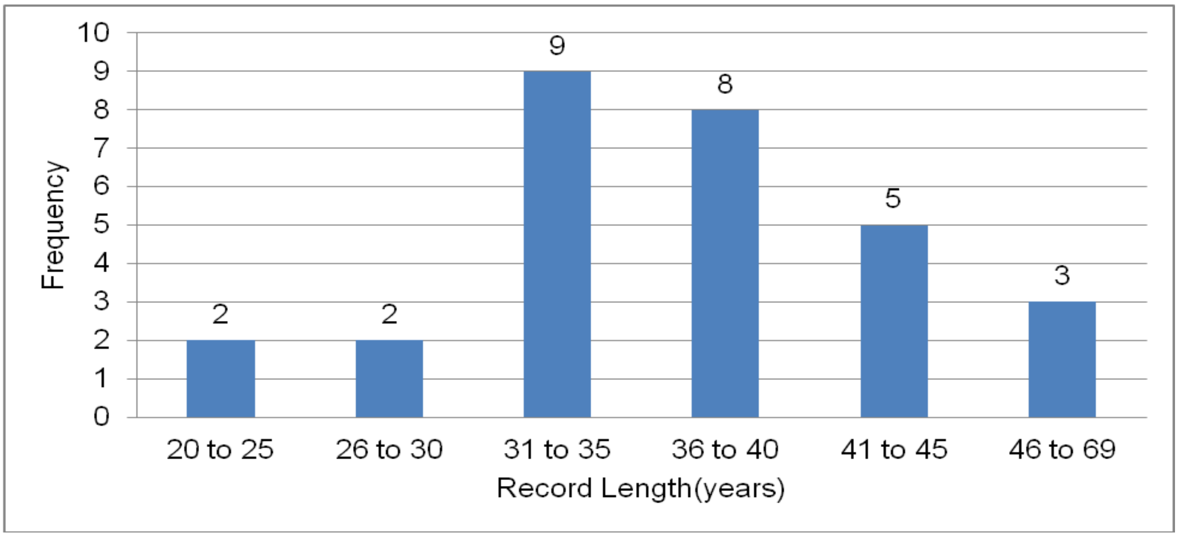

Figure 2.7 Distribution of streamflow record lengths of 28 stations from South Australia

Figure 2.8 Geographical distribution of the selected 28 stations from South Australia

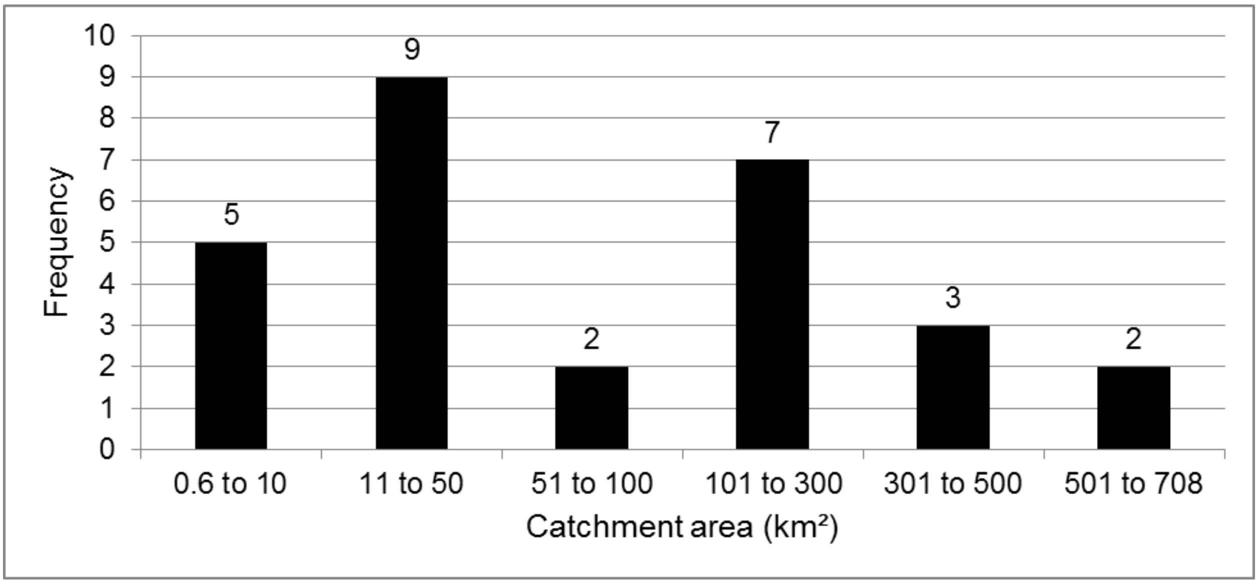

Figure 2.9 Distribution of catchment areas of 28 stations from South Australia

2.2.4 Catchments from Tasmania

A total of 51 catchments have been selected from Tasmania (listed in Appendix Table A4).

The record lengths of annual maximum flood series of these 51 stations range from 19 to 74 years (mean: 30.51 years, median: 28 years and standard deviation: 11.05 years). The distribution of record lengths is shown in Figure 2.10.

The catchment areas of the selected 51 catchments range from 1.3 km^2 to 1,900 km^2 (mean: 320 km^2 and median: 158 km^2). The geographical distribution of the selected 51 catchments is shown in Figure 2.11. The distribution of catchment areas of these stations is shown in Figure 2.12.

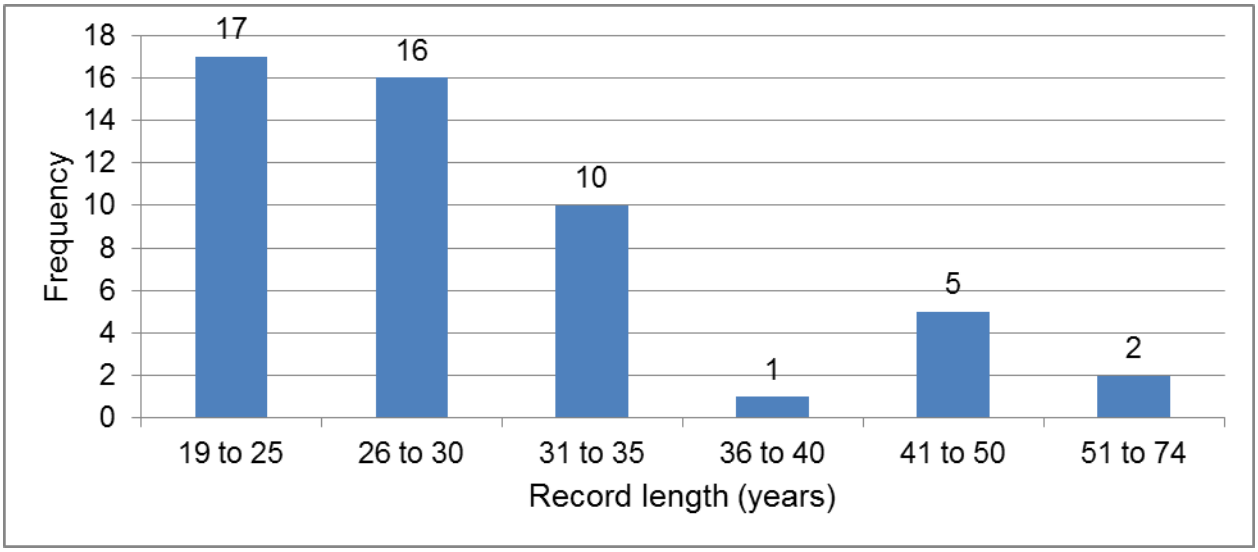

Figure 2.10 Distribution of streamflow record lengths of 51 stations from Tasmania

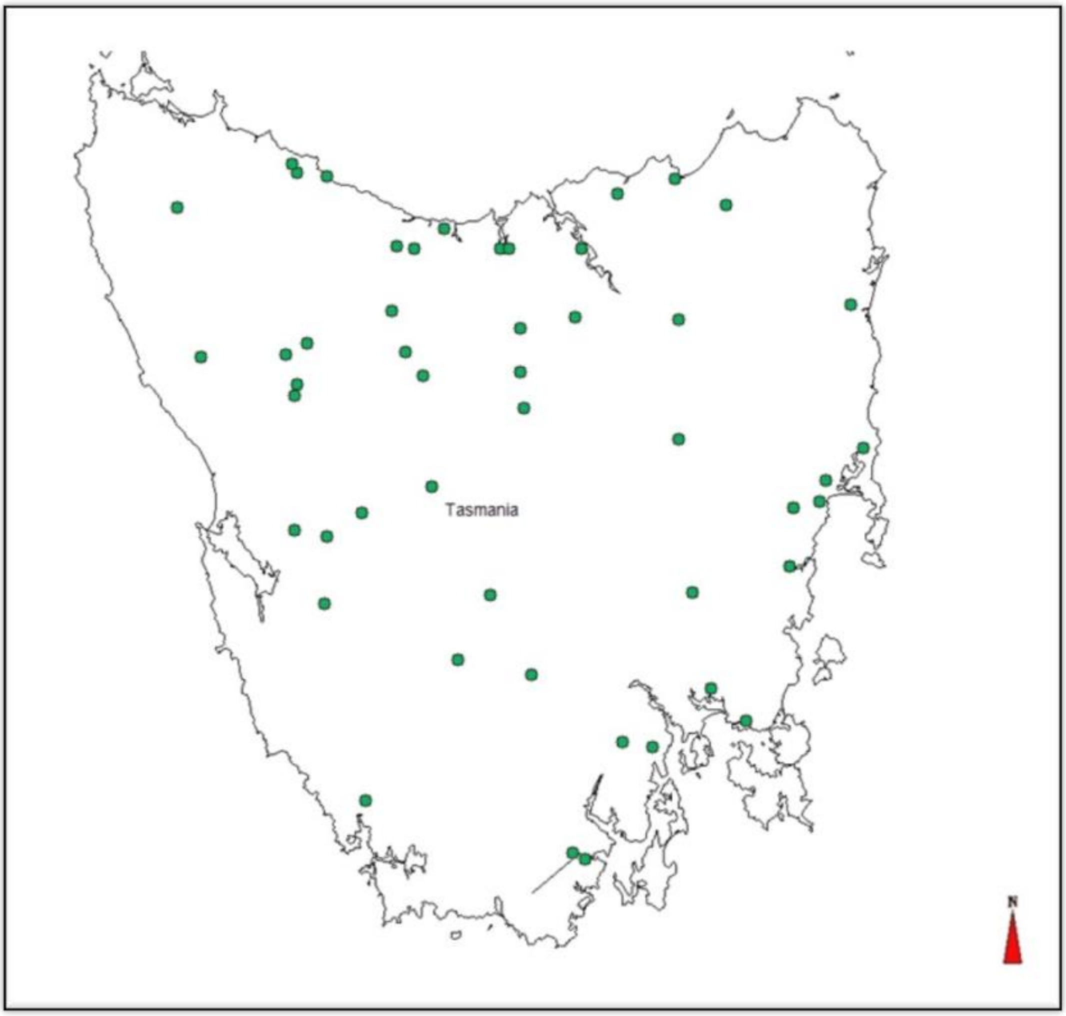

Figure 2.11 Geographical distribution of the selected 51 stations from Tasmania

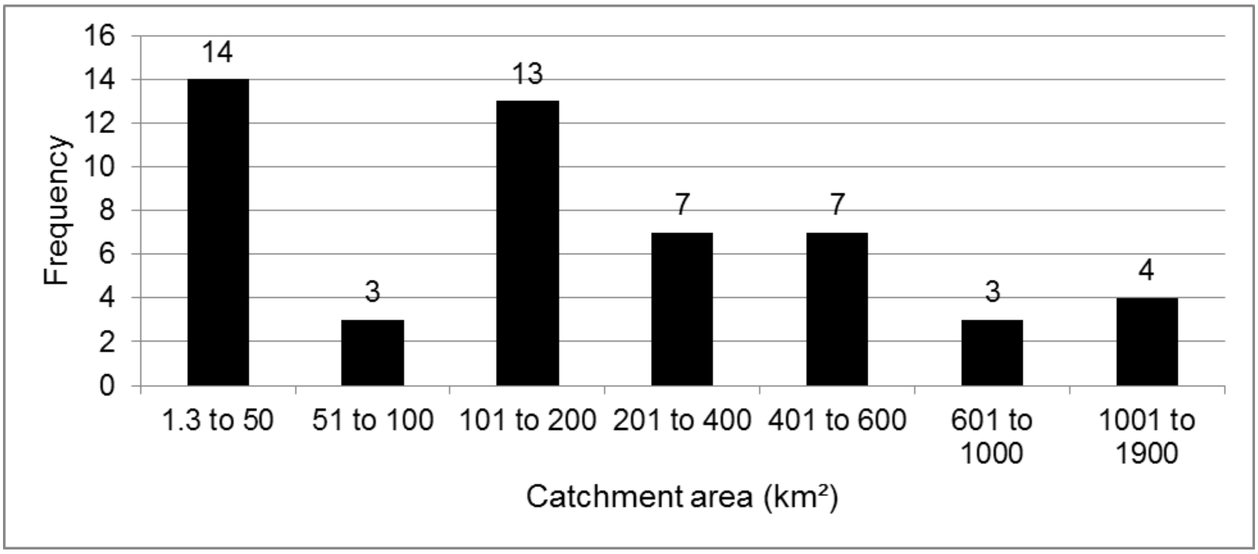

Figure 2.12 Distribution of catchment areas of 51 stations from Tasmania

2.2.5 Catchments from Queensland (data-rich parts)

A total of 196 catchments have been selected from Queensland (listed in Appendix Table A5).

The record lengths of annual maximum flood series of these 196 stations range from 20 to 102 years (mean: 43 years, median: 42 years and standard deviation: 17.05 years). The distribution of record lengths is shown in Figure 2.13.

The catchment areas of the selected 196 catchments range from 7 km^2 to 963 km^2 (mean: 304 km^2, median: 227 km^2). The geographical distribution of the selected 196 catchments is shown in Figure 2.14. The distribution of catchment areas of these stations is shown in Figure 2.15.

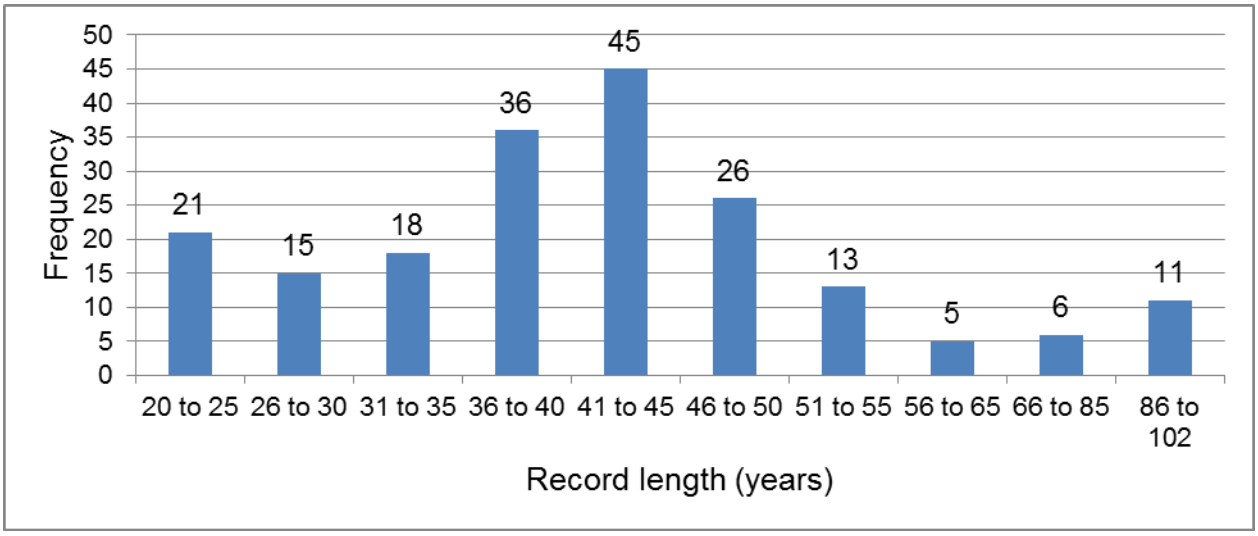

Figure 2.13 Distribution of streamflow record lengths of 196 stations from Queensland

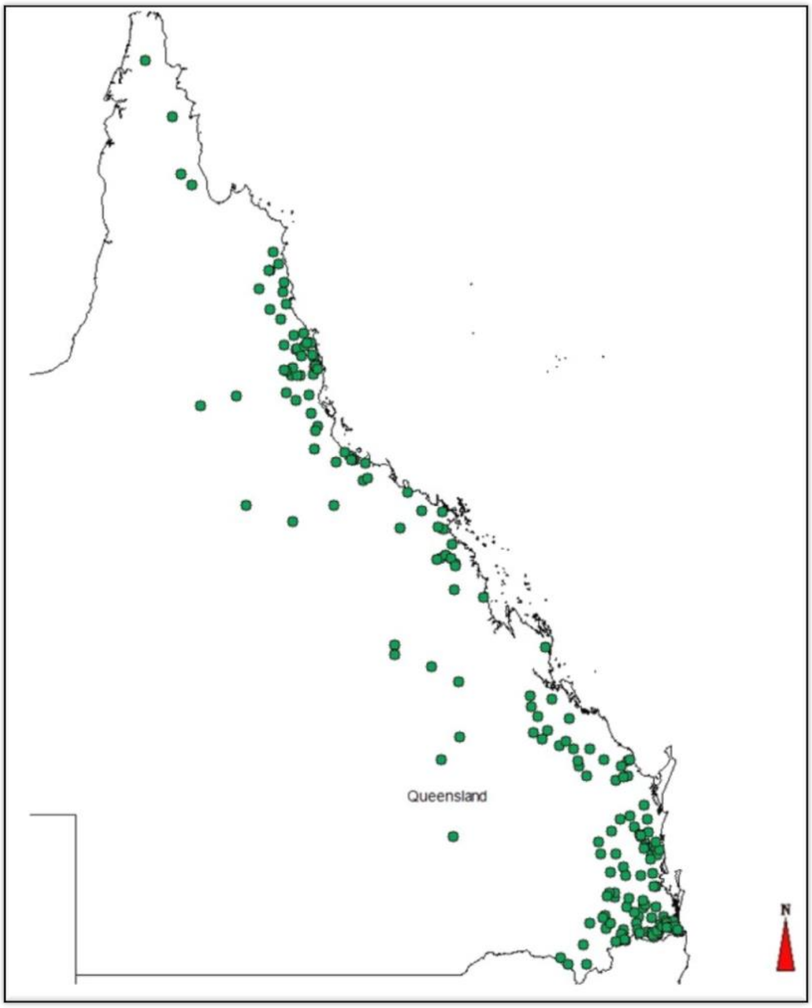

Figure 2.14 Geographical distribution of the selected 196 stations from Queensland

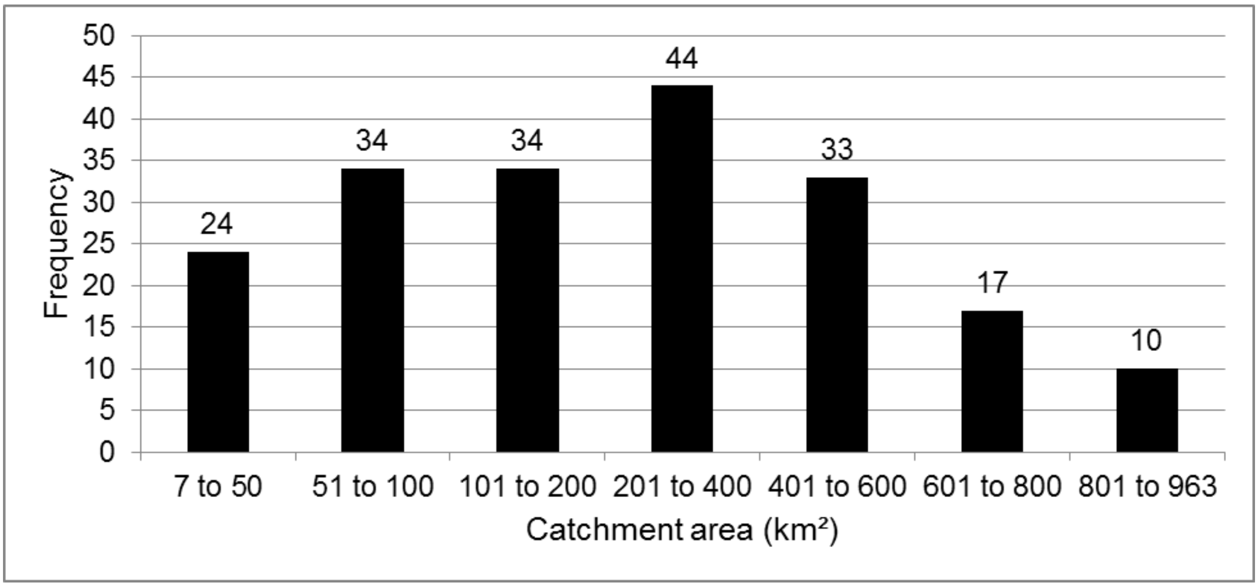

Figure 2.15 Distribution of catchment areas of 196 stations from Queensland

2.2.6 Catchments from Western Australia (data-rich parts)

A total of 111 catchments have been selected from Western Australia (listed in Appendix Table A6).

The record lengths of annual maximum flood series of these 111 stations range from 20 to 60 years (mean: 32.17 years, median: 30 years and standard deviation: 9.78 years). The distribution of record lengths is shown in Figure 2.16.

The catchment areas of the selected 111 catchments range from 0.5 km^2 to 1049.8 km^2 (mean: 160 km^2 and median: 49 km^2). The geographical distribution of the selected 111 catchments is shown in Figure 2.17. The distribution of catchment areas of these stations is shown in Figure 2.18.

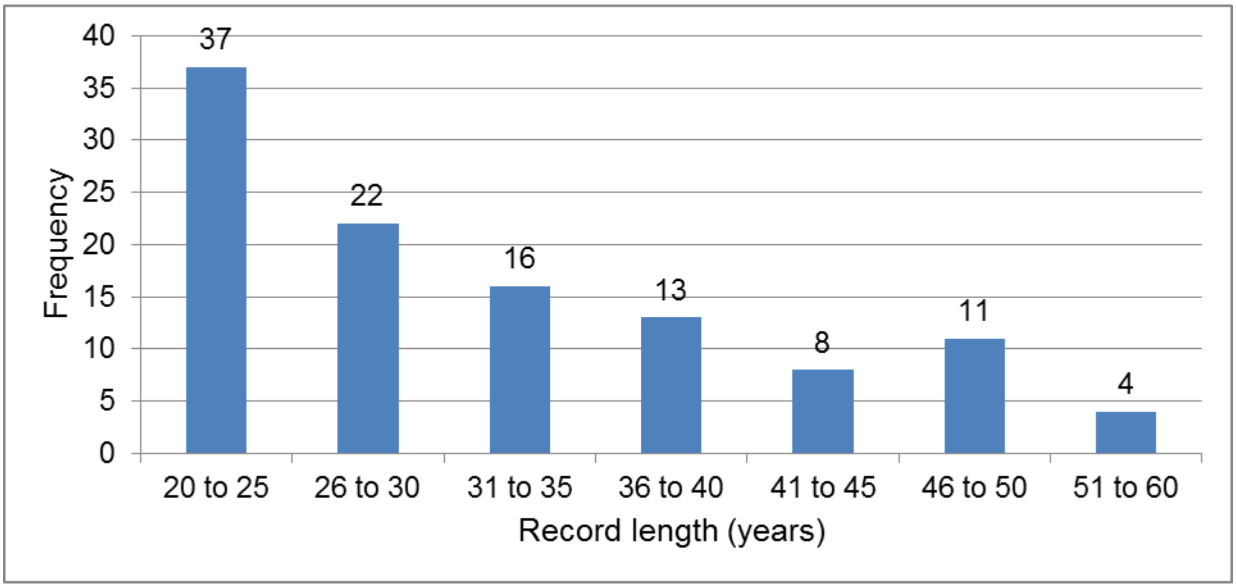

Figure 2.16 Distribution of streamflow record lengths of 111 stations from Western Australia

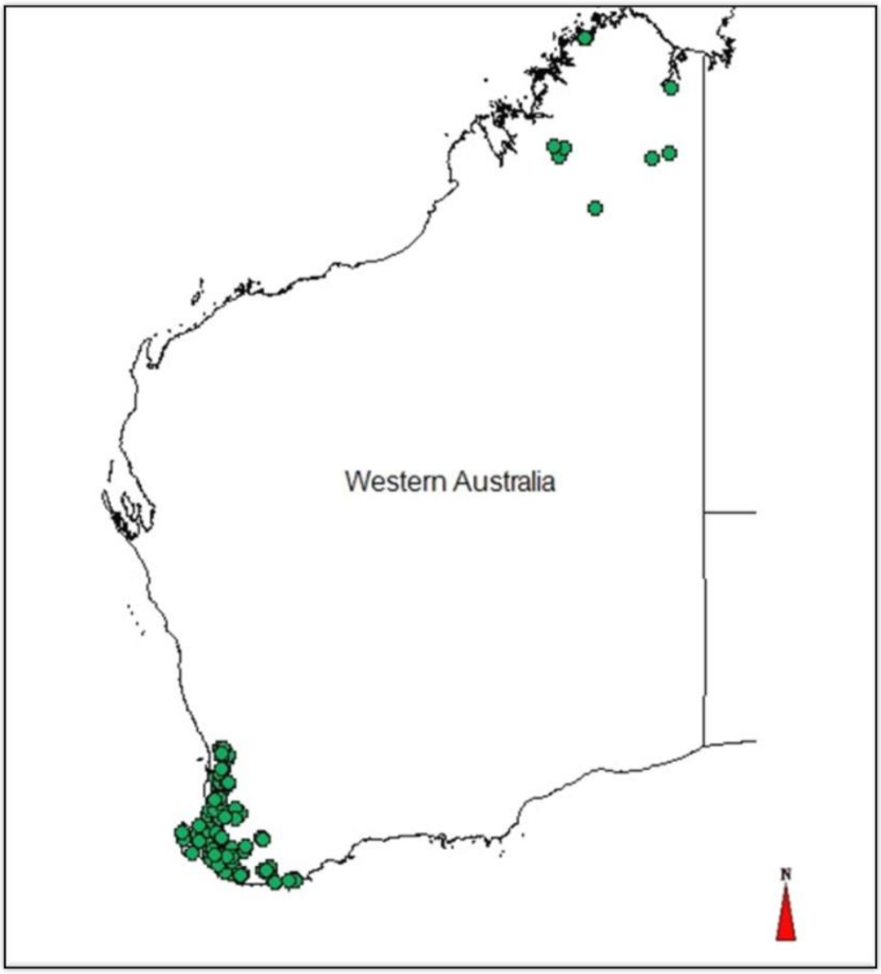

Figure 2.17 Geographical distribution of the selected 111 stations from Western Australia

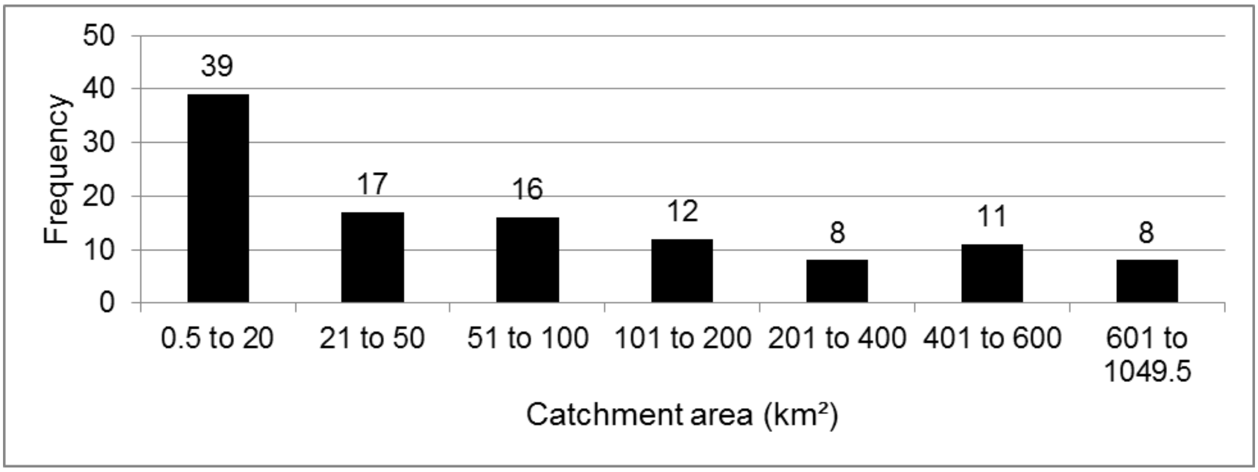

Figure 2.18 Distribution of catchment areas of 111 stations from Western Australia

2.2.7 Catchments from the Northern Territory (data-rich parts)

A total of 50 catchments have been selected from the Northern Territory (listed in Appendix Table A7).

The record lengths of annual maximum flood series of these 50 stations range from 19 to 57 years (mean: 37.68 years, median: 42 years and standard deviation: 12.58 years). The distribution of record lengths is shown in Figure 2.19.

The catchment areas of the selected 50 catchments range from 1.4 km^2 to 4,325 km^2 (mean: 641 km^2 and median: 352 km^2). The geographical distribution of the selected 50 catchments is shown in Figure 2.20. The distribution of catchment areas of these stations is shown in Figure 2.21.

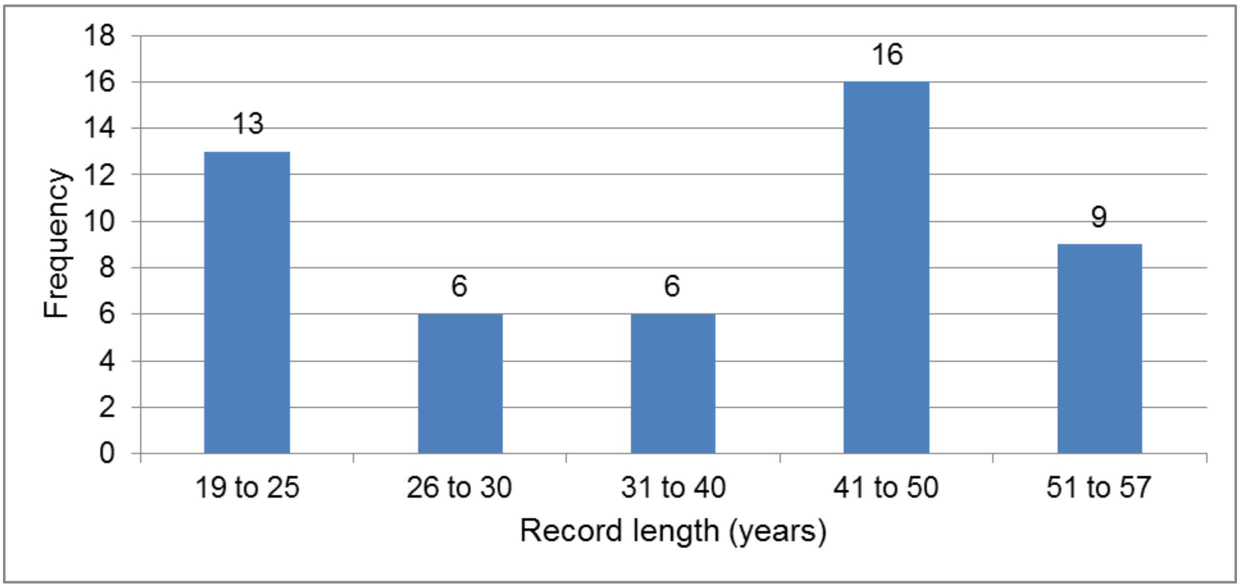

Figure 2.19 Distribution of streamflow record lengths of 50 stations from the Northern Territory

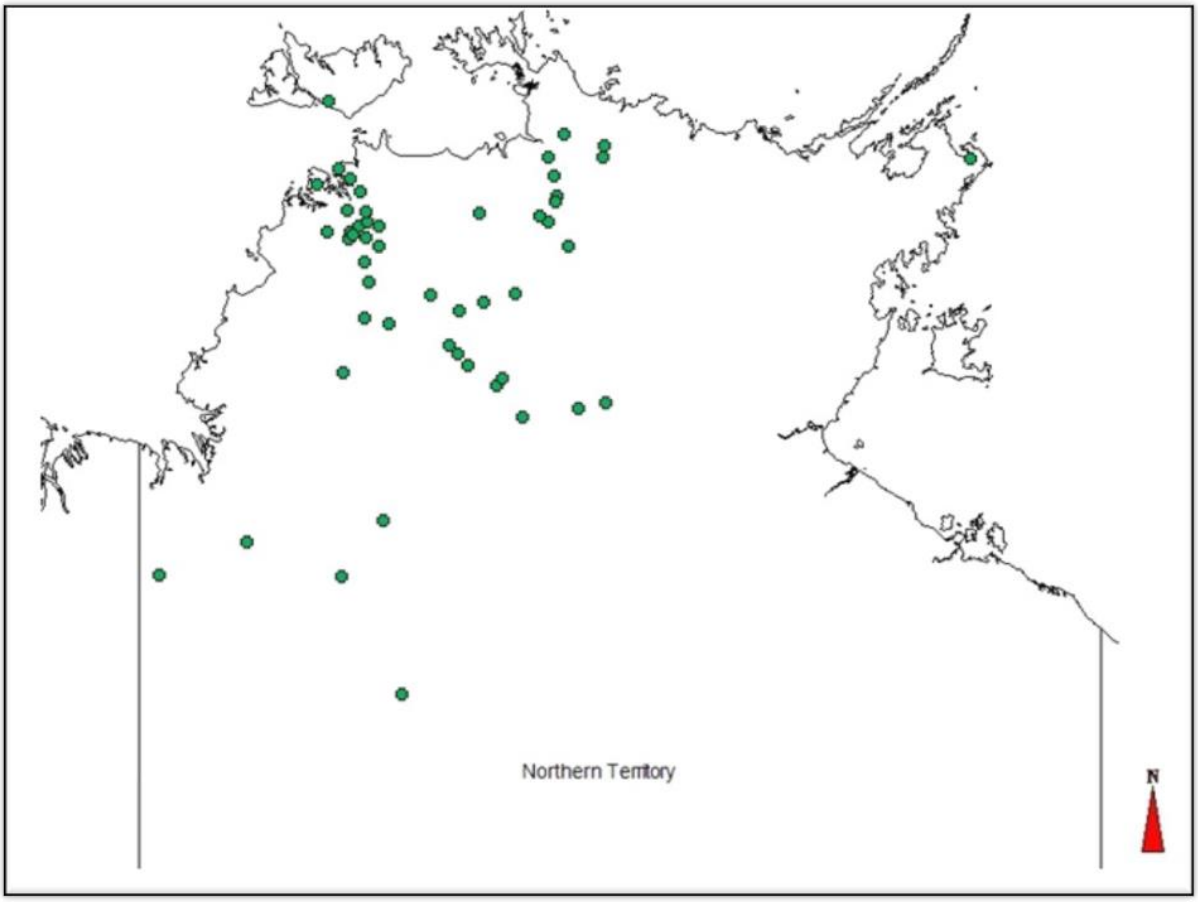

Figure 2.20 Geographical distributions of the selected 50 stations from the Northern Territory

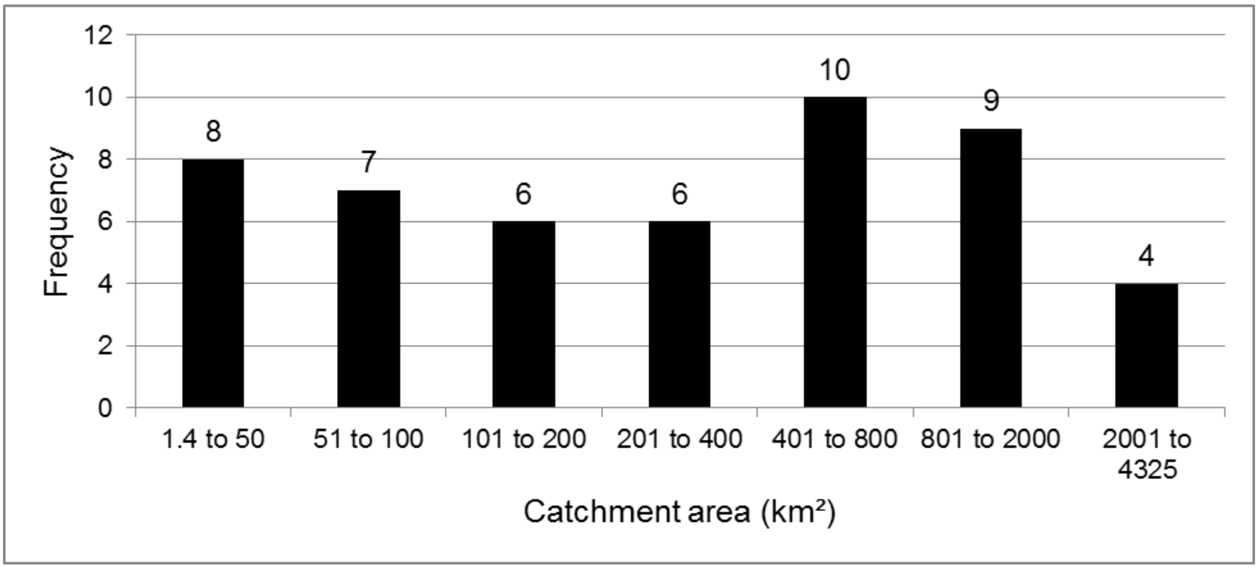

Figure 2.21 Distribution of catchment areas of 50 stations from the Northern Territory

2.3 Catchments from arid areas of Australia

A total of 55 catchments have been selected from the arid areas including the Pilbara area in Western Australia and other arid areas (listed in Appendix Table A8).

The record lengths of flood series of these 55 stations range from 10 to 46 years (mean: 26.75 years, median: 27 years and standard deviation: 9.07 years). The distribution of record lengths is shown in Figure 2.22.

The catchment areas of the selected 55 catchments range from 0.1 km^2 to 5,975 km^2 (mean: 760 km^2 and median: 259 km^2). The geographical distribution of the selected 55 catchments is shown in Figure 2.23. The distribution of catchment areas of these stations is shown in Figure 2.24.

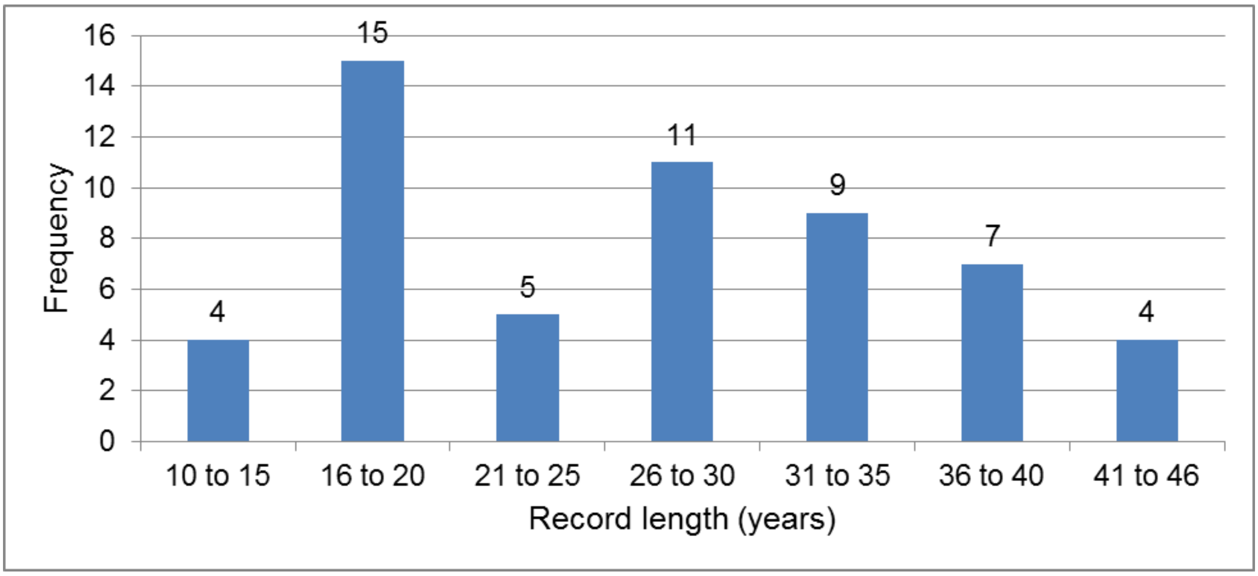

Figure 2.22 Distribution of streamflow record lengths of 55 stations from the arid areas

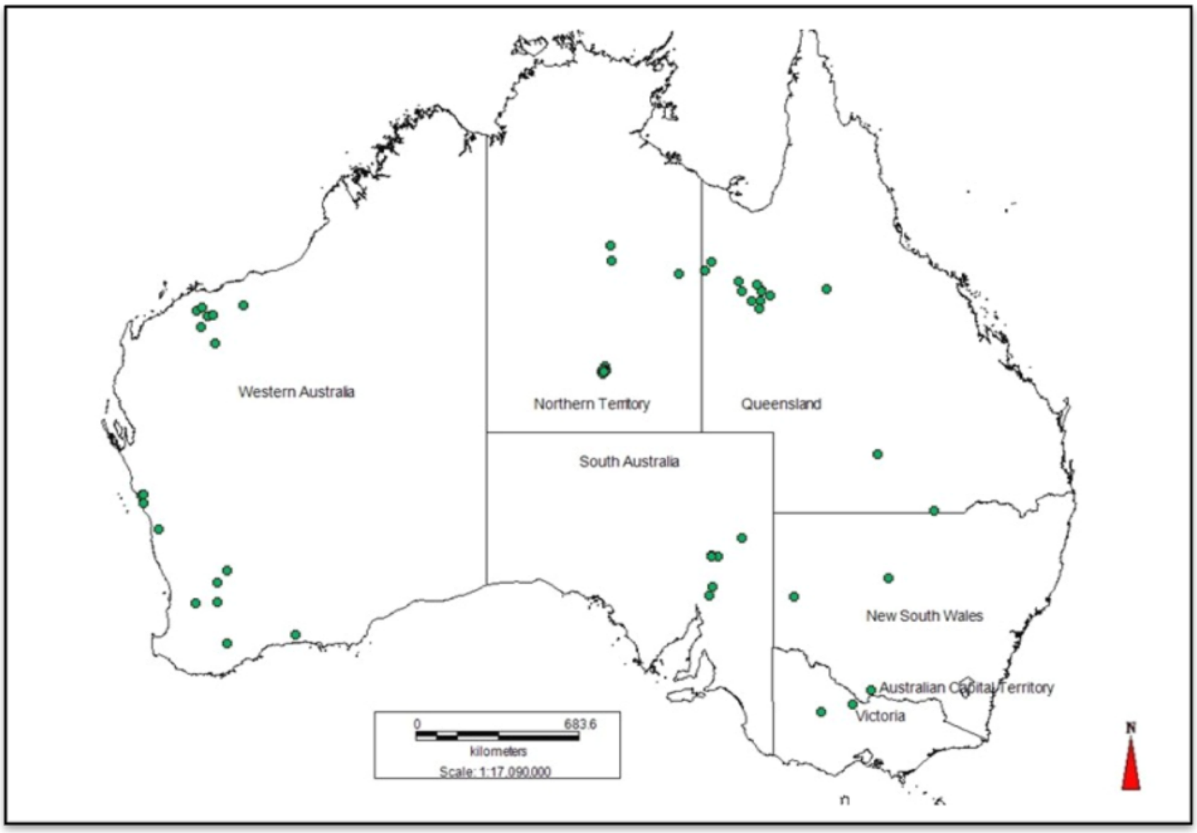

Figure 2.23 Geographical distribution of the selected 55 stations from the arid areas

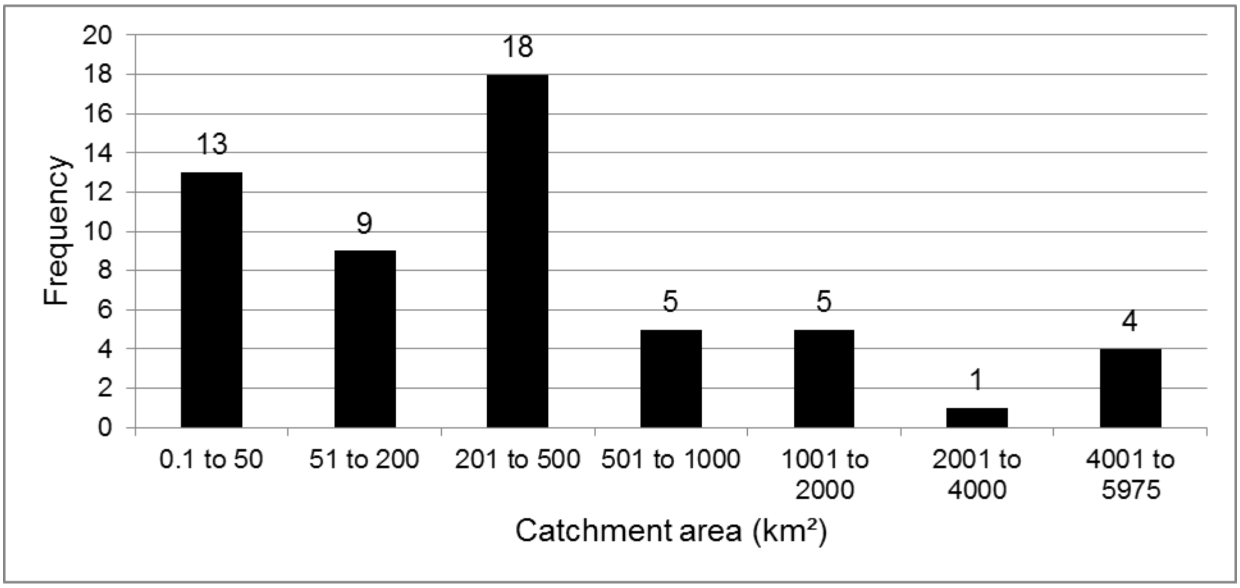

Figure 2.24 Distribution of catchment areas of 55 stations from the arid areas

2.4 Catchments from all Australia (data-rich areas without arid area catchments)

A total of 798 catchments have been selected from the data-rich areas of Australia.

The record lengths of the annual maximum flood series of these 798 stations range from 19 to 102 years (mean: 37.18 years, median: 37 years and standard deviation: 12.89 years). The distribution of record lengths of these 798 stations is shown in Figure 2.25.

The catchment areas of the selected 798 catchments range from 0.5 km^2 to 4,325 km^2 (mean: 294 km^2, median: 178 km^2). However, for Victoria, New South Wales, South Australia, Queensland and South-west Western Australia, the catchment areas range from 0.6 km^2 to 1,049 km^2. Only few catchments in Tasmania and the Northern Territory are in the range of 1,000 km^2 to 4,325 km^2.

The geographical distribution of the selected 798 catchments from the data-rich areas is shown in Figure 2.26. The distribution of catchment areas of these stations is shown in Figure 2.27.

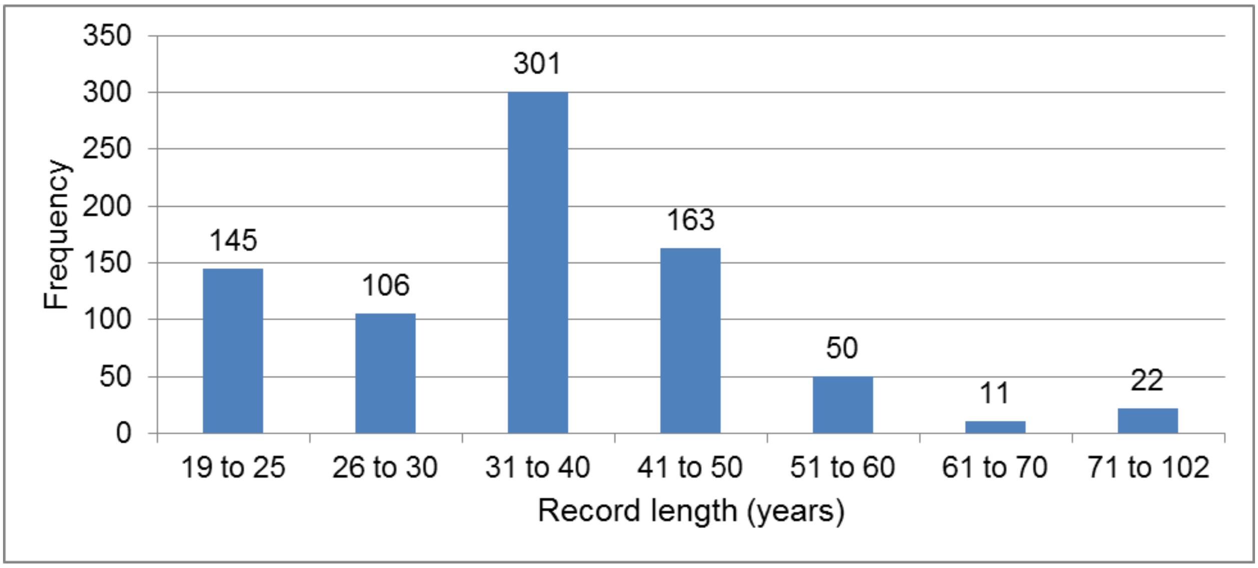

Figure 2.25 Distribution of streamflow record lengths of 798 stations from all data-rich areas of Australia

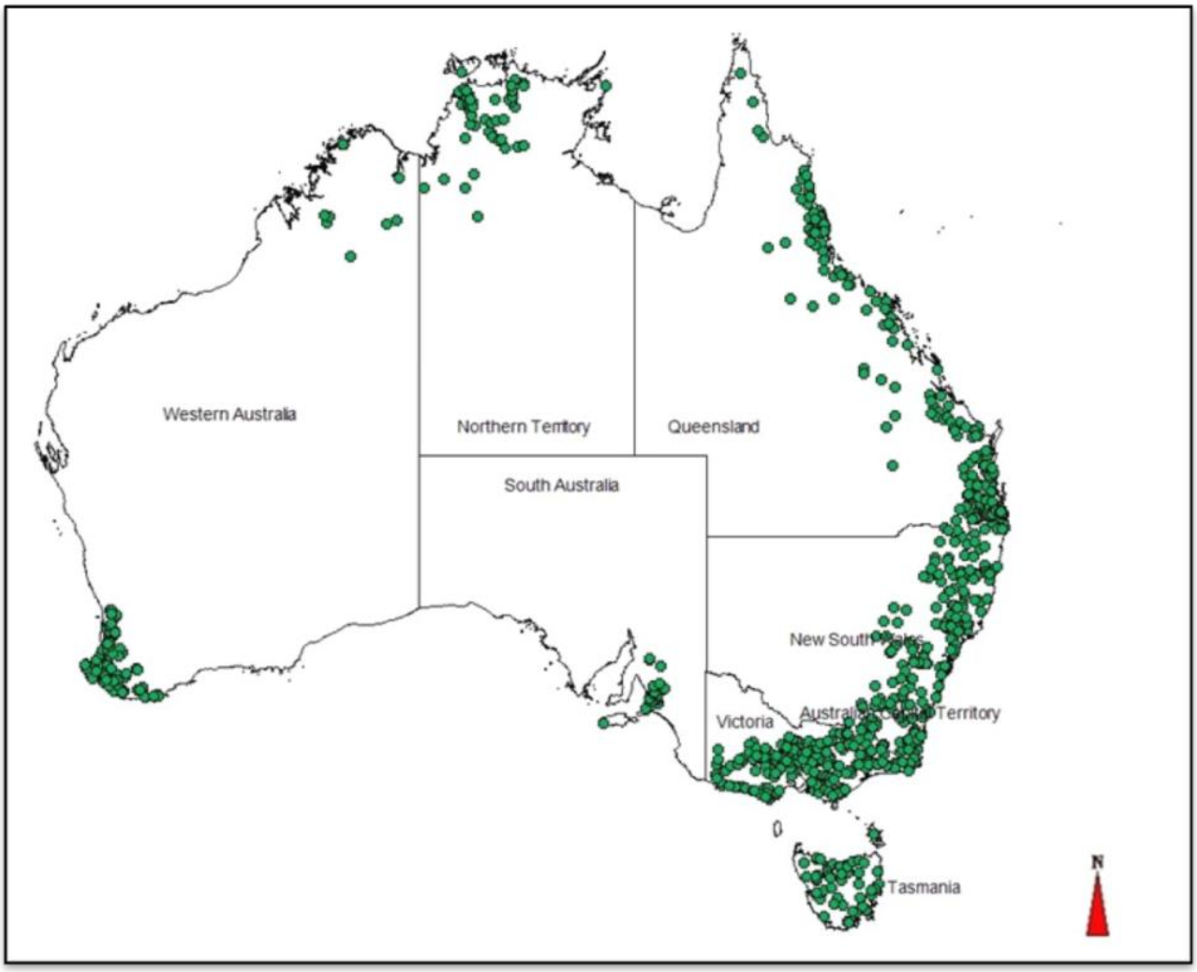

Figure 2.26 Geographical distribution of the selected 798 stations from data-rich areas

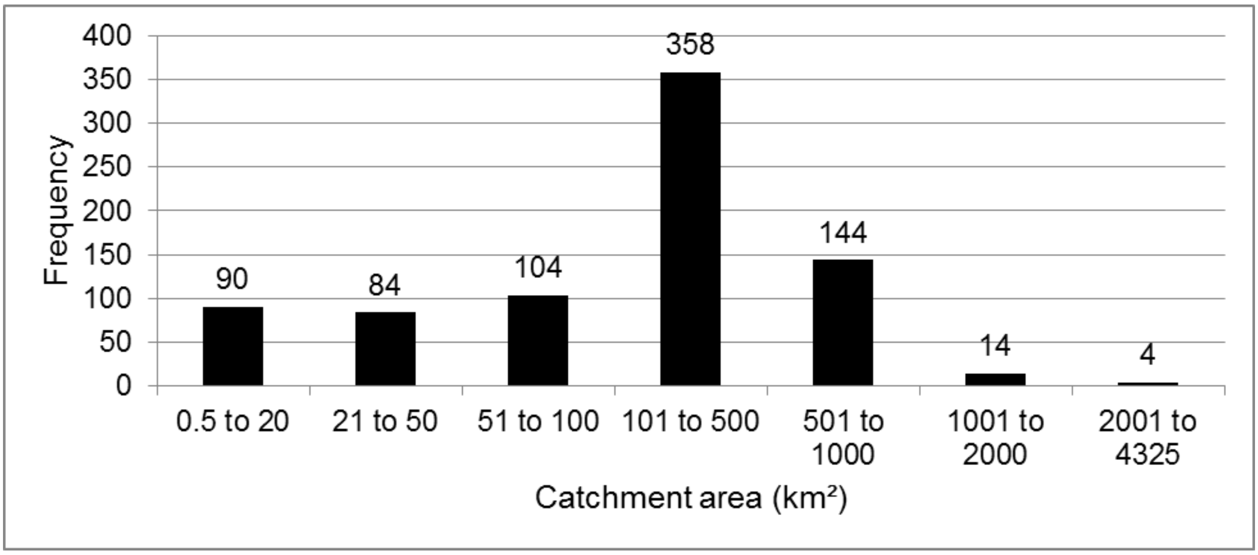

Figure 2.27 Distribution of catchment areas of 798 stations from data-rich areas of Australia

2.5 Summary of the selected catchments (data-rich and arid areas)

A total of 798 catchments are selected from the data-rich areas and 55 catchments from arid areas i.e. a total of 853 catchments from all over Australia. A summary of these 853 selected catchments from data-rich and arid areas is provided in Table 2.1. The geographical distribution of the selected 853 catchments is shown in Figure 2.28.

Table 2.1 Summary of the selected 853 catchments (data-rich and arid areas)

State	No. of stations	Streamflow record length (years) (range and median)	Catchment size (km^2) (range and median)
New South Wales & Australian Capital Territory	176	20 – 82 (34)	1 – 1036 (204)
Victoria	186	20 – 60 (38)	3 – 997 (209)
South Australia	28	20 – 63 (37)	0.6 – 708 (62.6)
Tasmania	51	19 – 74 (28)	1.3 – 1900 (158.1)
Queensland	196	20 – 102 (42)	7 - 963 (227)
Western Australia	111	20 – 60 (30)	0.5 – 1049.8 (49.2)
Northern Territory	50	19 – 57 (42)	1.4 - 4325 (352)
Sub Total	**798**	19 – 102 (37)	0.5 – 4325 (178.5)
Arid areas	55	10 – 46 (27)	0.1 - 5975 (259)
TOTAL	**853**	10 – 102 (36)	0.1 – 5975 (181)

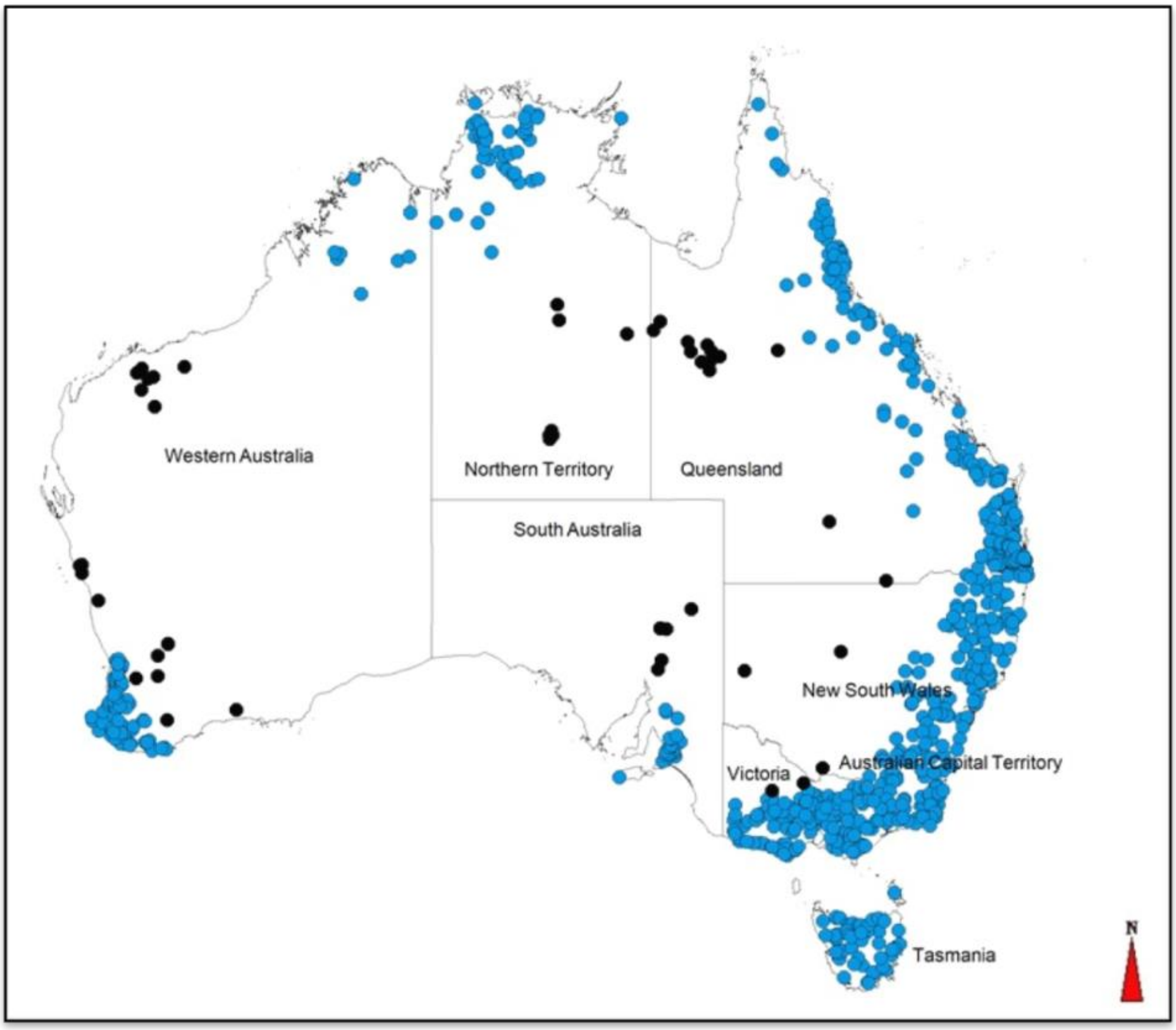

Figure 2.28 Geographical distribution of the selected 853 catchments (data-rich and arid areas)

2.6 Selection of climatic and catchment characteristics variables

A total of nine predictor variables are used in the development and testing of the RFFE Technique 2015, as outlined below:

i. catchment area in km^2 (*area*);
ii. mean annual rainfall at catchment centroid in mm (rain);
iii. design rainfall intensity at catchment centroid (in mm/h) for 6-hour duration and AEP of 50% ($I_{6,50}$);
iv. design rainfall intensity at catchment centroid (in mm/h) for 6-hour duration and AEP of 2% ($I_{6,2}$);
v. a ratio of design rainfall intensities of $I_{6,2}$ and $I_{6,50}$ ($I_{6,2}/I_{6,50}$);

vi. design rainfall intensity at catchment centroid (in mm/h) for duration equal to t_c hours and AEP of 50% ($I_{tc,50}$);

vii. design rainfall intensity at catchment centroid (in mm/h) for duration equal to t_c hours and AEP of 2% ($I_{tc,2}$);

viii. a ratio of design rainfall intensities of $I_{tc,2}$ and $I_{tc,50}$ ($I_{tc,2}/I_{tc,50}$); and

ix. *shape factor*, which is defined as the shortest distance between catchment outlet and centroid divided by the square root of catchment area.

The time of concentration (t_c) was approximated by Equation 2.1 (which was also recommended for use with the probabilistic rational method for eastern New South Wales and Victoria in ARR1987 (I. E. Aust., 1987). It is noted that other equations to estimate time of concentration (e.g. French, 2002 and Pegram, 2002) could have been adopted, but use of Equation 2.1 is deemed adequate as in the RFFE technique a measure of time of concentration is needed which can be applied consistently all over Australia relatively easily.

$$t_c = 0.76\,(area)^{0.38} \tag{2.1}$$

where t_c is the time of concentration (hours) and area is the catchment area (km^2).

Design rainfall intensities were extracted (at catchment centroid) using the new intensity-frequency-duration (IFD) data from Australian Bureau of Meteorology website (BOM, 2013).

Summary statistics of the relevant catchment characteristics data for different regions (Table 4.1 shows regions) are provided in Appendix A (Tables A9 to A15).

2.7 Streamflow data preparation and at-site flood frequency analysis

For the 798 selected stations from the data-rich regions, the gaps in the annual maximum (AM) flood series were filled as far as could be justified, outliers were detected and error associated with rating curve extrapolation was investigated, as presented below.

2.7.1 Infilling the gaps in the streamflow data

The rationale adopted for filling gaps in the flood record was that the infilled data would provide more useful information than ‘noise’. Any gap in the AM flood data series was in-filled by one of the two methods. Method 1 involved comparison of the monthly instantaneous maximum (IM) data with monthly maximum mean daily (MMD) data at the same station for years with data gaps (Haddad et al., 2010). If a missing month of instantaneous maximum flow corresponded to a month of very low maximum mean daily flow, then that was taken to show the annual maximum did not occur during that missing month. Method 2 involved a simple linear regression of the annual MMD flow series against the annual IM series of the same station. Regression equations developed were used for filling gaps in the IM record, but not to extend the overall period of record. For Victoria, 407 data points were in-filled by Method 1 and 96 data points were in-filled by Method 2. This represents about 6% of the total data points for Victoria. Overall, about 7% of the data points were in-filled for 798 Australian stations from the data-rich regions.

2.7.2 Detection of Potentially Influential Low Flows (PILFs) in the AM flood series

In the flood frequency analyses for the development of the RFFE Technique 2015, the interest was on defining flood frequencies for AEPs from 50% to 1%. The objective of low outlier tests is to identify those small annual floods which might have an undue influence on the fitting of the distribution in the AEP range of interest and should thus be censored from the AM series.

In the identification of low outliers, the Bulletin 17 B method, known as the Grubbs and Beck (GB) test (Grubbs and Beck, 1972) was initially tested, but it was found to be unsatisfactory failing to identify many potential low outlier values from the AM series. In one example (Site

130319A from QLD), it was found that use of GB test did not detect any low outlier; however an interactive method resulted in the detection of 7 low outliers, which produced quite different quantile estimates as shown in Table 2.2.

In USA, Lamontagne et al. (2013) and Cohn et al. (2013) presented a new Multiple Grubbs-Beck (MGB) test as part of the update to USA flood frequency guidelines, which will be part of Bulletin 17C. The MGB test is a statistical method designed to detect multiple low outliers, which are referred to as Potentially Influential Low Flows (PILFs) in this study. The MGB test is based on the probability distribution of the k^{th} smallest sample in a normally distributed sample. The MGB test has been incorporated into FLIKE (Kuczera, 1999); this has been adopted in this study to check for PILFs in the AM flood data preparation.

The summary of censoring of PILFs from the 176 stations from NSW and ACT is presented in Figure 2.29, which shows that in 18 cases greater than 40% data points needed censoring as per the new MGB test, 65 stations (37% of the stations) did not require any censoring and 111 stations (63% of the stations) required censoring. Although, in few cases the results might be thought to be 'unusual' e.g. about 40 to 50% of the AM data points need to be censored, in the investigation, it was found to be consistent with the judgement of experienced hydrologists who often adopt an interactive censoring. Interestingly, the flood quantile results based on MGB test censoring agreed very well with the GEV-L moments method, which provided added assurance for the MGB test.

Table 2.2 Impact of censoring Potentially Influential Low Flows (PILFs) on flood quantile estimates (Site 130319A from QLD, AM data covered 1961-2011) (Method used in quantile estimation: Bayesian LP3 method)

	Flood discharge (m^3/s)	
AEP	All 51 AM data	7 low values removed
50%	34	46
20%	234	192
10%	456	441
5%	683	921
2%	943	2224
1%	1098	4129

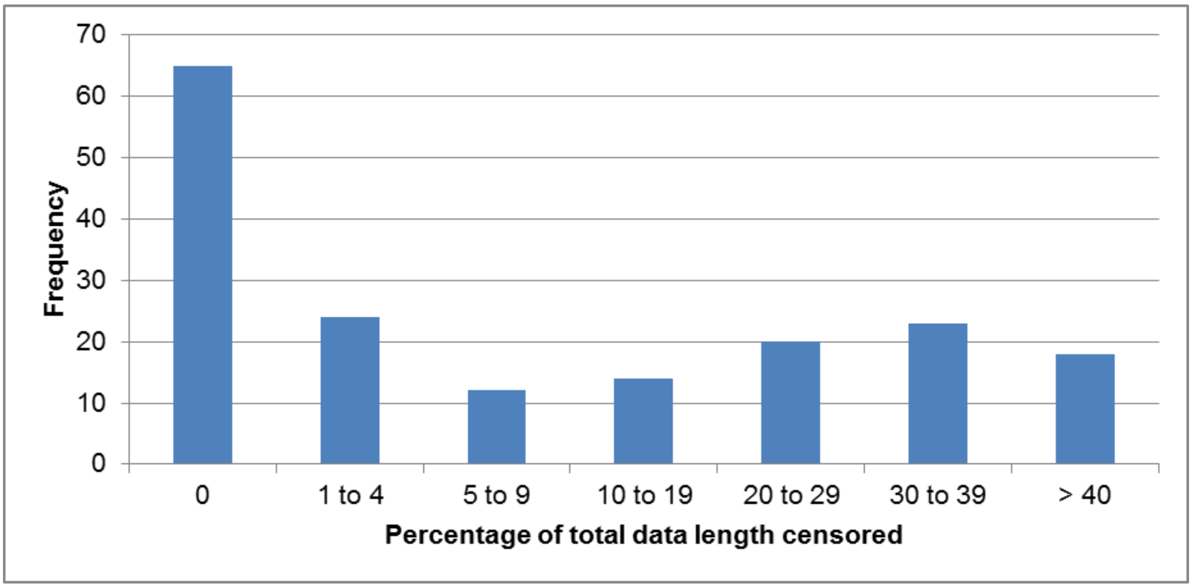

Figure 2.29 Summary results of censoring *Potentially Influential Low Flows (PILFs)* from NSW and ACT (176 stations) using MGB test

2.7.3 Impact of rating curve extrapolation error on flood quantile estimates

A rating curve is generally constructed based on the assumption that a one to one correlation exists between the river discharge and stage, which is generally referred to as the "true rating curve". However, the true rating curve is unknown and the standard method of constructing a rating curve consists of taking field measurements of water stage, *h*, and river discharge, *Q*. These measurements help to identify discrete points (*Q, h*) that are subsequently interpolated through an analytical relationship that generates the rating curve. Then the rating curve extension is needed to get the discharge value for the larger floods, which can introduce systematic uncertainty, either over or under estimation of true river discharge. The rating curve uncertainty is generally unknown but can be expected to increase as the water level rises above the highest measured flow. Potter and Walker (1981) suggested it could be as high as 30% in the extrapolation zone. In the interpolation zone, the uncertainty would be smaller (e.g. 1-5%) where the fitted rating curve is well supported by discharge-stage measurements (Kuczera, 1996; Reis and Stedinger, 2005). The rating curve related uncertainty in flow estimation has been widely researched (e.g. WMO, 1980; 2007; ASI, 2001a, b).

In this study, a “rating ratio” (RR) (Haddad et al., 2010) was used to identify the stations which would have annual maximum flood data associated with a high degree of rating curve extrapolation uncertainty. The RR is estimated by dividing the annual maximum flood series data point for each year (estimated flow Q_E) by the maximum measured flow (Q_M) at that station. The RR can be expressed as:

$$RR = \frac{Q_E}{Q_M} \quad (2.2)$$

Since the rating curve for a gauging station is usually updated with the availability of new measured flow data, a station may have several rating curves, each with a unique Q_M value applicable for a set period of time. Therefore, the appropriate Q_M value applicable for the respective rating curve for a given year was used to estimate the RR value in this study.

If the RR value is smaller than 1, the corresponding AM flood data points may be considered to be free from rating curve extrapolation uncertainty. However, the AM flood data points are considered to be associated with a higher degree of rating curve uncertainty when the RR values are well above 1. These data points can cause significant uncertainty in flood frequency analysis.

As an example, potential rating curve uncertainty of the AM flood data points for station 201001 in NSW is presented in Figure 2.30. It can be seen that, 34 out of 54 AM data points (63% of total data points) have RR values greater than 1 and the maximum RR value is 6.47. The largest measured flow has an approximate AEP of 50%. These data points with RR >> 1 are associated with a higher degree of rating curve uncertainty, which will translate into flood frequency estimates with a higher degree of uncertainty, especially for smaller AEP floods such as 2% and 1%.

As seen in the histogram of rating ratios (RR) of annual maximum flood data points for 96 stations in NSW and ACT (this is a subset of the 176 stations selected from NSW and ACT) (Figure 2.31), 60.5% of the RR values are less than 1 and 39.5% values between 1 and 47.29. A RR value well above 1 could amplify the uncertainty in flood frequency analysis. However, eliminating all stations with RR value greater than 1 would affect the results in the RFFE as it would reduce the number of stations below the minimum required for a meaningful RFFE.

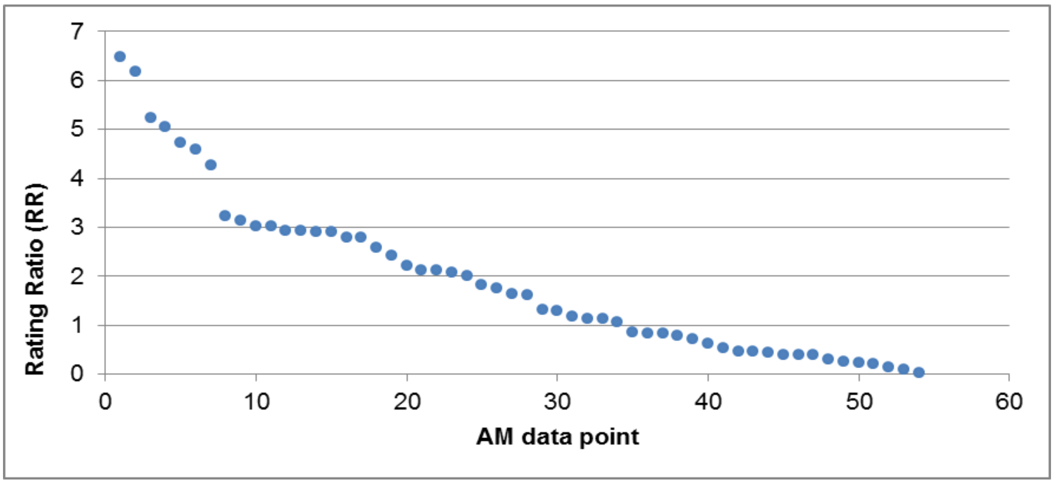

Figure 2.30 Plot of rating ratios (RR) for Station 201001 in NSW

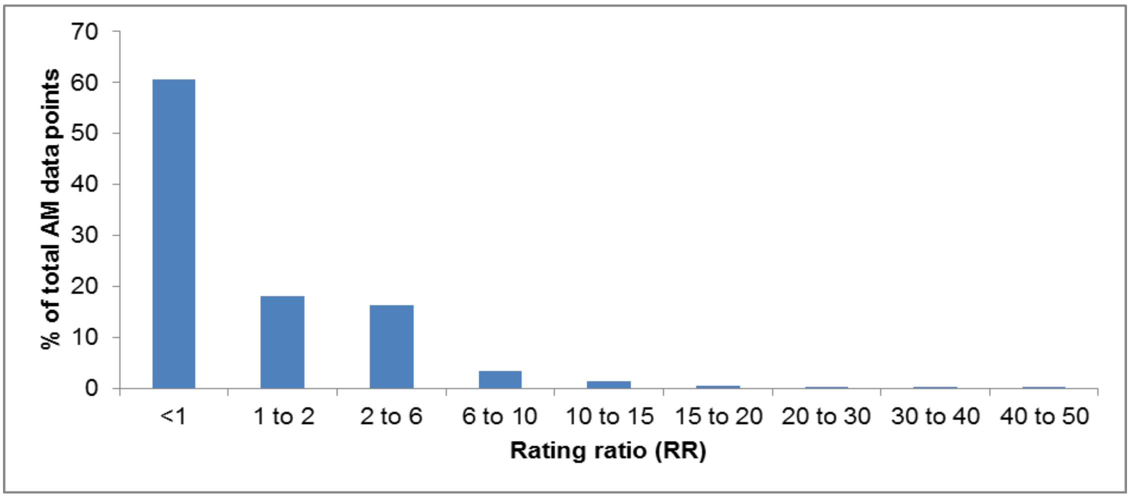

Figure 2.31 Histogram of rating ratio (RR) of AM flood data points from 96 catchments in NSW

In this investigation, log-log extrapolation of rating curve was explored as this is the most commonly adopted technique to extend the rating curve, among many other techniques. In log-log extrapolation, the uncertainty from the true rating curve increases systematically as the river discharge value increases beyond the range of discharge measurements. Therefore, an extrapolation zone is created as the rating curve is extended. The extrapolation zone is characterised based on the distance from the anchor point and not from the origin. Thus the systematic uncertainty is proportional to the distance from the anchor point (in log space). Here, the flow that has the RR value just greater than one was used as the “anchor point”. The flows with RR value greater than one are expected to be associated with rating curve extrapolation uncertainty. The higher the RR value for a data point, the greater the rating curve uncertainty associated with the data point.

In this investigation, the FLIKE software, which implements the principles outlined in Kuczera (1999), was adopted to fit the LP3 distribution using the Bayesian parameter fitting procedure to assess the impact of rating curve uncertainty on flood quantile estimates. No prior information was used in the FLIKE with both the "no rating curve" and the "rating curve uncertainty" cases. In the "no rating curve uncertainty" cases, the uncertainty coefficient of variation (CV) value was considered to be 0% for simplicity. In the "rating curve uncertainty" cases, three scenarios were considered where flows in the extrapolation zone were corrupted by a multiplicative uncertainty assumed to be log-normally distributed with mean one and CV values equal to 10%, 20% and 30%.

From the selected 96 catchments, 12 were selected for in-depth investigation (Table 2.3). As can be seen from Table 2.3, these 12 catchments range from 66 km^2 to 900 km^2 and the annual maximum flood record length ranges from 32 years to 60 years. The skew of $\log_e(Q)$, where Q is annual maximum flood series, is presented in the last column, which shows that 8 of these catchments have negative skew, including one having a value very close to zero, and 4 have positive skew values. These different skew values are useful to assess whether the impact of rating curve uncertainty on flood quantile estimates is affected by skew of the flood series for the catchment.

Table 2.3 Selected 12 catchments from NSW for investigating impacts of rating curve extrapolation error on flood quantile estimates

Station ID	Maximum RR	Average RR	Catchment area (km^2)	Record Length (years)	Period of Record	mean	SD	skew
203030	1.25	0.60	332	32	1980-2011	4.736	0.280	-0.607
204037	4.01	0.89	62	40	1972-2011	3.087	1.594	-0.854
204906	2.63	1.06	446	39	1973-2011	5.569	0.924	-0.995
207006	20.73	5.85	363	36	1976-2011	6.493	0.536	-0.159
209001	30.11	11.35	203	34	1946-1979	5.513	0.445	0.083
212008	2.33	0.29	199	60	1952-2011	4.290	0.907	0.262
218005	1.91	0.52	900	47	1965-2011	6.791	0.664	-0.553
219025	2	0.49	717	35	1977-2011	5.155	1.615	-0.263
222016	5.10	2.36	155	35	1976-2010	2.411	0.459	-0.004
410038	5.11	1.47	411	43	1969-2011	4.108	0.441	0.993
416008	8.89	2.84	866	40	1972-2011	5.776	0.387	0.515
419051	47.29	6.18	454	35	1977-2011	3.702	1.570	-0.429

The results of 12 selected stations are shown in Table 2.4. The results show that with the increasing CV values, the uncertainty in quantile estimates increases, in some cases reaching over 50% for 2% AEP, which indicates that the rating curve uncertainty has a notable impact on flood quantile estimates. The flood estimates for lower AEPs are found to be more affected by the rating curve uncertainties. Interestingly, there is no notable relationship between the RR values of the selected stations (shown in Table 2.3) and percentage differences in quantile estimates for different CVs, which is somewhat unexpected, and needs further investigation.

Figure 2.32 plots the differences in flood quantile estimates (between CV of 0% and CV of 20%) (for 2% AEP flood) with catchment size for the selected 96 catchments; this shows no linkage between the degree of differences in flood quantile estimates for different CVs and catchment area. Figures 2.33 and 2.34 show no relationship between differences in flood quantiles (for 2% AEP flood) due to different CVs (a measure of rating curve extrapolation error) and skew and SD of $\log_e(Q)$. Figure 2.35 shows that difference in flood quantiles between no rating curve uncertainty (CV = 0%) and CV = 20% can vary up to 50% for 2% AEP flood. The median difference for different AEPs (between CV of 0% and CV of 20%) based on 96 catchments in NSW and ACT are 1%, 2%, 3%, 6%, 9% and 12% for AEPs of 50%, 20%, 10%, 5%, 2% and 1%, respectively.

Table 2.4 Example demonstrating impact of rating curve uncertainty on flood quantile estimates

	2% AEP flood quantile (m^3/s)						
Station	No rating uncertainty (CV = 0%)	Rating uncertainty (CV = 10%)		Rating uncertainty (CV = 20%)		Rating uncertainty (CV = 30%)	
	Expected	Expected	% change from CV = 0%	Expected	% change from CV = 0%	Expected	% change from CV = 0%
203030	171	179	5	190	11	205	20
204037	250	268	7	296	19	330	32
204906	978	1076	10	1209	24	1352	38
207006	1953	2392	22	2538	30	2600	33
209001	645	687	6	753	17	845	31
212008	501	515	3	534	7	560	12
218005	2640	2891	10	3375	28	4036	53
219025	2340	2499	7	2770	18	3094	32
222016	29	31	5	34	15	39	33
410038	176	192	9	227	29	277	57
416008	790	831	5	890	13	967	22
419051	773	806	4	903	17	1014	31

The results indicated that a higher assumed value of rating curve uncertainty (i.e. a higher CV) in flood frequency analysis) increased estimated flood quantiles and inflated the uncertainty bounds around the estimated flood quantiles (i.e. increases the width of the 90% confidence limits). This was more noticeable for smaller AEP floods.

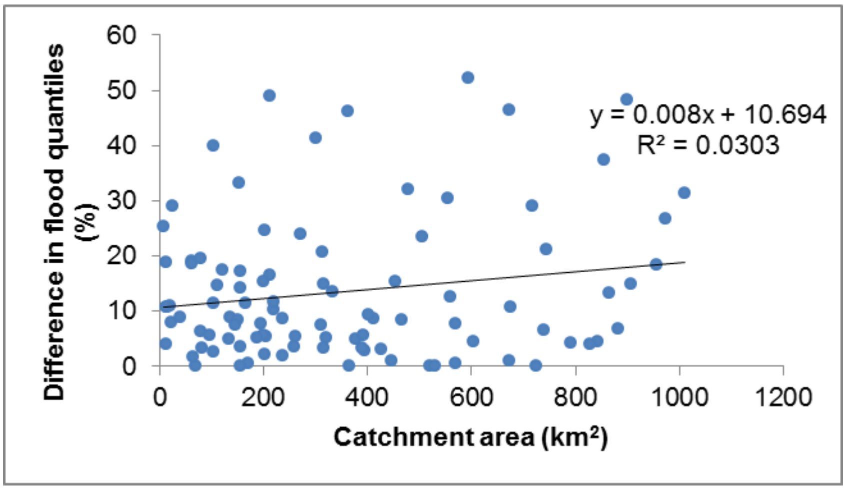

Figure 2.32 Catchment size vs. differences in flood quantile estimates between CV of 0% and CV of 20% for 96 NSW catchments (for 2% AEP flood)

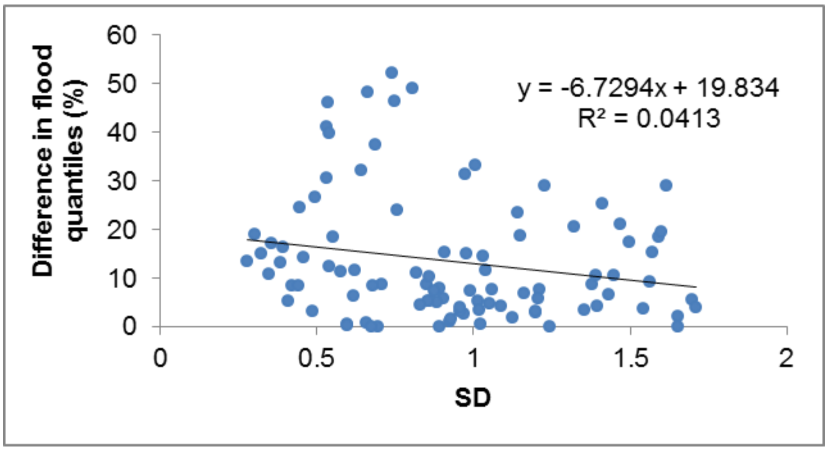

Figure 2.33 Plot of SD of $\log_e(Q)$ vs. differences in flood quantile estimates between CV of 0% and CV of 20% (96 catchments from NSW) (for 2% AEP flood)

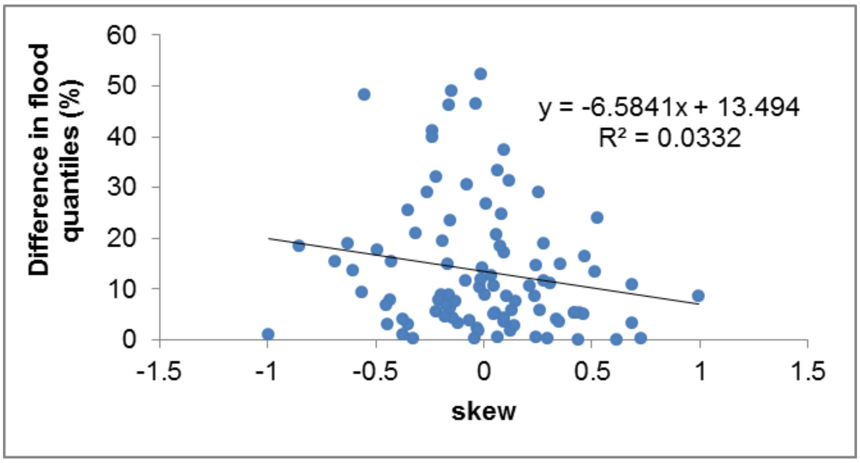

Figure 2.34 Plot of skew of $\log_e(Q)$ vs. differences in flood quantile estimates between CV of 0% and CV of 20% (96 catchments from NSW) (for 2% AEP flood)

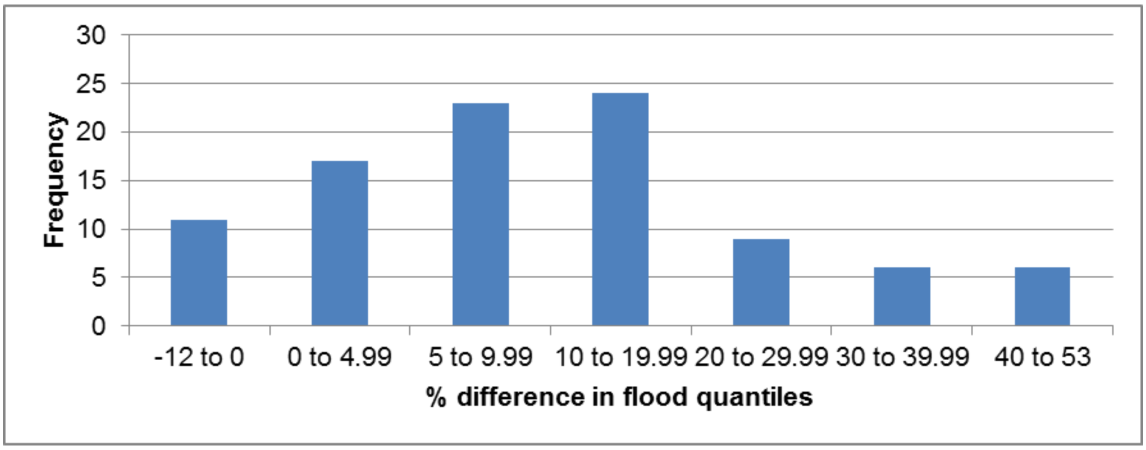

Figure 2.35 Difference in flood quantiles between CV of 0% and CV of 20% for 2% AEP flood quantiles (96 catchments from NSW)

The expected quantiles show notable differences between CV = 0% and CV = 20%, as can be seen in Figures 2.36 and 2.37 for 96 NSW catchments. These figures show that in most cases the expected quantile estimates increase as CV increases. Moreover, the differences in quantile estimates between CV = 0% and CV = 20% increase with a decrease in AEP. In the development of ARR Project 5 RFFE Technique 2015, it was decided to take flood quantile estimates with CV = 0% since it was felt that more research needs to be undertaken to understand the implication of rating curve extrapolation error on flood quantile estimates.

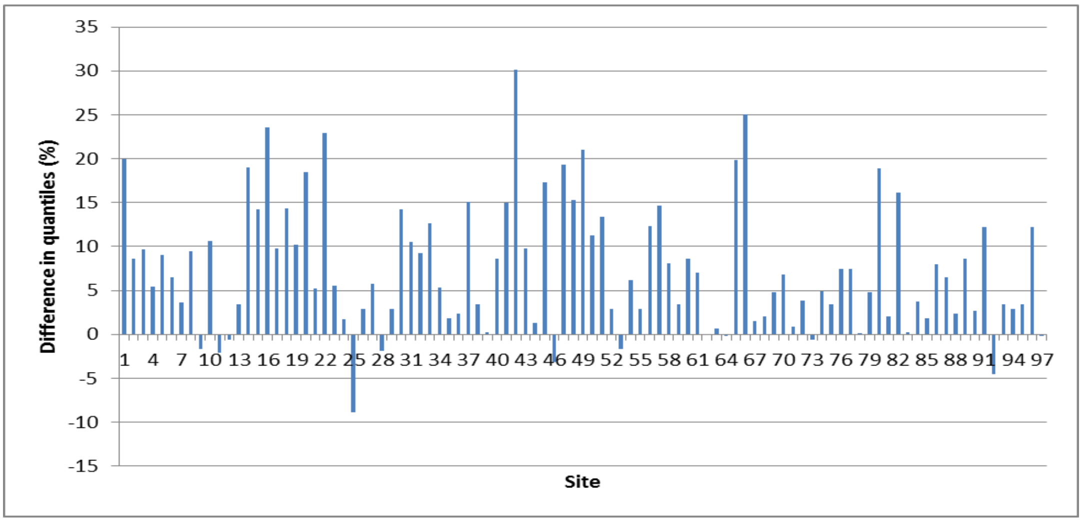

Figure 2.36 Differences in quantile estimates (expected quantiles from FLIKE) between CV = 0% and CV = 20% for 96 catchments in NSW (for 5% AEP flood)

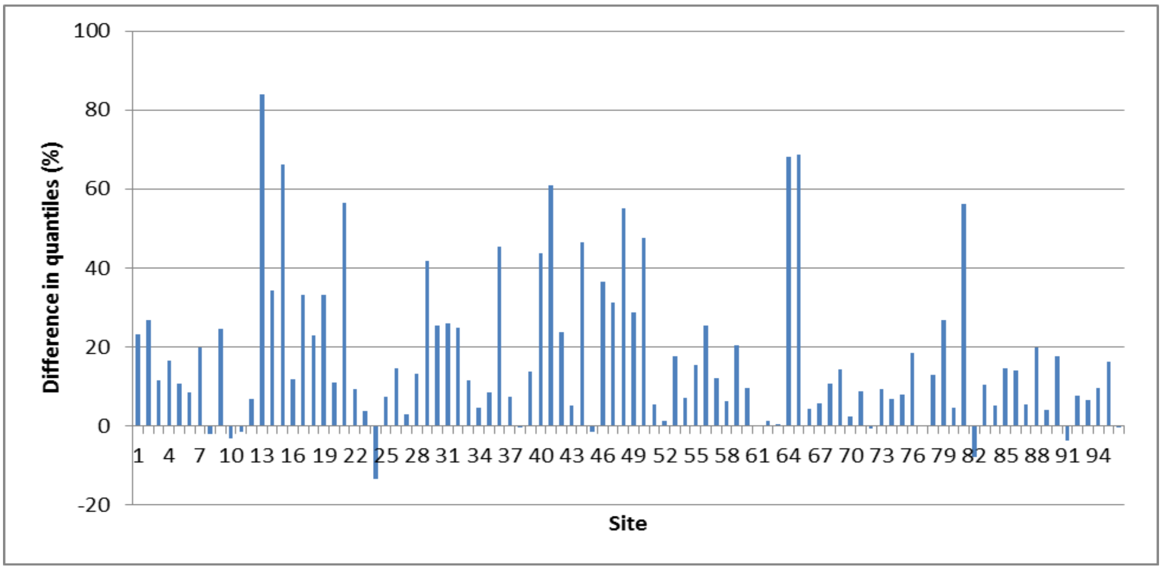

Figure 2.37 Differences in quantile estimates (expected quantiles from FLIKE) between CV = 0% and CV = 20% for 96 catchments in NSW (for 1% AEP flood)

2.7.4 At-site flood frequency analysis

For at-site flood frequency analysis, the LP3 distribution was fitted with the Bayesian parameter estimation procedure using the FLIKE software (Kuczera, 1999). The potentially influential low flows (PILFs) were identified using the multiple Grubbs-Beck test (Lamontagne et al., 2013; Cohn et al., 2013) (as mentioned in Section 2.7.2) and were censored in the flood frequency analysis.

The standard deviation (SD) and skew of the $\log_e(Q)$ series (where Q represents the AM flood series) were estimated after necessary censoring of PILFs from the respective AM flood series. It was found that the standard deviation (SD) of $\log_e(Q)$ AM flood series was not dependent on catchment size (for example see Figure 2.38). Likewise Figure 2.39 shows that skew (of $\log_e(Q)$) did not depend on catchment area, the average skew of NSW catchments was close to zero and there were almost equal numbers of catchments with negative and positive skew values.

Although the impacts of rating curve error on flood quantile estimation was investigated (as mentioned in Section 2.7.3), it was decided to take flood quantile estimates with CV = 0% (here CV is a measure of rating curve extrapolation error) in developing the RFFE Technique 2015 since it was felt that more research needs to be undertaken to understand the implication of rating curve extrapolation error on flood quantile estimates.

For each of the 798 stations selected from the data-rich areas, flood quantiles were estimated for AEPs of 50%, 20%, 10%, 5%, 2% and 1%.

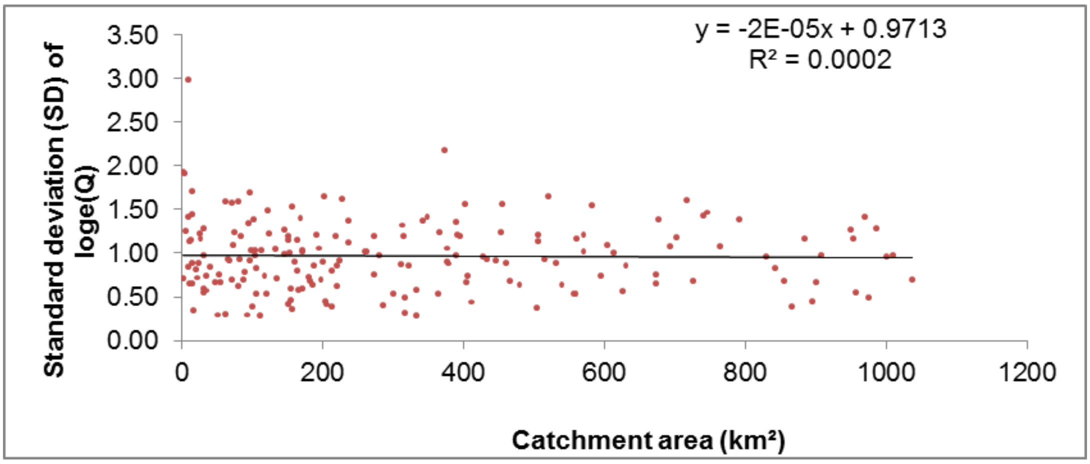

Figure 2.38 Relationship between SD of $\log_e(Q)$ and catchment area for NSW 176 catchments

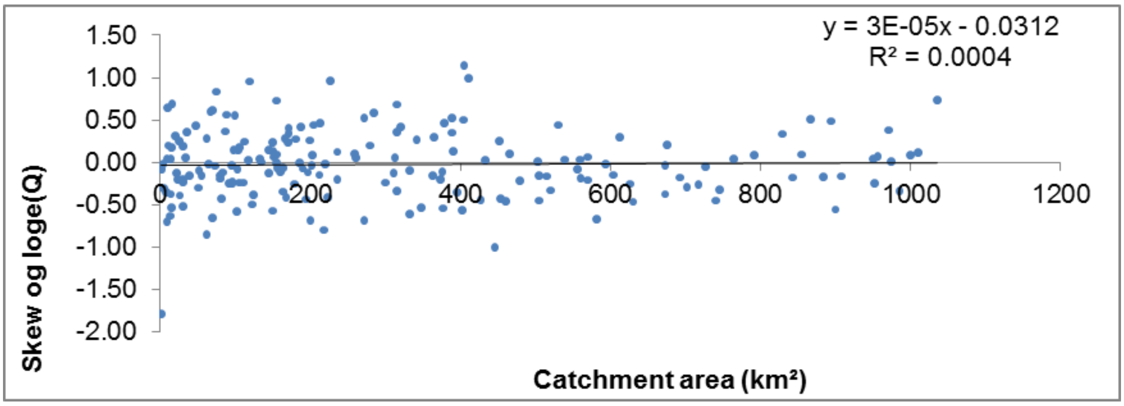

Figure 2.39 Relationship between skew of $\log_e(Q)$ and catchment area for NSW 176 catchments

Most of Australia's interior falls into the arid and semi-arid areas (referred to as arid areas), which are characterised by low mean annual rainfall in relation to mean annual potential evaporation. Rainfall events tend to be infrequent and their occurrence and severity are highly variable. Typically dry antecedent conditions may result in many rainfall events not producing any significant runoff. However, severe rainfall events can still result in significant flooding with serious consequences for a range of activities. Large transmission losses may also result in discharge reducing in a downstream direction, particularly in the lower river reaches of larger catchments in arid areas. The special flooding characteristics of catchments in arid areas make it desirable to treat them separately from catchments in more humid areas. In arid areas, annual maximum flood series generally contain many zero values and hence it is more appropriate to use the partial duration series in flood frequency analysis, which is adopted here.For the data-poor (arid) areas, the flood quantiles were estimated for AEPs of 50%, 20%, 10%, 5%, 2% and 1% at each of the 55 stations based on the abstracted partial duration series data (considering average number of events per year = 0.5) by fitting a Generalised Pareto distribution using L moments.

2.8 Archiving of the data

The list of selected catchments, annual maximum flood series data from the data-rich areas, partial duration series data for the arid areas, estimated flood quantiles and abstracted catchment characteristics data of all the 853 stations have been saved in a CD and archived with Engineers Australia (National Committee on Water Engineering).

3 Description of adopted statistical methods

3.1 Region-of-influence (ROI) approach

Acreman and Wiltshire (1987) proposed regions without fixed boundaries. Based on this concept, Burn (1990a, 1990b) and Zrinji and Burn (1994) proposed the region of influence (ROI) approach where each site of interest (i.e. a catchment where flood quantiles are to be estimated) can form its own local region. A key advantage of the ROI approach is that it can overcome the inconsistency in flood quantile estimates at the boundary of two neighbouring administrative regions (e.g. state borders).

A recent study by Eng et al. (2005) compared the performance of ROI approaches based on predictor-variable similarity or geographical proximity for estimating the 2% AEP peak discharge, using an ordinary least squares approach with 1091 sites in south-eastern USA. They found that using geographical proximity produced the smallest predictive errors over the study region. Similar results demonstrating the superiority of geographical proximity over predictor-variable similarity have been shown by others (e.g. Merz and Blöschl, 2005; Kjeldsen and Jones, 2007). Hence, Haddad and Rahman (2012), Haddad, Rahman and Stedinger (2012) and Micevski et al. (2014) applied the ROI approach to Australian regional flood studies using geographical proximity as a measure to form ROI regions, and this approach has also been adopted in this study.

In the formation of regions, the ROI approach has been adopted in this study for the parts of Australia where there are adequate numbers of gauged stations within close proximity to form ROI sub-regions (i.e. for the data-rich areas). The adopted ROI approach uses the geographical distance between stations as the distance metric.

One of the apparent limitations of the ROI approach for practical application is that for each of the gauged sites in the region, the regional prediction equation has a different set of model parameters; hence a single regional prediction equation cannot be pre-specified. To overcome this problem, the parameters of the regional prediction model for all the gauged catchment locations in a ROI region have been pre-estimated, stored and integrated with the RFFE Model 2015.

3.2 Parameter regression technique (PRT)

In this study for the data-rich regions of Australia, the first three moments of the LP3 distribution (i.e. the mean, standard deviation and skewness of the logarithm of the annual maximum flood series) are regionalised. This method is referred to as parameter regression technique (PRT). The LP3 distribution is described by the following equation:

$$\ln Q_x = M + K_x S \tag{3.1}$$

where Q_x = the discharge having an AEP of x% (design flood or flood quantile);
M = mean of the natural logarithms of the annual maximum flood series;
S = standard deviation of the natural logarithms of the annual maximum flood series; and
K_x = frequency factor for the LP3 distribution for AEP of x%, which is a function of the AEP and the skewness (SK) of the natural logarithms of the annual maximum flood series.

The prediction equations for the mean (M), standard deviation (S) and skewness (SK) were developed for all the gauged catchment locations in the data-rich areas using Bayesian GLS regression. These equations are used to predict the M, S and SK for an ungauged catchment of interest within the data-rich areas.

3.3 Bayesian Generalised Least Squares Regression

In developing the prediction equations, the Bayesian generalised least squares (GLS) regression (Stedinger and Tasker, 1985; Tasker and Stedinger, 1989) has been adopted in the data-rich areas. The GLS regression model explicitly accounts for the sampling variability in the dependent variable data, e.g. inter-station correlation and variation in record lengths of the annual maximum flood data from site to site. The GLS regression assumes that the hydrological variable of interest (e.g. a parameter of the LP3 distribution such as mean, M) denoted by y_i for a given site i can be described by a function of catchment characteristics (explanatory variables) with an additive error (Griffis and Stedinger, 2007):

$$y_i = \beta_0 + \sum_{j=1}^{k} \beta_j X_{ij} + \delta_i \; ; \; i = 1, 2, \ldots, n \tag{3.2}$$

where X_{ij} (j = 1,…, k) are explanatory variables, β_j are the regression coefficients, δ_i is the model error which is assumed to be normally and independently distributed with model error variance σ_δ^2, and *n* is the number of sites in the region. In all cases only an at-site estimate of y_i denoted as $\hat{y}_i$ is available. To account for the error in the at-site estimate, a sampling error η_i must be introduced into the model so that:

$$\hat{\mathbf{y}} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\eta} + \boldsymbol{\delta} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \quad \text{where } \hat{y}_i = y_i + \eta_i;\ i = 1, 2, \ldots, n \tag{3.3}$$

Thus the observed regression model error $\boldsymbol{\varepsilon}$ is the sum of the model error δ and the sampling error η. The total error vector has a mean of zero and a covariance matrix:

$$E\left[\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}^T\right] = \boldsymbol{\Lambda}(\sigma_\delta^2) = \sigma_\delta^2\mathbf{I} + \Sigma(\hat{\mathbf{y}}) \tag{3.4}$$

where $\sum(\hat{\mathbf{y}})$ is the covariance matrix of the sampling error in the estimate of the flood quantile or the parameter of the LP3 distribution, **I** is a ($n \times n$) identity matrix. The covariance matrix for η_i depends on the record length available at each site and the cross correlation among annual maximum floods at different sites. Therefore, the observed regression model error is a combination of time-sampling error η_i and an underlying model error δ_i.

The GLS estimator of $\boldsymbol{\beta}$ and its covariance matrix for a known σ_δ^2 is given by:

$$\hat{\beta}_{GLS} = \left[\mathbf{X}^T \Lambda(\sigma_\delta^2)^{-1}\mathbf{X}\right]^{-1}\mathbf{X}^T\Lambda(\sigma_\delta^2)^{-1}\hat{\mathbf{y}} \tag{3.5}$$

$$\Sigma[\hat{\beta}_{GLS}] = \left[\mathbf{X}^T \Lambda(\sigma_\delta^2)^{-1}\mathbf{X}\right]^{-1} \tag{3.6}$$

The model error variance σ_δ^2 can be estimated by either generalised method of moments (MOM) or maximum likelihood estimators. The MOM estimator is determined by iteratively solving Equation 3.5 along with the generalised residual mean square error equation:

$$(\hat{\mathbf{y}} - \mathbf{X}\hat{\boldsymbol{\beta}}_{GLS})^T[\hat{\sigma}_\delta^2\mathbf{I} + \Sigma(\hat{\mathbf{y}})]^{-1}(\hat{\mathbf{y}} - \mathbf{X}\hat{\boldsymbol{\beta}}_{GLS}) = n - (k+1) \tag{3.7}$$

In some situations, the sampling covariance matrix explains all the variability observed in the data, which means the left-hand side of Equation 3.7 will be less than n – (k + 1) even if $\hat{\sigma}_\delta^2$ is zero. In these circumstances, the MOM estimator of the model error variance is generally taken to be zero.

With the Bayesian approach, it is assumed that there is no prior information on any of the β parameters; thus a multivariate normal distribution with mean zero and a large variance (e.g. greater than 100) is used as a prior for the regression coefficient parameters. This prior is considered to be almost non-informative, which produces a probability distribution function that is generally flat in the region of interest. The prior information for the model error variance σ_δ^2 is represented by a one-parameter exponential distribution. Further description of the adopted Bayesian GLS regression can be found in Haddad, Rahman and Kuczera (2011) and Haddad and Rahman (2012).

3.4 Model validation approach

To assess the performance of the developed RFFE technique, a leave-one-out (LOO) validation approach was applied where one catchment was left out and a model was developed using the remaining catchments and then the developed model was tested on the single catchment that was left out. The procedure was repeated until all the catchments were tested once. This ensures an independent testing of the RFFE technique for each of the catchments in the database. For both the data-rich and data-poor regions, the LOO validation approach was adopted. Further information on the LOO validation approach can be found in Haddad et al. (2013).

3.5 RFFE method adopted in the data-poor (arid) areas

The application of ROI and PRT methods was deemed inappropriate in the arid areas as ROI approach requires a number of gauging stations to form sub-regions and the number of gauging stations in the arid areas of Australia is insufficient for this purpose. Hence a simpler RFFE method was considered more appropriate for the arid areas. Here, an index type approach as suggested by Farquharson et al. (1992) and tested by Zaman, Rahman and Haddad (2012) was adopted. The 10% AEP flood quantile (Q_{10}) was used as the index variable and a dimensionless growth factor for AEP of x% (GF_x) was used to estimate Q_x:

$$Q_x = Q_{10} \times GF_x \tag{3.8}$$

A prediction equation was developed for Q_{10} as a function of catchment characteristics, and regional growth factors were developed based on the observed partial duration series flood data. In the arid areas, significant storm events do not typically occur every year, and some of these events do not produce significant floods. A partial duration series analysis with an average occurrence of less than one flood event per year was thus considered appropriate. In the application, partial series–based Q_x estimates can be converted to equivalent annual maximum flood series estimates using the Langbein transformation (Langbein, 1949).

The flood quantiles are estimated for AEPs of 50%, 20%, 10%, 5%, 2% and 1% at each of the 55 stations based on the abstracted partial duration series data (adopting the average number of events per year = 0.5) by fitting a Generalised Pareto distribution using L moments. The Q_x/Q_{10} values are first estimated at individual stations; the weighted average of these values (weighting is done based on record length at individual sites) over all the stations in a region then defines the growth factors (GF_x) for the region.

3.6 Development of confidence limits for the estimated flood quantiles

In developing the confidence limits for the estimated flood quantiles, a Monte Carlo simulation approach was adopted by assuming that the uncertainty in the first three parameters of the LP3 distribution (i.e. the mean, standard deviation and skewness of the logarithms of the annual maximum flood series) can be specified by a multivariate normal distribution. Here the correlations among the three parameters for a given region were estimated from the residuals of the GLS regression models of the LP3 parameters. The mean of the LP3 parameter was given by its regional predicted value and the standard deviation of the LP3 parameter was the square root of the average variance of prediction of the parameter at the nearest gauged site. Based on 10,000 simulated values of the LP3 parameters from the multivariate normal distribution as defined above, 10,000 Q_x values were estimated, which were then used to develop the 90% confidence intervals.

4 Formation of regions in the RFFE technique

In the adopted RFFE technique, Australia is divided into seven regions. There are five data-rich regions, as shown in Figure 4.1 and Table 4.1. For each of these data-rich regions, the ROI approach was implemented e.g. for data-rich Region 2, ROI was implemented using 51 stations from Tasmania. All the 558 stations from Victoria (VIC), the Australian Capital Territory (ACT), New South Wales (NSW) and Queensland (QLD) form Region 1. A total of 28 stations from South Australia (SA) form Region 3. Fifty stations from the Northern Territory (NT) and 8 stations from the Kimberley region of Western Australia (WA) i.e. a total of 58 stations are combined to form Region 4. A total of 103 stations from south-west Western Australia (WA) form Region 5.

The formation of regions in the arid areas in Australia is a difficult task, as there are only 55 catchments available from a vast area of Australia. There are two alternatives: (i) formation of one region with all the 55 stations; and (ii) formation of smaller sub-regions based on geographical proximity, noting that too small a region makes the developed RFFE technique of little statistical significance. Examination of a number of alternative sub-regions led to the formation of two regions from the 55 arid catchments: Region 6 (11 catchments from the Pilbara area of WA) and Region 7 (44 catchments from all other arid areas except Pilbara) (see Figure 4.1 for the extent of these two arid regions).

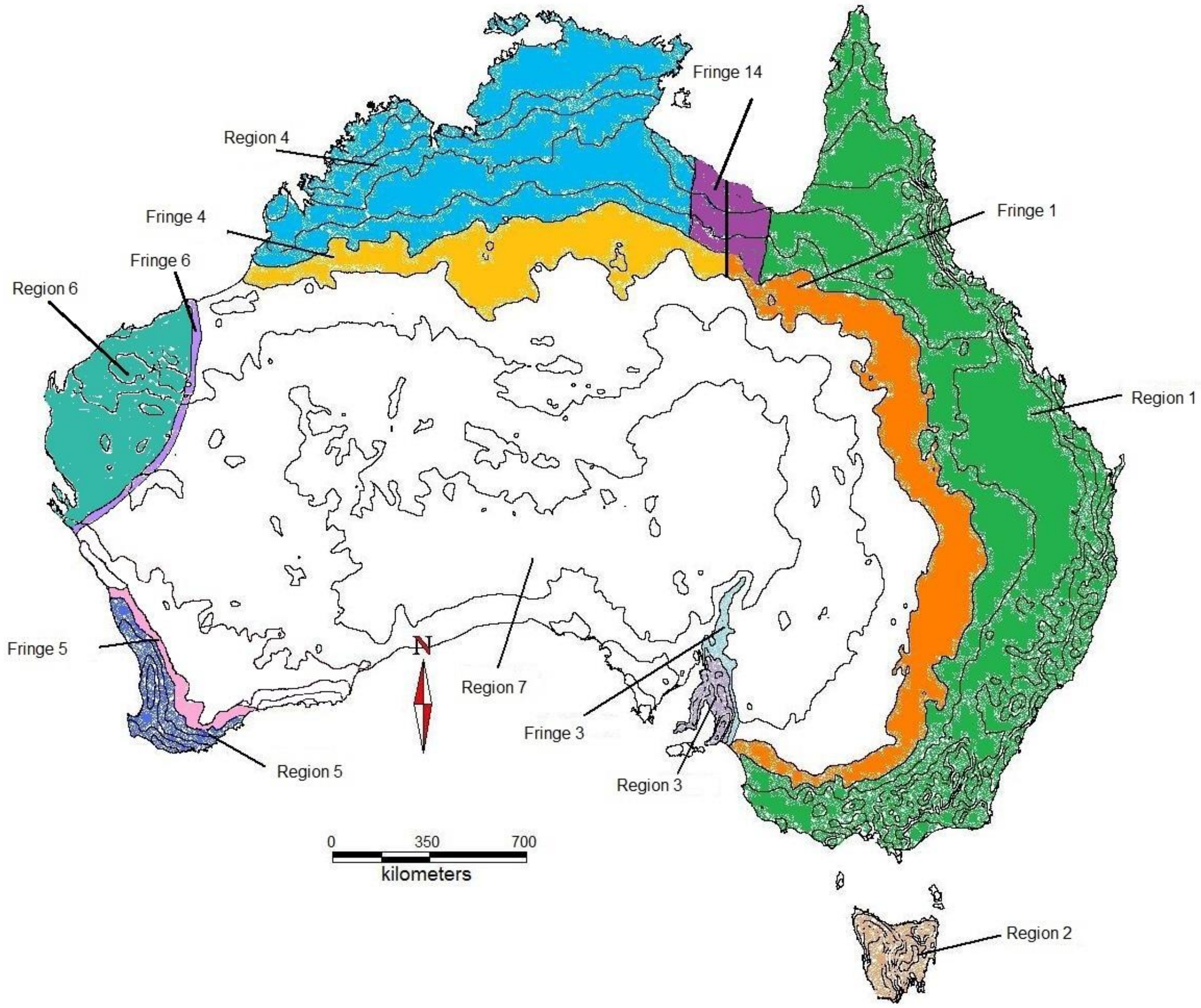

Figure 4.1 Adopted regions in the RFFE Technique 2015

Table 4.1 Details of five data-rich regions in RFFE Technique 2015

Region	Method to form region	Number of stations	Estimation model
Region 1: VIC + NSW + ACT + QLD	ROI	558	Bayesian GLS regression-PRT
Region 2: Tasmania		51	
Region 3: South Australia		28	
Region 4: NT + Kimberley WA		58	
Region 5: SW Western Australia		103	

Table 4.2 Details of two data-poor/arid regions in RFFE Technique 2015

Region	No. of stations	Estimation model
Region 6: Pilbara arid area	11	Fixed region Index flood method with Q_{10} as the index variable
Region 7: All other arid areas	44	Fixed region Index flood method with Q_{10} as the index variable

The boundaries between the arid (data-poor) and data-rich regions in Figure 4.1 are drawn approximately based on the 500 mm mean annual rainfall contour line. To reduce the effects of sharp variation in quantile estimates for the ungauged catchments located close to these regional boundaries, six fringe zones are delineated, as shown in Figure 4.1 and summarised in Table 4.3. For these fringe zones, the flood quantile at an ungauged catchment location is taken as the inverse distance weighted average value of the two nearby regional estimates.

Table 4.3 Details of six fringe zones in RFFE Technique 2015

Name	Location
Fringe 1	Between Region 1 and Region 7
Fringe 3	Between Region 3 and Region 7
Fringe 4	Between Region 4 and Region 7
Fringe 5	Between Region 5 and Region 7
Fringe 6	Between Region 6 and Region 7
Fringe 14	Between Region 1 and Region 4

5 Development of regional prediction equations for the data-rich regions

5.1 Searching for the best regression equation using Bayesian GLS regression

For each of the five data-rich regions shown in Table 4.1, prediction equations for *M*, *S* and *SK* for the regional LP3 model (Equation 3.1) were developed using Bayesian GLS regression, as discussed below. Initially a fixed region regression approach and an exploratory data analysis, using all the catchments (for a given data-rich region) and catchment predictor variables were considered. This was carried out to determine the best functional form of the regression equation for use with the ROI method. The fixed region regression using Bayesian GLS regression was carried out for each of the three parameters of the LP3 distributions (i.e. *M*, *S* and *SK*).

A total of nine predictor variables were considered in the analysis (see Section 2.6 for details of these predictor variables). The variables associated with rainfall duration equal to time of concentration (t_c) were not considered as these were found to be highly correlated with catchment area (in some cases the correlation coefficients were greater than 0.9). In all, 511 (i.e. 2^9- 1) different combinations are possible for nine predictor variables; however, 256 models were trialled for each of the *M*, *S* and *SK*, only taking the models that have an intercept.

In the preliminary analysis, the relation between *M* and catchment area was found to be curvilinear; however, the relation between *M* and logarithms of catchment area was generally found to be linear. Homoscedasticity (a constant variance in the response variable over the range of the predictor variables) and normality of the residuals are requirements for regression. The logarithmic transformation of the predictor variables enhances the homoscedasticity of the data and was therefore applied in this analysis.

The final selection of predictor variables for inclusion into a model for a given region was made based on several statistical criteria, including model error variance (MEV), GLS coefficient of determination (R^2_GLSR), average variance of prediction at a new site (AVPN), average variance of prediction at an old site (AVPO), Akaike information criterion (AIC), Bayesian information criterion (BIC) and statistical significance of a predictor variable using the Bayesian plausibility value (BPV).

The analysis for Region 2 (Tasmania) is provided here as an example. Figure 5.1 shows example plots of the statistics used in selecting the best set of predictor variables for *M*, *S* and *SK* models for Region 2. According to the model error variance and R^2_GLSR, a number of combinations of the predictor variables (out of the possible 256 combinations) appeared to be feasible. For the *M* model, combinations 34, 35, 64 and 170 were finally shortlisted. Combinations 170 and 64 contained 6 and 8 predictor variables respectively and had lower model error variances and larger R^2_GLSR compared to combinations 34 and 35. Combinations 34 and 35 contained two predictor variables (*area* and $I_{6,50}$) and 3 predictor variables (*area,* $I_{6,50}$ and SF), respectively. The gain from the 3 to 6 extra predictor variables in combinations 170 and 64 was relatively modest. Combination 35 had slightly smaller model error variance compared with combination 34 (0.58 as compared to 0.63) and slightly larger R^2_GLSR (0.78 compared to 0.75). The AVPO, AVPN, AIC and BIC values favoured combination 35 over combination 34, and hence combination 35 (having three predictor variables: *area,* $I_{6,50}$ and *shape factor*) was finally selected as the best set of predictor variables for the mean (*M)* model for Region 2 (Tasmania).

For the standard deviation (*S*) model, combination 1 (a constant value i.e. no predictor variable model) showed a slightly higher model error variance (0.036) than combinations 5 (0.025), 17 (0.030), and 81 (0.028) (which contain one to three predictor variables). The lowest AIC and BIC values were found for combination 17; and the lowest AVPO and AVPN values were found for combination 5 (having one predictor variable). These combinations needed one to three predictor variables adding extra complexity to the model without much gain. Combination 1 without any predictor variable, while showing a slightly larger AVPO and AVPN, was the preferred option both from an application and statistical point of view; however, both combinations 1 and 5 were trialled in this study for the standard deviation (*S*) model for Region 2 (Tasmania). It was found that combination 1 provided slightly better results in the flood quantile estimation than combination 5 and hence was finally adopted. For the skew (*SK*) model, combination 5 (one predictor variable, ratio $I_{6,2}/I_{6,50}$) showed a slightly smaller model error variance than combination 1 (a constant value i.e. no predictor variable model). Combination 5 also showed a reasonable R^2_GLSR value (52%). The lowest AIC and BIC values were found for combination 179, which had 6 predictor variables. Combination 1 however showed lower AVPO and AVPN values compared to combination 5. Both combinations 1 and 5 were trialled in this study. It was found that combination 1 provided slightly better results in the flood quantile estimation and hence was finally adopted.

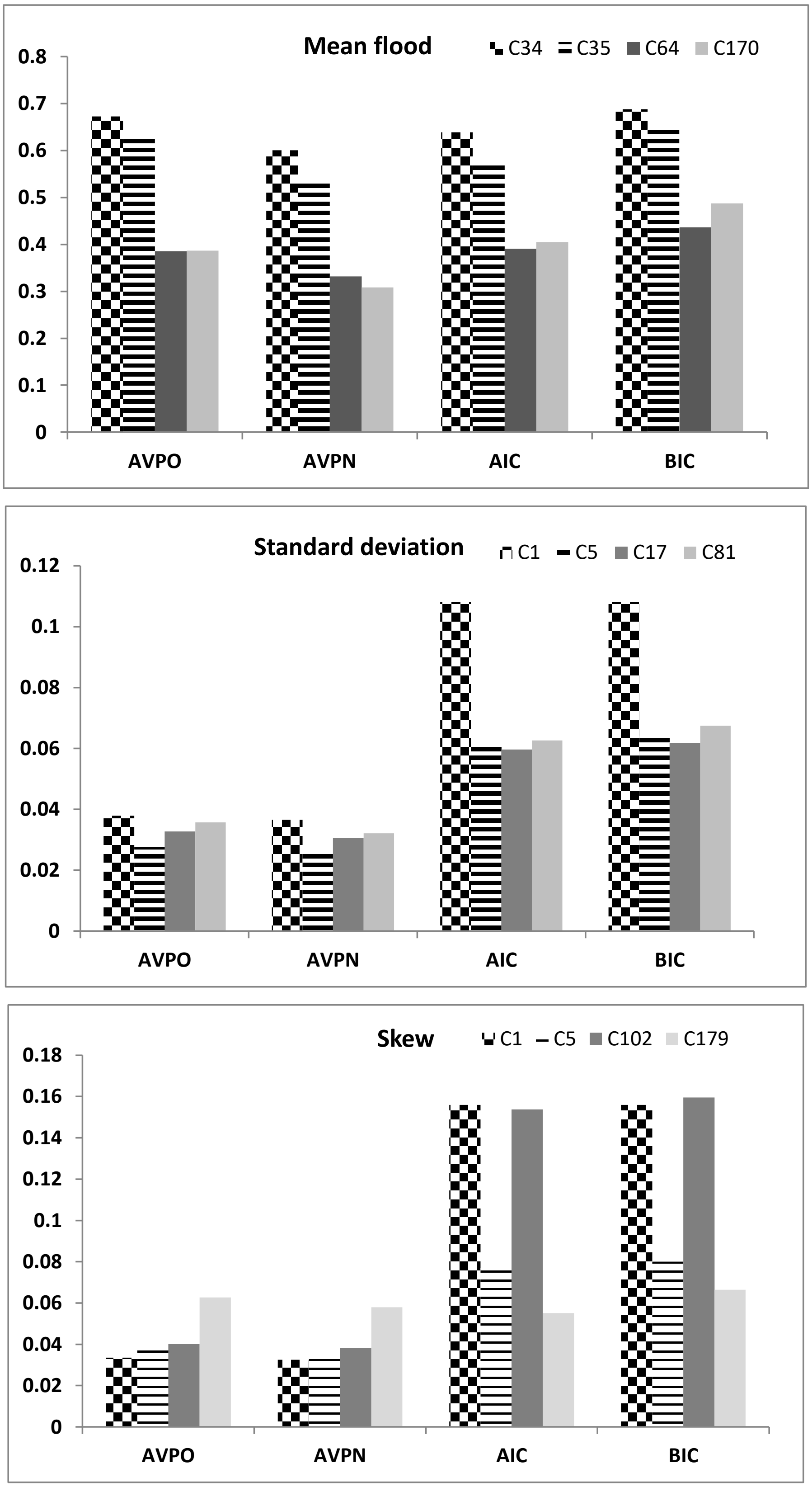

Figure 5.1 Selection of predictor variables for mean (*M*), standard deviation (*S*) and skew (*SK*) models, AVPO = average variance of prediction (old), AVPN = average variance of prediction (new) AIC = Akaike information criterion, BIC = Bayesian information criterion

The significance of the estimated regression coefficient values of the finally adopted models were then evaluated using the Bayesian plausibility value (BPV) test as described by Gruber et al. (2007). The BPV allows one to perform the equivalent of a classical hypothesis *p*-value test within a Bayesian framework. The BPV test was carried out at the 5% significance level. The advantage of the BPV is that it uses the posterior distribution of each β-parameter. For the mean (*M*) model flood, the BPV values for the regression coefficients associated with the predictor variables *area*, and design rainfall intensity $I_{6,50}$ were found to be smaller than 0%. For the predictor variable shape factor the BPV was found to be 6%. Thus the inclusion of these predictor variables for *M* model for Region 2 (Tasmania) was justified as they were significantly different from zero.

For the standard deviation (*S*) model, the BPV value for combination 1 (no predictor variable model) was found to be 0%. For combination 5 (with predictor variable ratio $I_{6,2}/I_{6,50}$), the BPV value was found to be 2%. For the skew (*SK*) model, the BPV for combination 1 (no predictor variable model) was found to be 0%. For combination 5 (with predictor variable ratio $I_{6,2}/I_{6,50}$), the BPV value was found to be 4%.

The prediction equations for *M*, *S* and *SK* for the regional LP3 model (Equation 3.1) for each of the five data-rich regions (shown in Table 4.1) were developed following the above procedure. The general forms of these prediction equations are provided below (Equations 5.1 to 5.9). It should be noted that the regression coefficients for each of these prediction equations were developed at each of the gauged locations in a given region based on ROI approach as mentioned in Section 5.2.

Region 1: VIC + NSW + ACT + QLD

$M = b_0 + b_1(\ln(area)) + b_2(\ln(I_{6,\,50})) + b_3\,(\ln(shape\ factor))$ (5.1)

S = regional weighted average value

SK = regional weighted average value

Region 2: Tasmania

$M = b_0 + b_1(\ln(area) - 4.90) + b_2(\ln(I_{6,50}) - 1.776) + b_3(\ln(shape\ factor) - (-0.2586))$ (5.2)

S = regional weighted average value

SK = regional weighted average value

Region 3: South Australia

$M = b_0 + b_1(\ln(area) - 4.07) + b_2(\ln(I_{6,50}) - 1.60)$ (5.3)

S = regional weighted average value

$SK = c_0 + c_1(\ln(area) - 4.07)$ (5.4)

Region 4: NT + Kimberley WA

$M = b_0 + b_1(\ln(area) - 5.51) + b_2(\ln(I_{6,50}) - 2.546)$ (5.5)

S = regional weighted average value

$SK = c_0 + c_1(\ln(I_{6,2}/ I_{6,50}) - 0.699)$ (5.6)

Region 5: SW Western Australia

$M = b_0 + b_1(\ln(area) - 3.40) + b_2(\ln(I_{6,50}) – 1.746)$ (5.7)

$S = c_0 + c_1(\ln(I_{6,2}/ I_{6,50}) - 0.725)$ (5.8)

$SK = d_0 + d_1(\ln(I_{6,2}/ I_{6,50})-0.725) + d_2(\ln(I_{6,2}) – 2.472)$ (5.9)

where

area = catchment area (km^2);

$I_{6,50}$ = design rainfall intensity (mm/h) at catchment centroid for 6-hour duration and AEP of 50%;

shape factor = shortest distance between catchment outlet and centroid divided by $area^{0.5}$; and

$I_{6,2}$ = design rainfall intensity (mm/h) at catchment centroid for 6-hour duration and AEP of 2%.

The weighted average values of S and SK were determined on the basis of record lengths at the stations within the ROI sub-region as mentioned in Section 5.2.

The values of b_0, b_1, b_2, b_3, c_0, c_1, d_0, d_1 and d_2 and regional weighted average values of S and SK (where appropriate) at all the 798 individual gauged catchment locations (in the data-rich regions) are estimated as noted in Section 5.2 and embedded in the application tool (REEF Model 2015). To derive flood quantile estimate at an ungauged catchment of interest, RFFE Model 2015 takes the inverse distance weighted average value of flood quantile estimates based on up to 15 nearest gauged catchment locations within 300 km radius from the catchment of interest. This ensures a smooth variation of flood quantile estimates over the space.

5.2 Implementation of region-of-influence (ROI) approach

The ROI approach in this study adopted the physical distance between sites as the distance metric (i.e. geographic proximity) as mentioned in Section 3.1. In applying the ROI approach, in the first iteration, a ROI sub-region consisting of the ten nearest stations to the site of interest was formed, the regional prediction equation was developed and its prediction error variance was noted. At each of the subsequent iterations, the radius of the ROI sub-region was increased by 10 km and new stations were added to the previously selected stations. This procedure ended when all the eligible stations were included in the ROI sub-region. The final ROI sub-region for the site of interest was then selected as the one exhibiting the lowest prediction error variance.

Table 5.1 shows the median number of sites in a ROI sub-region for the data-rich regions. This shows that the ROI for the mean flood (*M*) model has fewer sites than the standard deviation (*S*) and skew (*SK*) models for all the five data-rich regions. Taking Region 2 (Tasmania) as an example, the ROI for the mean flood model has 19 sites (median value) out of 51 i.e. 37% of the available sites, and the ROI for the skew model has the highest number of sites. This shows that the mean flood model does experience a greater degree of heterogeneity than the standard deviation and skew models.

Table 5.1 Median number of sites in the ROI sub-regions for the five data-rich regions

Region	Number of sites in the ROI sub-region			Total number of sites in the region
	M model	*S* model	*SK* model	
Region 1	77	127	249	558
Region 2	19	48	50	51
Region 3	25	26	27	28
Region 4	24	38	57	58
Region 5	26	27	102	103

5.3 Model diagnostics

The regression equations developed in this study using Bayesian GLS regression and ROI approach are statistical models and as such are associated with different types of errors/uncertainties due to errors/uncertainties in the data and modelling approaches. The results from the developed regression equations represent best-fit estimates with an associated scatter or variance.

To assess the degree of uncertainty associated with the developed regression equations, the predicted flood quantiles need to be compared with the true values, which are however "unknown". Differences between the predicted quantiles by the developed regression equations and at-site flood frequency analysis can be used to indicate the relative accuracy of the developed regression equations.

The Bayesian GLS regression depends on both the model and sampling error. Here the model error measures the ability of a set of predictor variables to predict a given parameter of the LP3 distribution (i.e. *M*, *S* or *SK*). The model error depends on the number and predictive power of the predictor variables in a particular regression equation. Sampling error measures the ability of a limited number of sites with a limited record length to describe the flood characteristics at a site. The sampling error depends on the number of sites in a ROI sub-region and the record length of the annual maximum series for each site in the ROI sub-region. The sampling error decreases as either the number of sites in the ROI sub-region or the length of record increases.

A measure of the uncertainty in the estimate by a regression equation for a given site *i*, is the variance of prediction (VP) (Stedinger and Tasker, 1985). The VP is the sum of the model error variance and sampling error variance. Assuming that the predictor variables for the sites in a regression analysis are representative of all possible sites in the region, the average accuracy of prediction for a regression equation can be determined by computing the average variance of prediction (AVP) (Griffis and Stedinger, 2007) for *n* number of sites in a ROI region. In this study the AVP was calculated using the Bayesian framework (more details can be seen in Gruber et al. (2007) and Rahman et al. (2012)).

A more traditional measure of the accuracy of the regression equations (developed here to estimate the parameters of the LP3 distribution) is the standard error of prediction (SEP), which is simply the square root of the variance of prediction. The average SEP for a regression equation can be computed in error percentage by using AVP in log units.

A measure of the proportion of the variance in the dependent variable explained by the independent variables in the ordinary least squares regression (OLSR) is the coefficient of determination, R^2. For GLSR regression, a more appropriate performance metric than R^2 is the R^2_{pseudo} or R^2_GLSR described by Griffis and Stedinger (2007). Unlike the R^2 in the OLSR, the R^2_GLSR is based on the variability in the dependent variable explained by the regression after removing the effect of the time-sampling error.

The AVP, SEP and R^2_GLSR for the final set of regional regression equations for the parameters (*M*, *S* and *SK*) of the LP3 distribution for each of the five data-rich regions are presented in Table 5.2. For a constant (i.e. only intercept) model, R^2_GLSR is not reported in Table 5.2. The results in Table 5.2 indicate that the average SEP values for the mean flood (*M*) model ranges from 46% to 83% and the SEP values of the *M* model are notably higher than those of the standard deviation (S) and skew (SK) models. The results in Table 5.2 indicate that the R^2_GLSR for the *M* model are in the range of 69% to 90%, the highest being for Region 2 and smallest being for Region 1. The average R^2_GLSR values for the *S* and *SK* models are considerably smaller than those of the *M* model, as shown in Table 5.2. For the *S* and *SK* models with no predictor variable, the R^2_GLSR is not reported. For these cases, no predictor variable is found useful and a regional weighted average value is adopted (e.g. for Region 1 and Region 2).

Table 5.2 Average variance of prediction (AVP), average standard error of prediction (SEP), and pseudo coefficient of determination (R^2_GLSR) for the regional ROI-based regression equations for five data-rich regions

LP3 parameter	***M***			***S***			***SK***		
Statistic metric	R^2_GLSR (%)	*AVP*	*SEP (%)*	R^2_GLSR (%)	*AVP*	*SEP (%)*	R^2_GLSR (%)	*AVP*	*SEP (%)*
Region 1	69	0.32	61	-	0.041	21	-	0.001	3
Region 2	90	0.25	54	-	0.148	40	-	0.026	16
Region 3	87	0.523	83	-	0.098	32	29	0.066	26
Region 4	84	0.19	46	-	0.077	28	2	0.052	23
Region 5	87	0.50	81	7	0.12	36	91	0.008	9

5.4 Results from leave-one-out validation

The reliability and accuracy of the quantile estimates by the RFFE technique was assessed using leave-one-out (LOO) validation. In the LOO validation, one catchment was left out from the model data set and the RFFE technique was applied to the catchment that was left out. The flood quantiles estimated using the RFFE technique were then compared with the at-site flood frequency estimates obtained by FLIKE (Kuczera, 1999) as mentioned in Section 2.7.4. The procedure was repeated for each catchment in the regional data set to provide an overall assessment of the performance of the RFFE technique.

The reliability of the RFFE flood quantile confidence limits described in Section 3.6 was assessed empirically using standardised quantile residuals. The quantile residual is the difference between the logarithm of flood quantile estimates obtained using at-site flood frequency analysis and the RFFE technique. The standardised quantile residual is the quantile residual divided by its standard deviation which is the square root of the sum of the RFFE predictive variance of the flood quantile and at-site quantile variance (Haddad and Rahman, 2012; Micevski et al., 2014). This accounts for both the model error (e.g. inadequacy of the RFFE model) and the sampling error (e.g. due to limited streamflow record length). If the uncertainty in the log quantile estimates has been adequately described, the standardized quantile residuals should be consistent with a standard normal distribution.

Figure 5.2 shows the plots of standardised residuals vs. normal scores for Region 1 for AEPs of 50% to 1%. The plots for Regions 2, 3, 4 and 5 are shown in Appendix B (Figures B.1, Figure B.3, Figure B.5 and Figure B.7, respectively). Figure 5.2 reveals that most of the 558 catchments closely follow a 1:1 straight line indicating that the assumption of normality of the residuals is not inconsistent with the evidence; this is supported by the application of the Anderson-Darling and Kolmogorov-Smirnov tests which show that the assumption of the normality of the residuals cannot be rejected at the 10% level of significance. Under the assumptions of normality, approximately 90% of the standardised quantile residuals should lie between ± 2, which is largely satisfied. There are a few catchments with standardised residual values close to ± 3. These correspond to instances where the RFFE confidence limits may not be reliable. Same conclusion applies to the other data-rich regions. The main conclusion from this analysis is that the quantification of uncertainty in the quantile estimates by the RFFE technique is reliable for the vast majority of the cases. Figures 5.2, B.1, B.3, B.5 and B.7 serve as a reminder that some catchments may not be adequately represented by the catchments used in the RFFE analysis. Users of the RFFE Model 2015 should check that the catchment of interest is not atypical compared with the gauged catchments included in the ROI used to develop the RFFE estimate. To assist users in this regard the RFFE Model 2015 lists the RFFE Model gauged catchments located nearest to the ungauged catchment of interest.

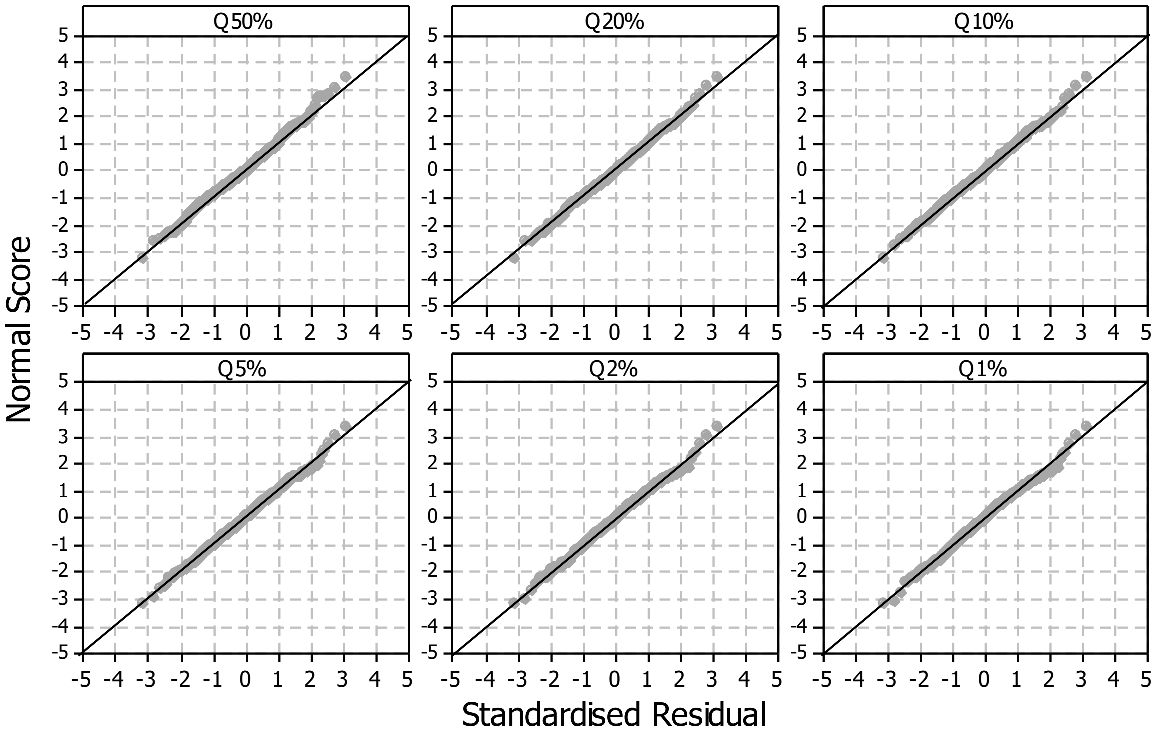

Figure 5.2 Standardised residuals vs. Z score for AEPs of 50% to 1% for Region 1

The observed and predicted flood quantiles are plotted in Figure 5.3 for Region 1. These plots for other regions are shown in Appendix B (Figure B.2 for Region 2, Figure B.4 for Region 3, Figure B.6 for Region 4 and Figure B.8 for Region 5). These plots generally show a good agreement between the observed and predicted quantiles; however, there are few outliers as expected.

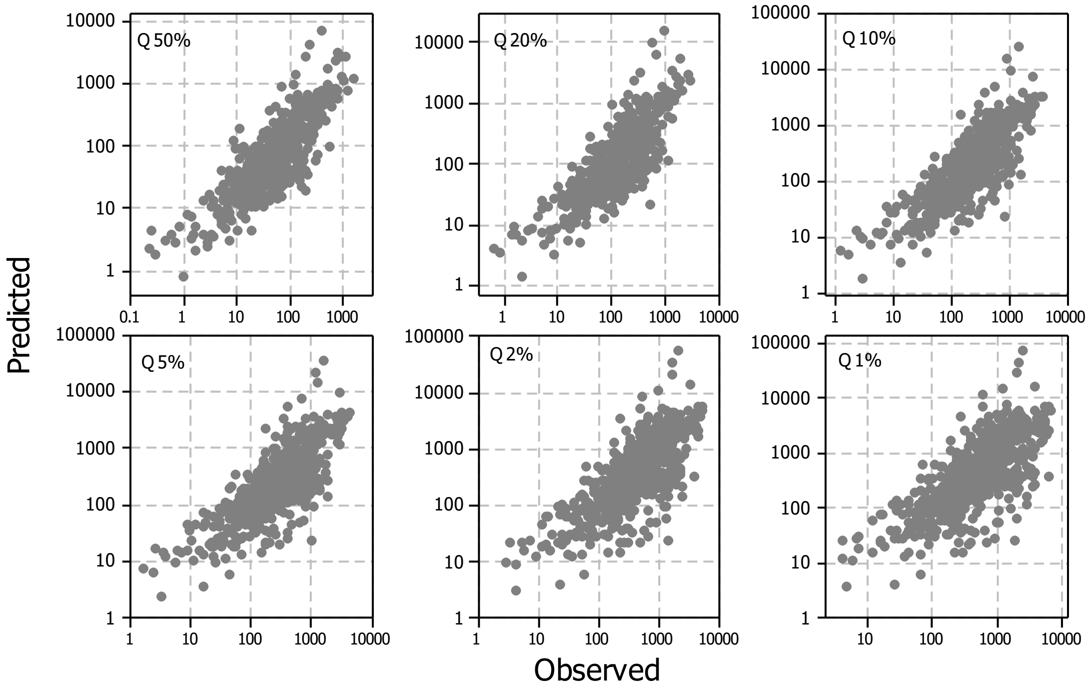

Figure 5.3 Observed vs. predicted quantiles (in log space) for AEPs of 50% and 1% for Region 1 (flood discharges are in m^3/s)

The accuracy of the flood quantile estimates provided by the RFFE technique was evaluated by using the relative error (RE) defined by Equation 5.10. It should be noted that the relative error given by Equation 5.10 makes no allowance for the fact that the at-site flood frequency estimates are themselves subject to sampling error. Therefore, this error should be seen as an upper bound on the true relative error.

It should be noted here that LOO is a more rigorous validation technique compared with the split-sample validation where the model is tested on a smaller number of catchments (e.g. 10% of the total catchments). Hence, the relative error that is generated by LOO is expected to be higher than if split-sample validation were used. The medians of the absolute relative error values from the LOO validation for different regions are reported in Table 5.3. It can be seen that for the data-rich regions, Region 5 (SW Western Australia) has the highest relative error (59 to 69%) and Region 3 (South Australia) has the smallest relative error (33 to 41%).

$$RE(\%) = \frac{Q_{RFFE} - Q_{FFA}}{Q_{FFA}} \times 100 \qquad (5.10)$$

where Q_{RFFE} = flood quantile estimate at a given site for a given AEP by RFFE Technique 2015; and

Q_{FFA} = flood quantile estimate from at-site flood frequency analysis using LP3 distribution by FLIKE (Kuczera, 1999).

Table 5.3 Median of absolute relative error (RE) values (%) for data-rich regions by REEF Technique 2015

Region	Median RE (%)					
	AEP					
	50%	20%	10%	5%	2%	1%
Region 1	51	49	52	53	57	59
Region 2	53	46	46	46	46	45
Region 3	38	39	33	35	39	41
Region 4	33	36	36	38	39	47
Region 5	61	59	66	68	68	69

The distribution of median RE values were examined for different catchment sizes. The median RE values for small and medium catchment sizes (in the model dataset) were found to be quite similar (for example, see Tables 5.4 to 5.6). No relationship was found between RE and catchment size, with coefficient of determination (R^2) values of the regression between RE and catchment area were found to be smaller than 1% (for example see Figure 5.4). Similar results were found for other regions and AEPs. However, the applicability of the RFFE Technique to very small catchments (beyond the lower limit of the model catchments) could not be checked due to unavailability of gauged streamflow data for these catchments.

Table 5.4 Median of absolute RE values for different catchment sizes (Region 2, 5% AEP) by RFFE Technique 2015

Catchment area (km^2)	No. of catchments	RE (%)
1 to 5	3	42
6 to 10	0	-
11 to 20	4	36
21 to 50	7	57
51 to 100	3	46
101 to 200	13	46
201 to 500	12	47
501 to 1000	5	36
1001 to 2000	4	95
All data	51	46

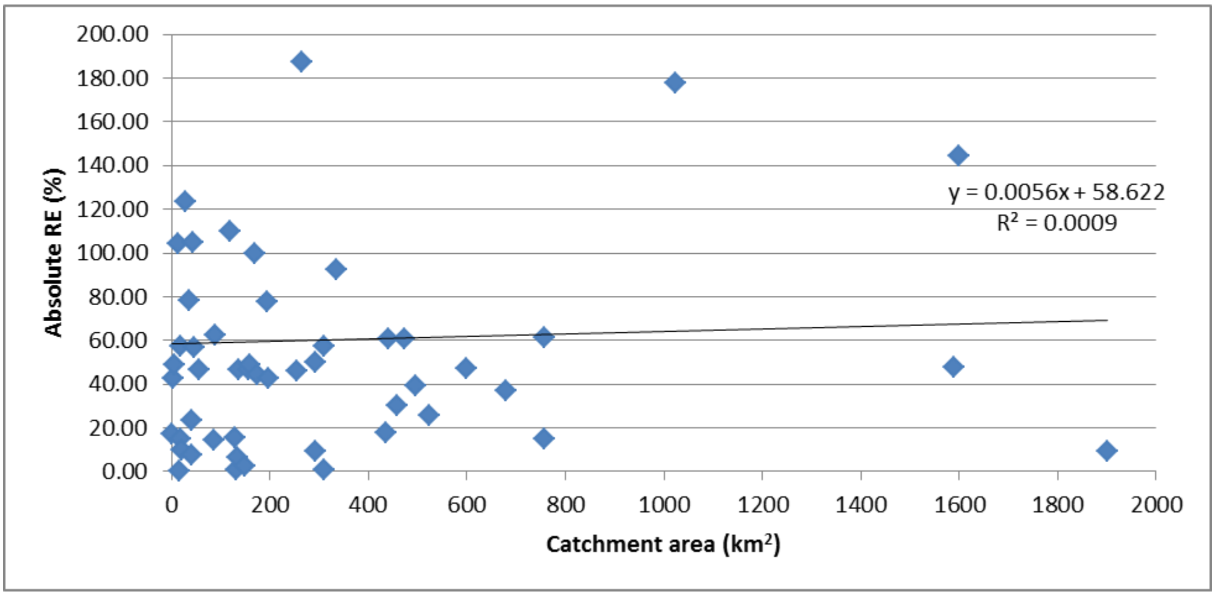

Figure 5.4 Plot showing relationship between catchment area and absolute RE (Region 2, 5% AEP)

Table 5.5 Median of absolute RE values for different catchment sizes (Region 4, 5% AEP)

Catchment area (km^2)	No. of catchments	RE (%)
1 to 5	1	2
6 to 10	0	-
11 to 20	3	26
21 to 50	5	21
51 to 100	9	78
101 to 200	6	51
201 to 500	12	34
501 to 1000	10	36
1001 to 2000	8	26
2001 to 4500	4	40
All data	58	38

Table 5.6 Median of absolute RE values for different catchment sizes (Region 1, 5% AEP)

Catchment area (km^2)	No. of catchments	RE (%)
1 to 5	6	51
6 to 10	8	34
11 to 20	19	52
21 to 50	49	57
51 to 100	76	41
101 to 200	112	51
201 to 500	170	55
501 to 1000	118	53
All data	558	53

6 Development of regional prediction equations for arid (data-poor) regions

As mentioned in Section 3.5, an index type approach was adopted for the data-poor/arid regions (see Equation 3.8). The estimated growth factors for Pilbara arid area (Region 6) and all other arid areas (Region 7) are presented in Table 6.1, which shows that the growth factors for the Pilbara arid area (Region 6) for smaller AEP floods (5%, 2% and 1%) are higher than Region 7 case.

Table 6.1 Growth factors for the arid regions

AEP	Region 6: Pilbara arid area	Region 7: All other arid areas
50%	0.285	0.293
20%	0.687	0.719
10%	1.000	1.000
5%	1.376	1.306
2%	2.044	1.794
1%	2.755	2.267

The adopted prediction equation for the index variable Q_{10} has the following form:

$$\log_{10}(Q_{10}) = b_0 + b_1(\log_{10}(area)) + b_2(\log_{10}(I_{6,50})) \qquad (6.1)$$

where b_0, b_1 and b_2 are regression coefficients, estimated using ordinary least squares regression;

area represents catchment area in km^2, and

$I_{6,50}$ is design rainfall intensity (mm/h) at catchment centroid for 6-hour duration and AEP of 50%. The values of b_0, b_1 and b_2 and the regional growth factors are embedded into the application tool (REEF Model 2015).

Results in Table 6.2 show that the adopted regression coefficients are significantly different from zero. The R^2 values for Regions 6 and 7 are found to be 0.96 and 0.87, respectively, which represents quite a good fit. For both the arid regions, the regression coefficients associated with the predictor variables catchment area (b_1) and $I_{6,50}$ (b_2) are found to be positive, which indicate that Q_{10} increases with increasing catchment area and rainfall intensity, which is as expected.

Table 6.2 Regression statistics of the developed prediction equations for the arid regions

Region	Regression coefficients	Probability *(p)*	Coefficient of determination *(R^2)*
Region 6: Pilbara arid area (No. of stations = 11)	b_o	0.000	0.96
	b_1	0.000	
	b_2	0.000	
Region 7: All other arid areas (No. of stations = 44)	b_o	0.000	0.87
	b_1	0.000	
	b_2	0.000	

The standardised residuals vs. predicted flood quantiles (for Q_{10}) for Region 6 and Region 7 are presented in Figures 6.1 and 6.2, respectively. It can be seen from these figures that most of the standardised residuals are within ± 2.0 × standard deviation, which indicate the absence of any notable outlier data point. Similar results are obtained for AEPs of 50%, 20%, 10%, 5% and 1% (as can be seen in Appendix C).

The quantile-quantile plots (QQ-plot) of the standardised residuals for Region 6 and Region 7 are presented in Figures 6.3 and 6.4 (for Q_{10}), respectively, which indicate that the residuals are near-normally distributed. Similar results are obtained for AEPs of 50%, 20%, 10%, 5% and 1% (as can be seen in Appendix C).

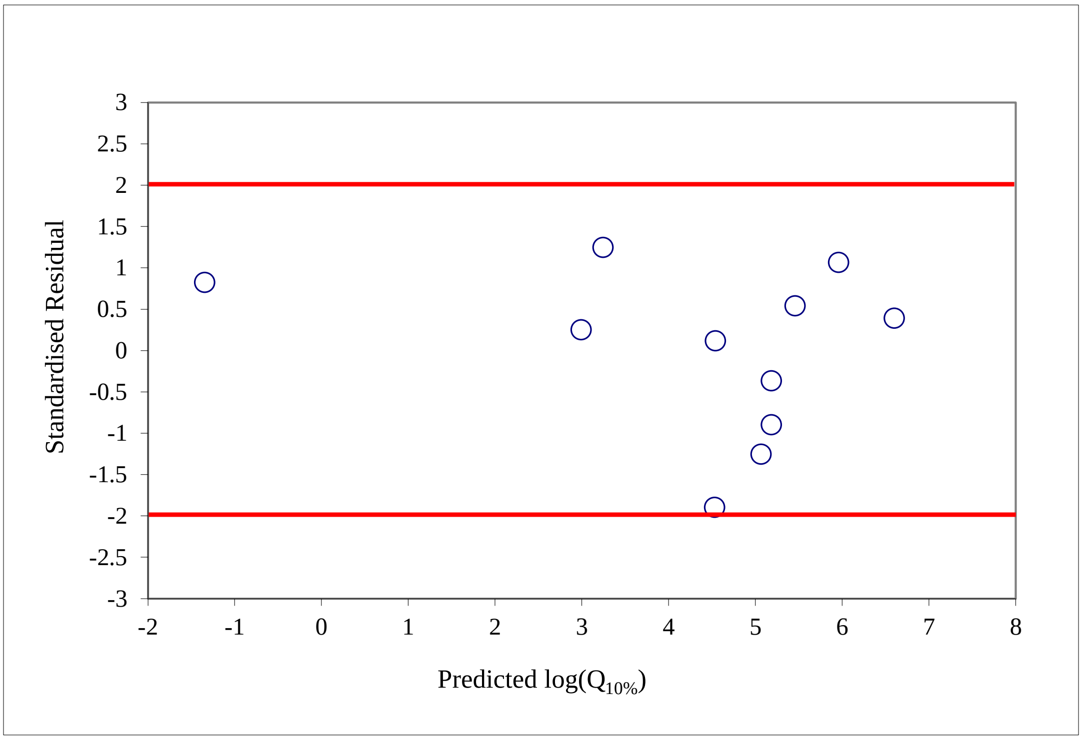

Figure 6.1 Standardised residuals vs. predicted quantiles for 10% AEP (Region 6)

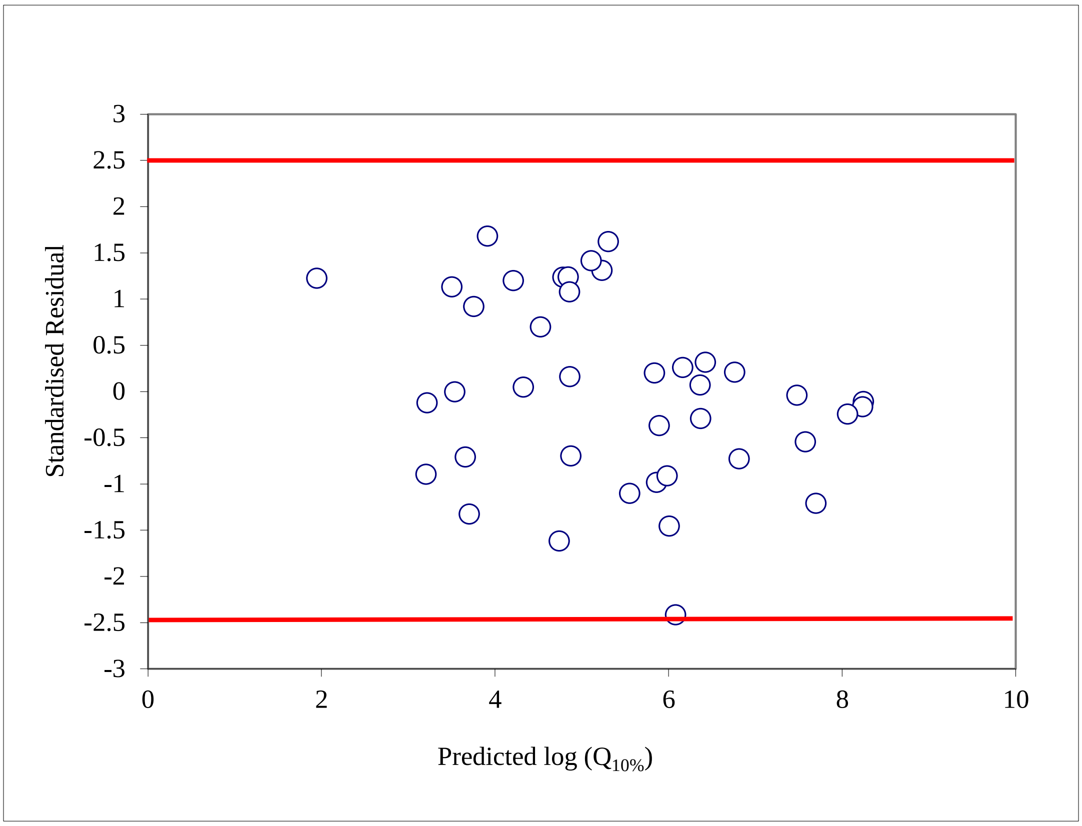

Figure 6.2 Standardised residuals vs. predicted quantiles for 10% AEP (Region 7)

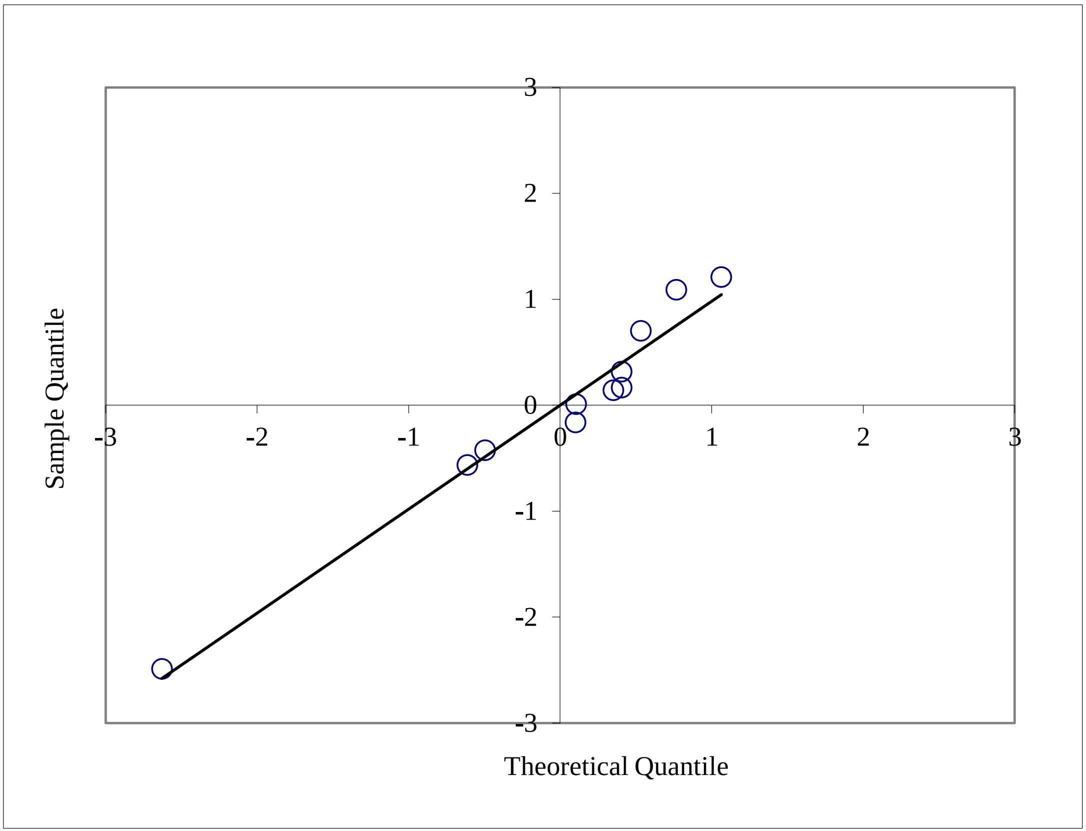

Figure 6.3 QQ-plot of the standardised residuals for 10% AEP (Region 6)

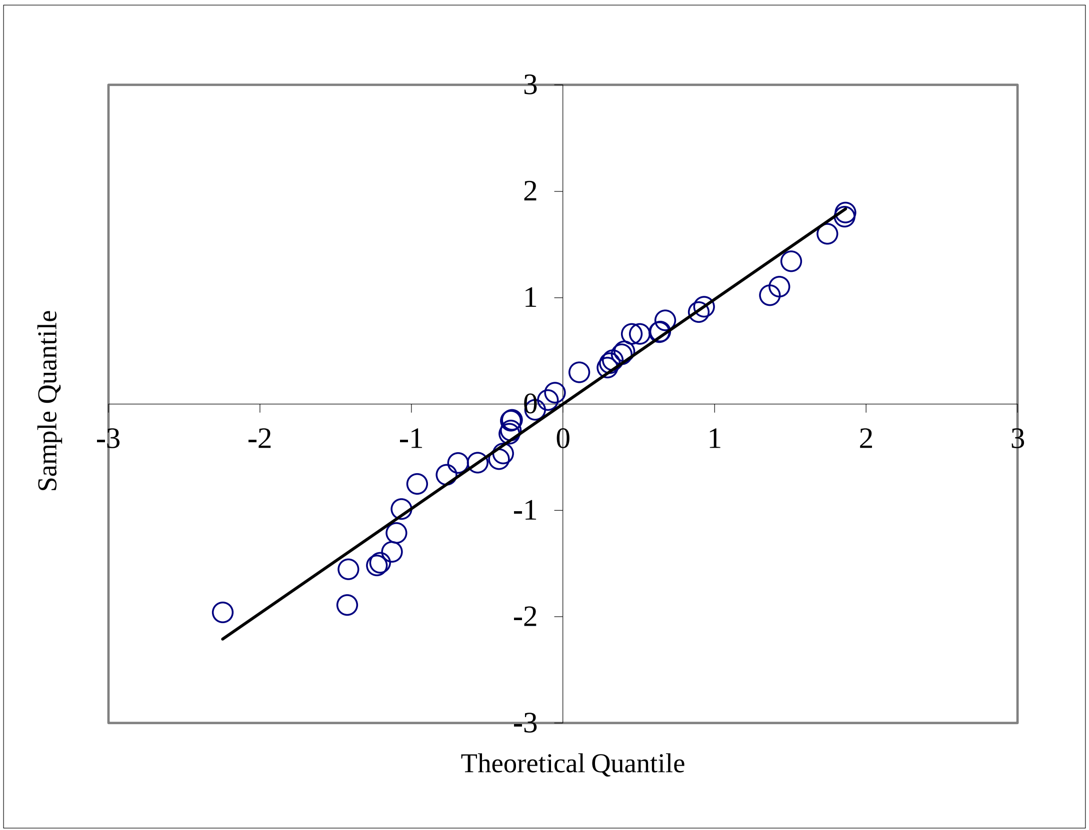

Figure 6.4 QQ-plot of the standardised residuals for 10% AEP (Region 7)

A leave-one-out (LOO) cross validation approach was adopted to test the performance of the developed RFFE technique for the arid regions (similar to data-rich regions). The predicted flood quantiles from LOO for each of the study catchments were compared with the at-site flood quantile estimates. The at-site flood quantiles were estimated using a GPA distribution and L moments procedure as mentioned in Section 3.5. The median relative error (RE) values (based on LOO validation) for Region 6 and Region 7 are presented in Table 6.3. It can be seen that median relative error values range from 35% to 43% for Region 6 and 49% to 67% for Region 7.

Table 6.3 Median of absolute relative error (RE) (%) for two arid regions by RFFE Technique 2015

AEP	50%	20%	10%	5%	2%	1%
	Median RE (%)					
Region 6	35	37	35	42	37	43
Region 7	63	67	67	61	57	49

7 Application tool

The coefficients of the developed regression equations (Equations 5.1 to 5.9 for the five data-rich regions at each of the 798 gauged catchment locations and Equation 6.1 for the two arid regions) are embedded in a computer-based application tool (called RFFE Model 2015). The user is required to enter simple data input like latitude, longitude, catchment area and design rainfall intensity for the ungauged catchment of interest to generate the design flood estimates and 90% confidence limits for AEPs of 50%, 20%, 10%, 5%, 2% and 1%. It also provides a set of the nearest gauged catchments (which have been used in developing the RFFE Model 2015) so that the user can compare the characteristics of the ungauged catchment of interest with the nearest gauged catchments of the model data set. The chapter on regional flood frequency estimation in Australian Rainfall and Runoff (4th edition) provides further information on the application tool with worked examples.

8 Supplementary information

A large number of peer reviewed technical papers and reports have been produced from Project 5, which are listed in Appendix D. These provide important information on preliminary data preparation and analyses.

9 Summary

As a part of ARR Project 5 Regional Flood Methods (Stage 3), an extensive data collation and modelling exercise have been undertaken to develop Regional Flood Frequency Estimation (RFFE) Technique 2015 and the application tool RFFE Model 2015. The major outcomes of this study are provided below:

- The flood data from 853 gauged catchments in Australia have been collated covering data till 2012 for most of these catchments. Australia has been divided into data-rich and data-poor (arid) regions. The record lengths of the annual maximum flood series data of the 798 catchments from the data-rich regions range from 19 to 102 years (mean: 37 years and median: 37 years). The catchment areas of the selected 798 catchments from data-rich regions range from 0.5 km^2 to 4,325 km^2 (mean: 295 km^2 and median: 179 km^2). However, for Victoria, the Australian Capital Territory, New South Wales, South Australia, Queensland and South-west Western Australia, the catchment areas range from 0.6 km^2 to 1,049 km^2. Only few catchments in Tasmania and the Northern Territory are in the range of 1,000 km^2 to 4,325 km^2. The record lengths of the flood series of the 55 stations from the arid regions range from 10 to 46 years (mean: 27 years and median: 27 years). For each of these 55 stations, partial duration series are extracted for estimating flood quantiles. The catchment areas of the selected 55 catchments from the arid regions range from 0.1 km^2 to 5,975 km^2 (mean: 760 km^2 and median: 259 km^2).

- The newly developed Multiple Grubbs-Beck (MGB) test has been adopted to detect Potentially Influential Low Flows (PILFs) in the annual maximum flood series data which have to be censored from the series. It has been found that MGB test identifies a greater number of PILFs than the original Grubbs-Beck test. The outcome from the MGB test is found to be consistent with the judgement of experienced hydrologists who often adopt an interactive censoring in flood frequency analysis.

- The peak flows of many events in the annual maximum series analysed are considerably larger than the largest measured flow and are thus subject to rating curve extrapolation error. The impacts of rating curve error on flood quantile estimates have been investigated. The expected quantiles show notable differences between coefficient of variation (CV) = 0% (no rating curve error case) and CV = 20% (rating curve error is estimated by assuming a CV of 20%). In most cases, the expected quantile estimates increase as CV increases. Moreover, the differences in quantile estimates between CV = 0% and CV = 20% increase with a decrease in AEP. In the development of the RFFE Technique 2015, it has been decided to consider flood quantile estimates with CV = 0% since it is felt that more research needs to be undertaken to understand the implication of rating curve extrapolation error on flood quantile estimates.

- Flood quantiles are estimated for 6 AEPs, which are 50%, 20%, 10%, 5%, 2% and 1%. For the data-rich regions, flood quantiles are estimated from the annual maximum flood series data using FLIKE software assuming an LP3 distribution and Bayesian parameter estimation procedure. For the data-poor regions, partial duration series data (considering average number of events per year = 0.5) is used to estimate flood quantiles by using a Generalised Pareto distribution and L moments procedure.

- Five data-rich regions and two data-poor (arid) regions have been identified, as can be seen in Figure 4.1, Table 4.1 and Table 4.2. The boundaries between the arid and data-rich regions are drawn approximately based on the 500 mm mean annual rainfall contour line. To reduce the effects of sharp variation in quantile estimates for the ungauged catchments located close to these regional boundaries, six fringe zones have been delineated, as shown in Figure 4.1 and Table 4.3.

- For the data-rich regions, a region-of-influence approach has been adopted to define sub-region for each of the 798 gauged sites. A Bayesian generalised least squares (GLS) regression approach has been used to develop prediction equations for three parameters/moments of the LP3 distribution (parameter regression technique). The developed prediction equations for each of the five data-rich regions are provided by Equations 5.1 to 5.9. These prediction equations require two to three predictor variables (catchment area, design rainfall intensity (Bureau of Meteorology 2013 design rainfall data at catchment centroid) and shape factor), which are relatively easy to obtain. These prediction equations largely satisfy the assumptions of the regression analysis.

- For the two arid regions, an index type approach has been applied where 10% AEP flood quantile has been used as the index variable. The prediction equations for the index variable are developed based on a fixed-region approach for each of the two arid regions (Equation 6.1). These equations require two predictor variables (catchment area and design rainfall intensity). The estimated regional growth factors for the two arid regions are presented in Table 6.1.

- A leave-one-out validation approach has been used to assess the performance of the developed RFFE technique. Based on this, it has been found that the median of the absolute relative error values range from 33% to 69% for the data-rich regions (Table 5.3) and 35% to 67% for the arid regions (Table 6.3). It should be noted that there are few cases where the relative error values exceed 100%. The distributions of median relative error values for small and medium catchment sizes (in the model dataset) have been found to be similar. Also, no relationship has been found between relative error and catchment size. However, the applicability of the RFFE Technique to very small catchments (beyond the lower limit of the model catchments) could not be checked due to unavailability of gauged streamflow data for these catchments.

- The coefficients of the developed regression equations for the LP3 parameters at each of the 798 gauged locations and for the two arid regions are estimated and embedded in a computer-based application tool (called RFFE Model 2015). The user is required to enter simple data input like latitude, longitude, catchment area and design rainfall intensity for the ungauged catchment of interest to generate the design flood estimates and 90% confidence limits for the ungauged catchment of interest.

Despite the best possible efforts in data collation, some errors in the data might have remained. Given the high variability of Australian hydrology and the current density and streamflow record lengths of the gauged stations used to develop the RFFE Technique 2015, the degree of error associated with the RFFE technique may not be reduced. To enhance the accuracy of the RFFE Technique 2015, a greater number of stations with longer period of streamflow records should be used when they become available in future.

The development of the RFFE Technique 2015 is based on the assumption that the catchment characteristics represented in the regression equation (e.g. catchment area, design rainfall intensity and shape factor) account for the important differences in flood characteristics between sites in a region. It should be recognised that flood estimates generated by the RFFE Model 2015 for a catchment with flood characteristics that are distinctly different from typical gauged catchments in the region may not only be associated with larger error margins but also significant bias. In such situations hydrological judgment must be used to assess if any adjustment of the regional flood frequency estimate is required (based on comparison of other relevant catchment characteristics). To support such an assessment, the RFFE Model 2015 output describes the set of gauged catchments used in developing the RFFE Model, which are located closest to the ungauged catchment of interest.

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Appendices

Appendix A List of selected catchments (and catchment data summary) in ARR Project 5 Stage 3

Table A1 Selected catchments from New South Wales and ACT

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
201001	Eungella	Oxley	-28.36	153.29	213	54	1958-2011
201005	Boat Harbour No.20.55 cm	Rous	-28.32	153.35	111	28	1958-1985
202001	Durrumbul (Sherrys Crossing)	Brunswick	-28.53	153.46	34	40	1972-2011
203002	Repentance	Coopers Ck	-28.64	153.41	62	35	1977-2011
203005	Wiangaree	Richmond	-28.50	152.97	702	30	1982-2011
203010	Rock Valley	Leycester	-28.73	153.16	179	26	1986-2011
203012	Binna Burra	Byron Ck	-28.71	153.50	39	34	1978-2011
203014	Eltham	Wilsons	-28.76	153.40	223	25	1987-2011
204008	Ebor	Guy Fawkes	-30.41	152.35	31	29	1983-2011
204017	Dorrigo No.2 & No.3	Bielsdown Ck	-30.31	152.71	82	40	1972-2011
204025	Karangi	Orara	-30.26	153.03	135	42	1970-2011
204026	Bobo Nursery	Bobo	-30.25	152.85	80	29	1956-1985
204030	Aberfoyle	Aberfoyle	-30.26	152.01	200	34	1978-2011
204031	Shannon Vale	Mann	-29.72	151.85	348	20	1992-2011
204033	Billyrimba	Timbarra	-29.20	152.25	985	33	1979-2011
204034	Newton Boyd	Henry	-29.76	152.21	389	40	1972-2011
204036	Sandy Hill(below Snake Cre	Cataract Ck	-28.93	152.22	236	59	1953-2011
204037	Clouds Ck	Clouds Ck	-30.09	152.63	62	40	1972-2011
204043	Bonalbo	Peacock Ck	-28.74	152.67	47	51	1961-2011
204056	Gibraltar Range	Dandahra Ck	-29.49	152.45	104	36	1976-2011
204067	Fine Flower	Gordon Brook	-29.40	152.65	315	29	1983-2011
205002	Thora	Bellinger	-30.43	152.78	433	29	1983-2011
205006	Bowraville	Nambucca	-30.64	152.86	539	35	1972-2006
205007	Woolgoolga	Woolgoolga Ck	-30.12	153.16	11	22	1961-1982

NSW and ACT

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
205014	Gleniffer Br	Never Never	-30.39	152.88	51	24	1983-2006
206001	Jeogla	Styx	-30.59	152.16	163	33	1979-2011
206009	Tia	Tia	-31.19	151.83	261	57	1955-2011
206014	Coninside	Wollomombi	-30.48	152.03	376	57	1955-2011
206017	Causeway (Hatchery)	Serpentine Ck	-30.48	152.32	22	24	1962-1985
206018	Apsley Falls	Apsley	-31.05	151.77	894	51	1961-2011
206025	near Dangar Falls	Salisbury Waters	-30.68	151.71	594	39	1973-2011
206026	Newholme	Sandy Ck	-30.42	151.66	8	37	1975-2011
206034	Abermala	Mihi Ck	-30.70	151.71	117	26	1985-2010
207006	Birdwood(Filly Flat)	Forbes	-31.39	152.33	363	36	1976-2011
207013	D/S Bunnoo R Junction	Ellenborough	-31.48	152.45	515	36	1976-2011
207014	Avenel	Wilson	-31.33	152.74	505	27	1985-2011
207015	Mount Seaview	Hastings	-31.37	152.25	342	27	1985-2011
208001	Bobs Crossing	Barrington	-32.03	151.47	20	57	1955-2011
208006	Forbesdale (Causeway)	Barrington	-32.04	151.87	630	39	1973-2011
208007	Nowendoc	Nowendoc	-31.52	151.72	218	38	1974-2011
208009	Barry	Barnard	-31.58	151.31	150	26	1986-2011
208015	Landsdowne	Landsdowne	-31.79	152.51	96	26	1986-2011
208024	D/S Back R Jctn	Barnard	-31.56	151.34	285	29	1983-2011
208026	Jacky Barkers	Myall	-31.64	151.74	560	27	1985-2011
208027	Measuring Weir	Barnard	-31.66	151.50	693	24	1988-2011
209001	Monkerai	Karuah	-32.24	151.82	203	34	1946-1979
209002	Crossing	Mammy Johnsons	-32.25	151.98	156	36	1976-2011
209003	Booral	Karuah	-32.48	151.95	974	43	1969-2011
209018	Dam Site	Karuah	-32.28	151.90	300	32	1980-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
210011	Tillegra	Williams	-32.32	151.69	194	80	1932-2011
210014	Rouchel Brook (The Vale)	Rouchel Brook	-32.15	151.05	395	52	1960-2011
210017	Moonan Brook	Moonan Brook	-31.94	151.28	103	71	1941-2011
210018	Moonam Dam Site	Hunter	-31.92	151.22	764	38	1974-2011
210022	Halton	Allyn	-32.31	151.51	205	71	1941-2011
210040	Wybong	Wybong Ck	-32.27	150.64	676	56	1956-2011
210042	Ravensworth	Foy Brook	-32.40	151.05	170	30	1967-1996
210044	Middle Falbrook(Fal Dam Si	Glennies Ck	-32.45	151.15	466	55	1957-2011
210068	Pokolbin Site 3	Pokolbin Ck	-32.80	151.33	25	41	1965-2005
210069	Pokolbin Site 4	Muggyrang Ck	-32.81	151.27	5	28	1965-1992
210076	Liddell	Antiene Ck	-32.34	150.98	13	37	1969-2005
210079	Gostwyck	Paterson	-32.55	151.59	956	37	1975-2011
210080	U/S Glendon Brook	West Brook	-32.47	151.28	80	35	1977-2011
210084	The Rocks No.2	Glennies Ck	-32.37	151.24	227	38	1973-2010
210095	Vacy	Bucks Ck	-32.52	151.56	2	22	1976-1997
211008	Avondale	Jigadee Ck	-33.07	151.47	55	37	1975-2011
211009	Gracemere	Wyong	-33.27	151.36	236	39	1973-2011
211010	U/S Wyong R (Durren La)	Jilliby Ck	-33.25	151.39	92	27	1985-2011
211013	U/S Weir	Ourimbah Ck	-33.35	151.34	83	35	1977-2011
211014	Yarramalong	Wyong	-33.22	151.27	181	35	1977-2011
212008	Bathurst Rd	Coxs	-33.43	150.08	199	60	1952-2011
212011	Lithgow	Coxs	-33.54	150.09	404	50	1962-2011
212013	Narrow Neck	Megalong Ck	-33.73	150.24	26	23	1988-2010
212018	Glen Davis	Capertee	-33.12	150.28	1010	40	1972-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
212040	Pomeroy	Kialla Ck	-34.61	149.54	96	32	1980-2011
212042	Mount Walker	Farmers Ck	-33.50	150.10	67	27	1985-2011
212045	Island Hill	Coxs	-33.76	150.20	970	29	1983-2011
212320	Mulgoa Rd	South Ck	-33.88	150.77	88	40	1972-2011
213004	Parramatta Hospital	Parramatta	-33.81	151.00	106	20	1984-2003
213200	Wedderburn	O'Hares Ck	-34.16	150.84	73	33	1979-2011
214003	Albion Park	Macquarie Rivule	-34.58	150.71	35	33	1979-2011
215004	Hockeys	Corang	-35.15	150.03	166	82	1930-2011
215008	Kadoona	Shoalhaven	-35.79	149.64	280	39	1972-2010
215014	Bungonia	Bungonia Ck	-34.82	149.99	164	28	1984-2011
216002	Brooman	Clyde	-35.47	150.24	952	51	1961-2011
216004	Falls Ck	Currambene Ck	-34.97	150.60	95	40	1971-2010
216008	Kioloa	Butlers Ck	-35.54	150.37	1	25	1986-2010
216009	Buckenbowra No.3	Buckenbowra	-35.72	150.03	168	26	1986-2011
218003	Yowrie	Yowrie	-36.31	149.73	100	26	1959-1984
218005	D/S Wadbilliga R Junct	Tuross	-36.20	149.76	900	47	1965-2011
218007	Wadbilliga	Wadbilliga	-36.26	149.69	122	37	1975-2011
219001	Brown Mountain	Rutherford Ck	-36.60	149.44	15	62	1949-2010
219003	Morans Crossing	Bemboka	-36.67	149.65	316	68	1944-2011
219004	Tantawangalo School	Tantawangalo Ck	-36.76	149.62	160	30	1944-1973
219006	Tantawangalo Mountain (Dam)	Tantawangalo Ck	-36.78	149.54	87	59	1952-2010
219010	Brown Mountain (U/S Divers	Bonar Ck	-36.55	149.47	4	20	1955-1974
219013	North Brogo	Brogo	-36.54	149.83	460	21	1962-1982
219015	Near Bermagui	Nutleys Ck	-36.43	150.01	31	23	1966-1988
219017	Near Brogo	Double Ck	-36.60	149.8100	152	45	1967-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
219022	Candelo Dam Site	Tantawangalo Ck	-36.73	149.68	202	40	1972-2011
219025	Angledale	Brogo	-36.62	149.88	717	35	1977-2011
220001	New Buildings Br	Towamba	-36.96	149.56	272	26	1955-1980
220002	Rocky Hall (Whitbys)	Stockyard Ck	-36.95	149.50	75	24	1961-1984
220003	Lochiel	Pambula	-36.94	149.82	105	45	1967-2011
220004	Towamba	Towamba	-37.07	149.66	745	41	1971-2011
221002	Princes HWY	Wallagaraugh	-37.37	149.71	479	40	1972-2011
221010	Imlay Rd Br	Imlay Ck	-37.23	149.70	70	24	1982-2011
222004	Wellesley (Rowes)	Little Plains	-37.00	149.09	604	70	1942-2011
222009	The Falls	Bombala	-36.92	149.21	559	43	1952-1994
222015	Jacobs Ladder	Jacobs	-36.73	148.43	187	27	1976-2002
222016	The Barry Way	Pinch	-36.79	148.40	155	35	1976-2010
222017	The Hut	Maclaughlin	-36.66	149.11	313	33	1979-2011
401009	Maragle	Maragle Ck	-35.93	148.10	220	62	1950-2011
401013	Jingellic	Jingellic Ck	-35.90	147.69	378	39	1973-2011
401015	Yambla	Bowna Ck	-35.92	146.98	316	37	1975-2011
401016	The Square	Welumba Ck	-36.04	148.12	52	28	1984-2011
401017	Yarramundi	Mannus Ck	-35.77	147.93	197	28	1984-2011
410038	Darbalara	Adjungbilly Ck	-35.0200	148.25	411	43	1969-2011
410048	Ladysmith	Kyeamba Ck	-35.2000	147.51	530	48	1939-1986
410057	Lacmalac	Goobarragandra	-35.3300	148.35	673	54	1958-2011
410061	Batlow Rd	Adelong Ck	-35.3300	148.07	155	64	1948-2011
410076	Jerangle Rd	Strike-A-Light C	-35.9200	149.24	212	37	1975-2011
410088	Brindabella (No.2&No.3-Cab	Goodradigbee	-35.4200	148.73	427	44	1968-2011
410107	Mountain Ck	Mountain Ck	-35.0283	148.83	186	32	1980-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
410112	Jindalee	Jindalee Ck	-34.58	148.09	14	36	1976-2011
410114	Wyangle	Killimcat Ck	-35.24	148.31	23	35	1977-2011
410141	Michelago	Micaligo Ck	-35.71	149.15	190	29	1983-2011
410149	Nottingham Rd Br	Nottingham Ck	-35.22	148.67	30	29	1983-2011
410152	Edwardstown	Stony Ck	-35.14	148.11	9	25	1985-2009
410156	Book Book	Kyeamba Ck	-35.35	147.55	145	25	1986-2011
410160	White Hill	Williams Ck	-34.96	149.19	10	21	1990-2010
411001	Bungendore	Mill Post Ck	-35.28	149.39	16	25	1960-1984
411003	Butmaroo	Butmaroo Ck	-35.26	149.54	65	33	1979-2011
412050	Narrawa North	Crookwell	-34.31	149.17	740	34	1970-2003
412063	Gunning	Lachlan	-34.74	149.29	570	39	1961-1999
412076	Cudal	Bourimbla Ck	-33.33	148.71	124	20	1980-1999
412081	near Neville	Rocky Br Ck	-33.80	149.19	145	33	1969-2001
412083	Tuena	Tuena Ck	-34.02	149.33	321	33	1969-2001
412090	Cudal No.2	Boree Ck	-33.29	148.74	272	20	1970-1989
412096	Kennys Ck Rd	Pudmans Ck	-34.45	148.79	332	27	1976-2002
412110	U/S Giddigang Ck	Bolong	-34.30	149.63	171	21	1981-2001
416003	Clifton	Tenterfield Ck	-29.03	151.72	570	33	1979-2011
416008	Haystack	Beardy	-29.22	151.38	866	40	1972-2011
416016	Inverell (Middle Ck)	Macintyre	-29.79	151.13	726	40	1972-2011
416020	Coolatai	Ottleys Ck	-29.23	150.76	402	33	1979-2011
416023	Bolivia	Deepwater	-29.29	151.92	505	33	1979-2011
418005	Kimberley	Copes Ck	-29.92	151.11	259	40	1972-2011
418014	Yarrowyck	Gwydir	-30.47	151.36	855	37	1971-2007
418017	Molroy	Myall Ck	-29.80	150.58	842	33	1979-2011

NSW and ACT

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
418021	Laura	Laura Ck	-30.23	151.19	311	34	1978-2011
418025	Bingara	Halls Ck	-29.94	150.57	156	32	1980-2011
418027	Horton Dam Site	Horton	-30.21	150.43	220	40	1972-2011
418034	Black Mountain	Boorolong Ck	-30.30	151.64	14	29	1976-2004
419010	Woolbrook	Macdonald	-30.97	151.35	829	32	1980-2011
419016	Mulla Crossing	Cockburn	-31.06	151.13	907	34	1978-2011
419029	Ukolan	Halls Ck	-30.71	150.83	389	33	1979-2011
419035	Timbumburi	Goonoo Goonoo Ck	-31.27	150.92	503	30	1982-2011
419044	Damsite	Maules Ck	-30.53	150.30	171	24	1969-1992
419047	Woodsreef	Ironbark Ck	-30.41	150.73	581	23	1989-2011
419051	Avoca East	Maules Ck	-30.50	150.08	454	35	1977-2011
419053	Black Springs	Manilla	-30.42	150.65	791	37	1975-2011
419054	Limbri	Swamp Oak Ck	-31.04	151.17	391	37	1975-2011
419076	Old Warrah	Warrah Ck	-31.66	150.64	150	29	1983-2011
420010	Bearbung	Wallumburrawang Ck	-31.67	148.87	452	22	1980-2001
420012	Neilrex	Butheroo Ck	-31.74	149.35	405	22	1980-2001
421026	Sofala	Turon	-33.08	149.69	883	38	1974-2011
421034	Dam Site	Slippery Ck	-33.67	149.91	15	21	1980-2000
421036	below Dam Site	Duckmaloi	-33.75	149.94	112	25	1956-1980
421048	Obley No.2	Little	-32.71	148.55	612	25	1987-2011
421050	Molong	Bell	-33.03	148.95	365	37	1975-2011
421055	Rawsonville	Coolbaggie Ck	-32.15	148.46	626	31	1981-2011
421066	Hill end	Green Valley Ck	-32.95	149.46	119	22	1977-1998
421068	Saxa Crossing	Spicers Ck	-32.20	149.02	377	25	1978-2002

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
421076	Peak Hill No.2	Bogan	-32.72	148.13	1036	31	1981-2011
421101	U/S Ben Chifley Dam	Campbells	-33.61	149.70	950	24	1979-2002
421104	Stromlo	Brisbane Valley	-33.69	149.70	98	21	1980-2000
421106	Wiagdon	Cheshire Ck	-33.25	149.66	102	21	1981-2001

Table A2 Selected catchments from Victoria

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
221207	Errinundra	Errinundra	-37.45	148.91	158	40	1971 - 2010
221201	Weeragua	Cann(West Branch	-37.37	149.20	311	43	1970-2012
221208	Wingan Inlet National Park	Wingan	-37.69	149.49	420	34	1979-2012
221209	Weeragua	Cann(East Branch	-37.37	149.20	154	39	1973 - 2011
221210	The Gorge	Genoa	-37.43	149.53	837	40	1972 - 2011
221211	Combienbar	Combienbar	-37.44	148.98	179	38	1974 - 2011
221212	Princes HWY	Bemm	-37.61	148.90	725	37	1975 - 2011
222202	Sardine Ck	Brodribb	-37.51	148.55	650	47	1965 - 2011
222206	Buchan	Buchan	-37.50	148.18	822	38	1974 - 2011
222210	Deddick (Caseys)	Deddick	-37.09	148.43	857	42	1970 - 2011
222213	Suggan Buggan	Suggan Buggan	-36.95	148.33	357	41	1971 - 2011
222217	Jacksons Crossing	Rodger	-37.41	148.36	447	36	1976 - 2011
223202	Swifts Ck	Tambo	-37.26	147.72	943	38	1974 - 2011
223204	Deptford	Nicholson	-37.60	147.70	287	38	1974 - 2011
223212	D/S of Wilkinson Ck	Timbarra	-37.45	148.06	438	31	1982-2012
223213	D/S of Duggan Ck	Tambo	-37.00	147.88	96	26	1987-2012
223214	U/S of Smith Ck	Tambo	-36.96	147.93	32	24	1989-2012
223215	Hells Gate	Haunted Stream	-37.48	147.82	180	23	1990-2012
224213	Lower Dargo Rd	Dargo	-37.50	147.27	676	39	1973 - 2011
224214	Tabberabbera	Wentworth	-37.50	147.39	443	38	1974 - 2011
225213	Beardmore	Aberfeldy	-37.85	146.43	311	33	1973 - 2005
225218	Briagalong	Freestone Ck	-37.81	147.09	309	41	1971 - 2011
225219	Glencairn	Macalister	-37.52	146.57	570	45	1967 - 2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
225223	Gillio Rd	Valencia Ck	-37.73	146.98	195	41	1971 - 2011
225224	The Channel	Avon	-37.80	146.88	554	40	1972 - 2011
226007	Browns	Tyers	-38.05	146.36	207	52	1961-2012
226023	Neerim East	Latrobe	-37.94	146.03	378	36	1977-2012
226204	Willow Grove	Latrobe	-38.09	146.16	580	41	1971 - 2011
226209	Darnum	Moe	-38.21	146.00	214	40	1972 - 2011
226222	Near Noojee (U/S Ada R Jun	Latrobe	-37.88	145.89	62	41	1971 - 2011
226226	Tanjil Junction	Tanjil	-38.01	146.20	289	52	1960 - 2011
226402	Trafalgar East	Moe Drain	-38.18	146.21	622	37	1975 - 2011
227200	Yarram	Tarra	-38.46	146.69	25	47	1965 - 2011
227205	Calignee South	Merriman Ck	-38.36	146.65	36	37	1975 - 2011
227210	Carrajung Lower	Bruthen Ck	-38.40	146.74	18	39	1973 - 2011
227211	Toora	Agnes	-38.64	146.37	67	38	1974 - 2011
227213	Jack	Jack	-38.53	146.53	34	42	1970 - 2011
227219	Loch	Bass	-38.38	145.56	52	39	1973 - 2011
227225	Fischers	Tarra	-38.47	146.56	16	40	1973 - 2012
227226	Dumbalk North	Tarwineast Branc	-38.50	146.16	127	42	1970 - 2011
227227	Leongatha	Wilkur Ck	-38.39	145.96	106	40	1973-2012
227231	Glen Forbes South	Bass	-38.47	145.51	233	37	1974 - 2010
227236	D/S Foster Ck Jun	Powlett	-38.56	145.71	228	33	1979 - 2011
227237	Toora	Franklin	-38.63	146.31	75	34	1979-2012
227243	D/S Reedy Ck	Bruthen Ck	-38.42	146.83	124	21	1992-2012
228209	Hamiltons Br	Lang Lang	-38.24	145.64	272	25	1980-2004
228217	Pakenham	Toomuc Ck	-38.07	145.46	41	29	1974 - 2002
228228	Cardinia	Cardinia Ck	-38.12	145.40	117	31	1974-2004

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
229215	Woori Yallock	Woori Yallock Ck	-37.77	145.51	311	31	1974-2004
229218	Watsons Ck	Watsons Ck	-37.67	145.26	36	26	1974 - 1999
230204	Riddells Ck	Riddells Ck	-37.47	144.67	79	38	1974 - 2011
230205	Bulla (D/S of Emu Ck Jun)	Deep Ck	-37.63	144.80	865	38	1974 - 2011
230208	Darraweit Guim	Deep Ck	-37.41	144.89	350	20	1975-1994
230209	Barringo (U/S of Diversion	Barringo Ck	-37.42	144.63	6	30	1983-2012
230211	Clarkefield	Emu Ck	-37.47	144.75	93	36	1975 - 2010
230213	Mount Macedon	Turritable Ck	-37.42	144.58	15	38	1975-2012
230218	Mount Eliza	Bolinda Ck	-37.37	144.69	12	29	1977-2005
230219	Darraweit Guim	Boyd Ck	-37.40	144.90	135	21	1978-1998
231212	Notuk	Djerriwarrh Ck	-37.60	144.53	19	21	1963-1983
231213	Sardine Ck- O'Brien Cro	Lerderderg Ck	-37.50	144.36	153	53	1959 - 2011
231231	Melton South	Toolern Ck	-37.91	144.58	95	32	1979 - 2010
232213	U/S of Bungal Dam	Lal Lal Ck	-37.66	144.03	157	33	1977 - 2009
232214	U/S of Bungal Dam	Black Ck	-37.63	144.06	13	29	1977-2005
232215	U/S of Bungal Dam	Woollen Ck	-37.64	144.08	6	29	1977-2005
233214	Forrest (above Tunnel)	Barwoneast Branc	-38.53	143.73	17	34	1978 - 2011
233215	Leigh R @ Mount Mercer	Leigh	-37.82	143.92	593	39	1974-2012
233223	Warrambine	Warrambine Ck	-37.93	143.87	57	43	1970-2012
234200	Pitfield	Woady Yaloak	-37.81	143.59	324	40	1972 - 2011
234203	Pirron Yallock (above H'Wy)	Pirron Yallock Ck	-38.36	143.42	166	40	1973-2012
234209	Lake Colac	Dean Ck	-38.34	143.56	49	30	1983-2012
235202	Upper Gellibrand	Gellibrand	-37.56	143.64	53	37	1975 - 2011
235203	Curdie	Curdies	-38.45	142.96	790	37	1975 - 2011
235204	Beech Forest	Little Aire Ck	-38.66	143.53	11	36	1976 - 2011

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
235205	Wyelangta	Arkins Ck West B	-38.65	143.44	3	34	1978 - 2011
235209	Beech Forest	Aire	-38.67	143.58	21	22	1991-2012
235210	Gellibrand	Lardner Ck	-38.54	143.54	52	39	1974-2012
235211	Kennedys Ck	Kennedys Ck	-38.59	143.26	268	39	1973-2011
235216	Lorne	Cumberland	-38.57	143.95	38	42	1971-2012
235219	Wyelangta	Aire	-38.71	143.48	90	39	1974-2012
235226	Allenvale	St George	-38.55	143.96	31	20	1970-1989
235227	Bunkers Hill	Gellibrand	-38.53	143.48	311	38	1974 - 2011
235232	Painkalac Ck Dam	Painkalac Ck	-38.45	144.07	36	39	1974-2012
235233	Apollo Bay- Paradise	Barhameast Branc	-38.76	143.62	43	35	1977 - 2011
235234	Gellibrand	Love Ck	-38.49	143.57	75	33	1979 - 2011
235237	Curdie (Digneys Br)	Scotts Ck	-38.45	142.99	361	31	1982-2012
236204	Streatham	Fiery Ck	-37.73	143.07	956	41	1972-2012
236205	Woodford	Merri	-38.32	142.48	899	38	1974 - 2011
236212	Cudgee	Brucknell Ck	-38.35	142.65	570	37	1975 - 2011
236213	Mena Park	Mount Emu Ck	-37.53	143.46	452	39	1974-2012
236219	Ararat	Hopkins	-37.32	142.94	258	24	1989-2012
237200	Toolong	Moyne	-38.32	142.22	570	40	1973-2012
237202	Heywood	Fitzroy	-38.13	141.62	234	45	1968-2012
237206	Codrington	Eumeralla	-38.26	141.94	502	40	1973-2012
237207	Heathmere	Surry	-38.25	141.66	310	37	1975 - 2011
238207	Jimmy Ck	Wannon	-37.37	142.50	40	38	1974 - 2011
238208	Jimmy Ck	Jimmy Ck	-37.38	142.51	23	45	1968-2012
238219	Morgiana	Grange Burn	-37.71	141.83	997	39	1973 - 2011
238220	Cavendish	Dundas	-37.53	142.00	211	23	1990-2012

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
238221	Mirranatwa	Dwyer Ck	-37.50	142.32	269	25	1974-1998
238223	Wando Vale	Wando	-37.50	141.42	174	39	1974-2012
238229	Chetwynd	Chetwynd	-37.31	141.48	69	40	1973-2012
238230	Teakettle	Stokes	-37.87	141.41	181	39	1974-2012
238231	Big Cord	Glenelg	-37.32	142.37	57	34	1979-2012
238235	Lower Crawford	Crawford	-37.98	141.46	606	43	1970-2012
401208	Berringama	Cudgewa Ck	-36.21	147.68	350	47	1965 - 2011
401209	Omeo	Livingstone Ck	-37.11	147.57	243	27	1968 - 1994
401210	below Granite Flat	Snowy Ck	-36.57	147.41	407	44	1968 - 2011
401212	Upper Nariel	Nariel Ck	-36.45	147.83	252	58	1954 - 2011
401216	Jokers Ck	Big	-36.95	141.47	356	60	1952 - 2011
401217	Gibbo Park	Gibbo	-36.75	147.71	389	41	1971 - 2011
401220	McCallums	Tallangatta Ck	-36.21	147.50	464	36	1976 - 2011
401226	Victoria Falls	Victoria	-37.09	147.46	180	22	1989-2012
401229	Cudgewa North	Cudgewa Ck	-36.07	147.88	487	20	1993-2012
401230	Towong	Corryong Ck	-36.11	147.97	363	20	1993-2012
402203	Mongans Br	Kiewa	-36.60	147.10	552	42	1970 - 2011
402204	Osbornes Flat	Yackandandah Ck	-36.31	146.90	255	45	1967 - 2011
402206	Running Ck	Running Ck	-36.54	147.05	126	37	1975 - 2011
402213	Osbornes Flat	Kinchington Ck	-36.32	146.89	122	43	1970-2012
402217	Myrtleford Rd Br	Flaggy Ck	-36.39	146.88	24	41	1970 - 2010
402223	U/S of Offtake	Kiewawest Branch	-36.79	147.16	101	21	1992-2012
403205	Bright	Ovens Rivers	-36.73	146.95	495	41	1971 - 2011
403209	Wangaratta North	Reedy Ck	-36.33	146.34	368	39	1973 - 2011
403213	Greta South	Fifteen Mile Ck	-36.62	146.24	229	39	1973 - 2011

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
403214	Rosewhite	Happy Valley Ck	-36.58	146.82	135	40	1973-2012
403217	Matong North	Rose	-36.83	146.58	154	32	1974-2005
403221	Woolshed	Reedy Ck	-36.31	146.60	214	37	1975 - 2011
403222	Abbeyard	Buffalo	-36.91	146.70	425	39	1973 - 2011
403232	Wandiligong	Morses Ck	-36.75	146.98	123	41	1972-2012
403233	Harris Lane	Buckland	-36.72	146.88	435	40	1972 - 2011
404207	Kelfeera	Holland Ck	-36.61	146.06	451	37	1975 - 2011
404208	Lima	Moonee Ck	-36.76	145.97	91	41	1973-2012
405205	Murrindindi above Colwells	Murrindindi	-37.41	145.56	108	37	1975 - 2011
405209	Taggerty	Acheron	-37.32	145.71	619	39	1973 - 2011
405212	Tallarook	Sunday Ck	-37.10	145.05	337	37	1975 - 2011
405214	Tonga Br	Delatite	-37.15	146.13	368	55	1957 - 2011
405215	Glen Esk	Howqua	-37.23	146.21	368	38	1974 - 2011
405217	Devlins Br	Yea	-37.38	145.48	360	37	1975 - 2011
405218	Gerrang Br	Jamieson	-37.29	146.19	368	53	1959 - 2011
405226	Moorilim	Pranjip Ck	-36.62	145.31	787	38	1974 - 2011
405227	Jamieson	Big Ck	-37.37	146.06	619	42	1970 - 2011
405228	Tarcombe Rd	Hughes Ck	-36.95	145.28	471	38	1975-2012
405229	Wanalta	Wanalta Ck	-36.64	144.87	108	43	1969 - 2011
405230	Colbinabbin	Cornella Ck	-36.61	144.80	259	39	1973 - 2011
405231	Flowerdale	King Parrot Ck	-37.35	145.29	181	38	1974 - 2011
405234	D/S of Polly McQuinn Weir	Seven Creeks	-36.89	145.68	153	48	1965-2012
405237	Euroa Township	Seven Creeks	-36.76	145.58	332	39	1973 - 2011
405238	Pyalong	Mollison Ck	-37.12	144.86	163	41	1972-2012

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
405240	Ash Br	Sugarloaf Ck	-37.06	145.05	609	39	1973 - 2011
405241	Rubicon	Rubicon	-37.29	145.83	129	39	1973 - 2011
405245	Mansfield	Ford Ck	-37.04	146.05	115	42	1970 - 2011
405248	Graytown	Major Ck	-36.86	144.91	282	41	1971 - 2011
405251	Ancona	Brankeet Ck	-36.97	145.78	121	39	1973 - 2011
405264	D/S of Frenchman Ck Jun	Big	-37.52	146.08	333	37	1975 - 2011
405274	Yarck	Home Ck	-37.11	145.60	187	35	1977 - 2011
405290	Broadford	Pine Ck	-37.29	145.05	3	23	1988-2012
405291	Whiteheads Ck	Whiteheads Ck	-37.03	145.21	51	23	1988-2012
405294	U/S of Violet Town	Honeysuckle Ck	-36.72	145.76	23	22	1989-2012
406208	Ashbourne	Campaspe	-37.39	144.45	33	42	1971-2012
406213	Redesdale	Campaspe	-37.02	144.54	629	37	1975 - 2011
406214	Longlea	Axe Ck	-36.78	144.43	234	40	1972 - 2011
406216	Sedgewick	Axe Ck	-36.90	144.36	34	37	1975 - 2011
406224	Runnymede	Mount Pleasant C	-36.55	144.64	248	37	1975 - 2011
406226	Derrinal	Mount Ida Ck	-36.88	144.65	174	34	1978 - 2011
406235	U/S of Heathcote-Mia Mia	Wild Duck Ck	-36.95	144.66	214	33	1981-2012
406250	Springhill-Tylden Rd	Coliban	-37.32	144.36	78	31	1983-2012
406262	Strathfieldsaye	Axe Ck	-36.81	144.39	83	24	1989-2012
407214	Clunes	Creswick Ck	-37.30	143.79	308	37	1975 - 2011
407217	Vaughan atD/S Fryers Ck	Loddon	-37.16	144.21	299	44	1968 - 2011
407220	Norwood	Bet Bet Ck	-37.00	143.64	347	38	1973 - 2010
407221	Yandoit	Jim Crow Ck	-37.21	144.10	166	39	1973 - 2011
407222	Clunes	Tullaroop Ck	-37.23	143.83	632	39	1973 - 2011

VIC

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
407227	Smeaton	Birch Ck	-37.34	143.92	146	38	1975-2012
407230	Strathlea	Joyces Ck	-37.17	143.96	153	39	1973 - 2011
407246	Marong	Bullock Ck	-36.73	144.13	184	39	1973 - 2011
407253	Minto	Piccaninny Ck	-36.45	144.47	668	39	1973 - 2011
407288	Lillicur	Bet Bet Ck	-37.19	143.52	124	23	1990-2012
408202	Amphitheatre	Avoca	-37.18	143.40	78	40	1973-2012
408206	Archdale Junction	Avoca	-36.88	143.50	681	26	1987-2012
415207	Eversley	Wimmera	-37.19	143.19	304	37	1975 - 2011
415217	Grampians Rd Br	Fyans Ck	-37.26	142.53	34	38	1973 - 2010
415220	Wimmera HWY	Avon	-36.64	142.98	596	37	1974 - 2010
415226	Carrs Plains	Richardson	-36.75	142.79	130	31	1971 - 2001
415237	Stawell	Concongella Ck	-37.02	142.82	239	35	1977 - 2011
415238	Navarre	Wattle Ck	-36.90	143.10	141	36	1976 - 2011
415244	Warrak	Shepherds Ck	-37.25	143.19	6	30	1983-2012
415245	Crowlands	Mount Cole Ck	-37.1650	143.0917	144	28	1985-2012

Table A3 Selected catchments from South Australia

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
A4260504	4km East of Yundi	Finniss River	-35.32	138.67	191	41	1971-2011
A4260529	Cambrai	Marne River upstream	-34.68	139.23	239	33	1974-2006
A4260533	Hartley	Bremer River	-35.21	139.01	473	37	1975-2011
A4260536	Worlds End	Burra Creek	-33.84	139.09	704	34	1875-2008
A4260557	Mount Barker	Mount Barker Creek dowstream	-35.09	138.92	88	31	1981-2011
A4260558	Dawesley	Dawesley Creek	-35.04	138.95	43	32	1980-2011
A5020502	Dam And Road Bridge	Myponga River upstream	-35.38	138.48	76.5	32	1980-2011
A5030502	Scott Bottom	Scott Creek	-35.1	138.68	26.8	41	1971-2011
A5030503	4.5km WNW Kangarilla	Baker Gully	-35.14	138.61	48.7	41	1971-2011
A5030504	Houlgrave	Onkaparinga River	-35.08	138.73	321	37	1975-2011
A5030506	Mount Bold Reservoir	Echunga Creek upstream	-35.13	138.73	34.2	37	1975-2011
A5030507	Lenswood	Lenswood Creek	-34.94	138.82	16.5	38	1974-2011
A5030508	Craigbank	Inverbrackie Creek	-34.95	138.93	8.4	38	1974-2011
A5030509	Aldgate Railway Station	Aldgate Ck	-35.02	138.73	7.8	38	1974-2011
A5030526	Uraidla	Cox Creek	-34.97	138.74	4.3	34	1978-2011
A5030529	Mount Bold Reservoir	Burnt Out Creek upstream	-35.13	138.71	0.6	20	1980-2011
A5040500	Gumeracha Weir	River Torrens	-34.82	138.85	194	63	1942-2011
A5040512	Mount Pleasant	Torrens River	-34.79	139.03	26	37	1975-2011
A5040517	Waterfall Gully	First Creek	-34.97	138.68	5	28	1978-2005
A5040518	Minno Creek Junction	Sturt River upstream M	-35.04	138.63	19	30	1979-2008

SA

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
A5040523	Castambul	Sixth Creek	-34.87	138.76	44	33	1979-2011
A5040525	Millbrook Reservoir	Kersbrook Ck upstream	-34.81	138.84	23	21	1991-2011
A5050502	Yaldara	North Para River	-34.57	138.88	384	63	1948-2011
A5050504	Turretfield	North Para River	-34.56	138.77	708	35	1974-2008
A5050517	Penrice	North Para River	-34.46	139.06	118	33	1979-2011
A5070500	Andrews	Hill River	-33.61	138.63	235	41	1971-2011
A5070501	Spalding	Hutt River	-33.54	138.6	280	41	1971-2011
A5130501	Gorge Falls	Rocky River upstream	-35.96	136.7	190	37	1975-2011

Table A4 Selected catchments from Tasmania

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
76	at Ballroom Offtake	North Esk	-41.5	147.39	335	74	1923-1996
159	D/S Rapid	Arthur	-41.12	145.08	1600	42	1955-1996
473	D/S Crossing Rv	Davey	-43.14	145.95	680	34	1964-1997
499	at Newbury	Tyenna	-42.71	146.71	198	33	1965-1997
852	at Strathbridge	Meander	-41.49	146.91	1025	27	1985-2011
1012	3.5 Km U/S Esperance	Peak Rivulet	-43.32	146.9	35	23	1975-1997
1200	at Whitemark Water Supply	South Pats	-40.09	148.02	21	22	1969-1990
2200	at The Grange	Swan	-42.05	148.07	440	33	1964-1996
2204	U/S Coles Bay Rd Bdg	Apsley	-41.94	148.24	157	24	1969-1992
2206	U/S Scamander Water Supply	Scamander	-41.45	148.18	265	28	1969-1996
2207	3 Km U/S Tasman Hwy	Little Swanport	-42.34	147.9	600	19	1971-1989
2208	at Swansea	Meredith	-42.12	148.04	88	27	1970-1996
2209	Tidal Limit	Carlton	-42.87	147.7	136	28	1969-1996
2211	U/S Brinktop Rd	Orielton Rivulet	-42.76	147.54	46	24	1973-1996
2213	D/S McNeils Rd	Goatrock Ck	-42.14	147.92	1.3	22	1975-1996
3203	at Baden	Coal	-42.43	147.45	55	26	1971-1996
5200	at Summerleas Rd Br	Browns	-42.96	147.27	15	30	1963-1992
6200	D/S Grundys Ck	Mountain	-42.94	147.13	42	29	1968-1996
7200	Dover Ws Intake	Esperance	-43.34	146.96	174	29	1965-1993
14207	at Bannons Br	Leven	-41.25	146.09	495	35	1963-1997
14210	U/S Flowerdale R Juncti	Inglis	-41	145.63	170	21	1968-1988
14215	at Moorleah	Flowerdale	-40.97	145.61	150	31	1966-1996
14217	at Sprent	Claytons Rivulet	-41.26	146.17	13.5	26	1970-1995

TAS

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
14220	U/S Bass HWY	Seabrook Ck	-41.01	145.77	40	20	1977-1996
16200	U/S Old Bass Hwy	Don	-41.19	146.31	130	24	1967-1990
17200	at Tidal Limit	Rubicon	-41.26	146.57	255	31	1967-1997
17201	1.5KM U/S Tidal Limit	Franklin Rivulet	-41.26	146.61	131	20	1975-1994
18201	0.5 Km U/S Tamar	Supply	-41.26	146.94	135	19	1965-1983
18221	D/S Jackeys Marsh	Jackeys Ck	-41.68	146.66	29	30	1982-2011
18312	D/S Elizabeth R Junctio	Macquarie	-41.91	147.39	1900	19	1989-2007
19200	2.6KM U/S Tidal Limit	Brid	-41.02	147.37	134	32	1965-1996
19201	2KM U/S Forester Rd Bdg	Great Forester	-41.11	147.61	195	27	1970-1996
19204	D/S Yarrow Ck	Pipers	-41.07	147.11	292	25	1972-1996
304040	U/S Derwent Junction	Florentine River	-42.44	146.52	435.8	61	1951-2011
304125	Below Lagoon	Travellers Rest River	-42.07	146.25	43.6	25	1949-1973
304597	At Lake Highway	Pine Tree Rivulet Ck	-41.8	146.68	19.4	43	1969-2011
308145	At Mount Ficham Track	Franklin River	-42.24	145.77	757	59	1953-2011
308183	Below Jane River	Franklin River	-42.47	145.76	1590.3	22	1957-1978
308225	Below Darwin Dam	Andrew River	-42.22	145.62	5.3	21	1988-2008
308446	Below Huntley	Gordon River	-42.66	146.37	458	27	1953-1979
308799	B/L Alma	Collingwood Ck	-42.16	145.93	292.5	31	1981-2011
308819	Above Kelly Basin Rd	Andrew River	-42.22	145.62	4.6	26	1983-2008
310061	At Murchison Highway	Que River	-41.58	145.68	18.4	24	1987-2010
310148	Above Sterling	Murchison River	-41.76	145.62	756.3	28	1955-1982
310149	Below Sophia River	Mackintosh River	-41.72	145.63	523.2	27	1954-1980
310472	Below Bulgobac Creek	Que River	-41.62	145.58	119.1	32	1964-1995
315074	At Moina	Wilmot River	-41.47	146.07	158.1	46	1923-1968
315450	U/S Lemonthyme	Forth River	-41.61	146.13	311	49	1963-2011

TAS

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
316624	Above Mersey	Arm River	-41.69	146.21	86	40	1972-2011
318065	Below Deloraine	Meander River	-41.53	146.66	474	28	1969-1996
318350	Above Rocky Creek	Whyte River	-41.63	145.19	310.8	33	1960-1992

Table A5 Selected catchments from Queensland

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
102101	Fall Ck	Pascoe	-12.88	142.98	651	44	1968-2011
104001	Telegraph Rd	Stewart	-14.17	143.39	470	42	1970-2011
105105	Developmental Rd	East Normanby	-15.77	145.01	297	42	1970-2011
105106	Mount Sellheim	West Normanby	-15.76	144.98	850	35	1971-2005
107001	Flaggy	Endeavour	-15.42	145.07	337	53	1959-2011
107002	Mount Simon	Annan	-15.65	145.19	375	20	1970-1989
108002	Bairds	Daintree	-16.18	145.28	911	43	1969-2011
108003	China Camp	Bloomfield	-15.99	145.29	264	41	1971-2011
108008	U/S Little Falls Ck	Whyanbeel Ck	-16.39	145.34	16	22	1991-2012
110003	Picnic Crossing	Barron	-17.26	145.54	228	86	1926-2011
110004	Malones	Emerald Ck	-16.99	145.49	63	21	1942-1962
110018	Railway Br	Mazlin Ck	-17.23	145.55	43	21	1992-2012
110101	Freshwater	Freshwater Ck	-16.94	145.70	70	37	1922-1958
111001	Gordonvale	Mulgrave	-17.10	145.79	552	43	1917-1972
111003	Aloomba	Behana Ck	-17.13	145.84	86	28	1943-1970
111005	The Fisheries	Mulgrave	-17.19	145.72	357	45	1967-2011
111007	Peets Br	Mulgrave	-17.14	145.76	520	39	1973-2011
111104	Powerline	Russell	-17.42	145.92	231	21	1967-1987
111105	The Boulders	Babinda Ck	-17.35	145.87	39	45	1967-2011
112001	Goondi	North Johnstone	-17.53	145.97	936	39	1929-1967
112002	Nerada	Fisher Ck	-17.57	145.91	16	83	1929-2011
112003	Glen Allyn	North Johnstone	-17.38	145.65	165	53	1959-2011

QLD

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
112004	Tung Oil	North Johnstone	-17.55	145.93	925	45	1967-2011
112101	U/S Central Mill	South Johnstone	-17.61	145.98	400	95	1917-2011
112102	Upper Japoonvale	Liverpool Ck	-17.72	145.90	78	42	1971-2012
113004	Powerline	Cochable Ck	-17.75	145.63	95	45	1967-2011
113007	Ebony Rd	Koolmoon Ck	-17.74	145.56	30	27	1986-2012
114001	Upper Murray	Murray	-18.11	145.80	156	41	1971-2011
116005	Peacocks Siding	Stone	-18.69	145.98	368	36	1936-1971
116008	Abergowrie	Gowrie Ck	-18.45	145.85	124	51	1954-2004
116010	Blencoe Falls	Blencoe Ck	-18.20	145.54	226	51	1961-2011
116011	Ravenshoe	Millstream	-17.60	145.48	89	49	1963-2011
116012	8.7KM	Cameron Ck	-18.07	145.34	360	50	1962-2011
116013	Archer Ck	Millstream	-17.65	145.34	308	50	1962-2011
116014	Silver Valley	Wild	-17.63	145.30	591	50	1962-2011
116015	Wooroora	Blunder Ck	-17.74	145.44	127	45	1967-2011
116017	Running Ck	Stone	-18.77	145.95	157	41	1971-2011
117002	Bruce HWY	Black	-19.24	146.63	256	38	1974-2011
117003	Bluewater	Bluewater Ck	-19.18	146.55	86	38	1974-2011
118003	Hervey Range Rd	Bohle	-19.32	146.70	143	27	1986-2012
118004	Middle Bohle R Junctio	Little Bohle	-19.33	146.68	54	20	1986-2005
118101	Gleesons Weir	Ross	-19.32	146.74	797	45	1916-1960
118106	Allendale	Alligator Ck	-19.39	146.96	69	37	1975-2011
119004	Bomb Range	Bullock Ck	-19.71	146.92	59	20	1972-1991
119006	Damsite	Major Ck	-19.67	147.02	468	33	1979-2011
120014	Oak Meadows	Broughton	-20.18	146.32	182	28	1971-1998
120102	Keelbottom	Keelbottom Ck	-19.37	146.36	193	44	1968-2011

QLD

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
120120	Mt. Bradley	Running	-19.13	145.91	490	36	1976-2011
120204	Crediton Recorder	Broken	-21.17	148.51	41	31	1957-1987
120206	Mt Jimmy	Pelican Ck	-20.60	147.69	545	27	1961-1987
120216	Old Racecourse	Broken	-21.19	148.45	100	42	1970-2011
120307	Pentland	Cape	-20.48	145.47	775	42	1970-2011
121001	Ida Ck	Don	-20.29	148.12	604	54	1958-2011
121002	Guthalungra	Elliot	-19.94	147.84	273	38	1974-2011
122004	Lower Gregory	Gregory	-20.30	148.55	47	39	1973-2011
124001	Caping Siding	O'Connell	-20.63	148.57	363	42	1970-2011
124002	Calen	StHelens Ck	-20.91	148.76	118	38	1974-2011
124003	Jochheims	Andromache	-20.58	148.47	230	35	1977-2011
125002	Sarich's	Pioneer	-21.27	148.82	757	51	1961-2011
125004	Gargett	Cattle Ck	-21.18	148.74	326	44	1968-2011
125005	Whitefords	Blacks Ck	-21.33	148.83	506	38	1974-2011
125006	Dam Site	Finch Hatton Ck	-21.11	148.63	35	35	1977-2011
126003	Carmila	Carmila Ck	-21.92	149.40	84	38	1974-2011
129001	Byfield	Waterpark Ck	-22.84	150.67	212	59	1953-2011
130004	Old Stn	Raglan Ck	-23.82	150.82	389	48	1964-2011
130108	Curragh	Blackwater Ck	-23.50	148.88	776	33	1973-2005
130207	Clermont	Sandy Ck	-22.80	147.58	409	46	1966-2011
130208	Ellendale	Theresa Ck	-22.98	147.58	758	39	1965-2003
130215	Lilyvale Lagoon	Crinum Ck	-23.21	148.34	252	35	1977-2011
130319	Craiglands	Bell Ck	-24.15	150.52	300	51	1961-2011
130321	Mt. Kroombit	Kroombit Ck	-24.41	150.72	373	41	1964-2004
130335	Wura	Dee	-23.77	150.36	472	40	1972-2011
130336	Folding Hills	Grevillea Ck	-24.58	150.62	233	39	1973-2011

QLD

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
130348	Red Hill	Prospect Ck	-24.45	150.42	369	36	1976-2011
130349	Kingsborough	Don	-23.97	150.39	593	35	1977-2011
130413	Braeside	Denison Ck	-21.77	148.79	757	40	1972-2011
130503	Wyseby Stn	Carnarvon Ck	-24.97	148.53	561	21	1967-1987
130507	Planet Downs	Planet Ck	-24.54	148.91	776	20	1973-1992
133003	Marlua	Diglum Ck	-24.19	151.16	203	36	1969-2004
135002	Springfield	Kolan	-24.75	151.59	551	46	1966-2011
135004	Dam Site	Gin Gin Ck	-24.97	151.89	531	46	1966-2011
136006	Dam Site	Reid Ck	-25.27	151.52	219	46	1966-2011
136102	Meldale	Three Moon Ck	-24.69	150.96	310	32	1949-1980
136108	Upper Monal	Monal Ck	-24.61	151.11	92	49	1963-2011
136110	The Gorge	Baywulla Ck	-25.09	151.38	163	22	1965-1986
136111	Dakiel	Splinter Ck	-24.75	151.26	139	46	1966-2011
136112	Yarrol	Burnett	-24.99	151.35	370	46	1966-2011
136202	Litzows	Barambah Ck	-26.30	152.04	681	91	1921-2011
136203	Brooklands	Barker Ck	-26.74	151.82	249	71	1941-2011
136301	Weens Br	Stuart	-26.50	151.77	512	76	1936-2011
137001	Elliott	Elliott	-24.99	152.37	220	63	1949-2011
137003	Dr Mays Crossing	Elliott	-24.97	152.42	251	37	1975-2011
137101	Burrum HWY	Gregory	-25.09	152.24	454	45	1967-2011
137102	Eureka	Sandy Ck	-25.34	152.14	158	21	1967-1987
137201	Bruce HWY	Isis	-25.27	152.37	446	45	1967-2011
137202	Childers	Oaky Ck	-25.29	152.29	161	21	1967-1987
138002	Brooyar	Wide Bay Ck	-26.01	152.41	655	102	1910-2011
138003	Glastonbury	Glastonbury Ck	-26.22	152.52	113	33	1979-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
138009	Tagigan Rd	Tinana Ck	-26.08	152.78	100	37	1975-2011
138010	Kilkivan	Wide Bay Ck	-26.08	152.22	322	102	1910-2011
138101	Kenilworth	Mary	-26.60	152.73	720	53	1921-1973
138102	Zachariah	Amamoor Ck	-26.37	152.62	133	91	1921-2011
138103	Knockdomny	Kandanga Ck	-26.40	152.64	142	34	1921-1954
138104	Kidaman	Obi Obi Ck	-26.63	152.77	174	43	1921-1963
138106	Baroon Pocket	Obi Obi Ck	-26.71	152.86	67	46	1941-1986
138107	Cooran	Six Mile Ck	-26.33	152.81	186	64	1948-2011
138110	Bellbird Ck	Mary	-26.63	152.70	486	52	1960-2011
138111	Moy Pocket	Mary	-26.53	152.74	820	48	1964-2011
138113	Hygait	Kandanga Ck	-26.39	152.64	143	40	1972-2011
138120	Gardners Falls	Obi Obi Ck	-26.76	152.87	26	26	1987-2012
138903	Bauple East	Tinana Ck	-25.82	152.72	783	31	1982-2012
141001	Kiamba	South Maroochy	-26.59	152.90	33	74	1938-2011
141003	Warana Br	Petrie Ck	-26.62	152.96	38	53	1959-2011
141004	Yandina	South Maroochy	-26.56	152.94	75	34	1959-2011
141006	Mooloolah	Mooloolah	-26.76	152.98	39	40	1972-2011
141008	Kiels Mountain	Eudlo Ck	-26.66	153.02	62	30	1983-2012
141009	Eumundi	North Maroochy	-26.50	152.96	38	30	1983-2012
142001	Upper Caboolture	Caboolture	-27.10	152.89	94	46	1966-2011
142201	Cashs Crossing	South Pine	-27.34	152.96	178	46	1918-1963
142202	Drapers Crossing	South Pine	-27.35	152.92	156	46	1966-2011
143010	Boat Mountain	Emu Ck	-26.98	152.29	915	45	1967-2011
143011	Raeburn	Emu Ck	-27.07	152.01	439	20	1966-1985
143015	Damsite	Cooyar Ck	-26.74	152.14	963	43	1969-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
143033	New Beith	Oxley Ck	-27.73	152.95	60	24	1989-2012
143101	Mutdapily	Warrill Ck	-27.75	152.69	771	39	1915-1953
143102	Kalbar No.2	Warrill Ck	-27.92	152.60	468	55	1913-1970
143103	Moogerah	Reynolds Ck	-28.04	152.55	190	36	1918-1953
143107	Walloon	Bremer	-27.60	152.69	622	50	1962-2011
143108	Amberley	Warrill Ck	-27.67	152.70	914	50	1962-2011
143110	Adams Br	Bremer	-27.83	152.51	125	40	1972-2011
143113	Loamside	Purga Ck	-27.68	152.73	215	38	1974-2011
143203	Helidon Number 3	Lockyer Ck	-27.54	152.11	357	85	1927-2011
143208	Dam Site	Fifteen Mile Ck	-27.46	152.10	87	26	1957-1985
143209	Mulgowie2	Laidley Ck	-27.73	152.36	167	49	1958-2011
143212	Tenthill	Tenthill Ck	-27.56	152.39	447	29	1984-2012
143219	Spring Bluff	Murphys Ck	-27.47	151.99	18	27	1986-2012
143229	Warrego HWY	Laidley Ck	-27.56	152.39	462	22	1991-2012
143303	Peachester	Stanley	-26.84	152.84	104	84	1928-2011
143306	U/S Byron Ck Junct	Reedy Ck	-27.14	152.64	56	30	1976-2005
143307	Causeway	Byron Ck	-27.13	152.65	79	34	1976-2009
143921	Rosentretters Br	Cressbrook Ck	-27.14	152.33	447	26	1987-2012
145002	Lamington No.1	Christmas Ck	-28.24	152.99	95	45	1910-1954
145003	Forest Home	Logan	-28.20	152.77	175	90	1918-2011
145005	Avonmore	Running Ck	-28.30	152.91	89	31	1922-1952
145007	Hillview	Christmas Ck	-28.22	153.00	132	20	1955-1974
145010	5.8KM Deickmans Br	Running Ckreek	-28.25	152.89	128	46	1966-2011
145011	Croftby	Teviot Brook	-28.15	152.57	83	45	1967-2011

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Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
145012	The Overflow	Teviot Brook	-27.93	152.86	503	43	1967-2009
145013	Rudd's Lane	Christmas Ck	-28.17	152.98	157	20	1968-1987
145018	Up Stream Maroon Dam	Burnett Ck	-28.22	152.61	82	41	1971-2011
145020	Rathdowney	Logan	-28.22	152.87	533	38	1974-2011
145101	Lumeah Number 2	Albert	-28.06	153.04	169	101	1911-2011
145102	Bromfleet	Albert	-27.91	153.11	544	93	1919-2011
145103	Good Dam Site	Cainbable Ck	-28.09	153.08	42	49	1963-2011
145104	32.2KM	Canungra Ck	-28.06	153.12	76	22	1966-1987
145107	Main Rd Br	Canungra Ck	-28.00	153.16	101	38	1974-2011
146002	Glenhurst	Nerang	-28.00	153.31	241	92	1920-2011
146003	Camberra Number 2	Currumbin Ck	-28.20	153.41	24	55	1928-1982
146004	Neranwood	Little Nerang Ck	-28.13	153.29	40	35	1927-1961
146005	Chippendale	Tallebudgera Ck	-28.16	153.40	55	27	1927-1953
146007	Pump House	Tallebudgera Ck	-28.15	153.40	57	27	1936-1962
146010	Army Camp	Coomera	-28.03	153.19	88	49	1963-2011
146011		Nerangwhipbird	-28.09	153.26	122	20	1966-1985
146012	Nicolls Br	Currumbin Ck	-28.18	153.42	30	41	1971-2011
146014	Beechmont	Back Ck	-28.12	153.19	7	40	1972-2011
146020	Springbrook Rd	Mudgeeraba Ck	-28.09	153.35	36	23	1990-2012
146095	Tallebudgera Ck Rd	Tallebudgera Ck	-28.15	153.40	56	41	1971-2011
416303	Clearview	Pike Ck	-28.81	151.52	950	48	1935-1987
416305	Beebo	Brush Ck	-28.69	150.98	335	43	1969-2011
416312	Texas	Oaky Ck	-28.81	151.15	422	42	1970-2011
416410	Barongarook	Macintyre Brook	-28.44	151.46	465	34	1968-2011

QLD

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
422210	Tabers	Bungil Ck	-26.41	148.78	710	45	1967-2011
422302	Killarney	Spring Ck	-28.35	152.34	21	46	1910-1955
422303	Killarney	Spring Ck South	-28.36	152.34	10	46	1910-1955
422304	Elbow Valley	Condamine	-28.37	152.16	275	57	1916-1972
422305	Gillespies	Emu Ck	-28.22	152.28	98	22	1924-1945
422306	Swanfels	Swan Ck	-28.16	152.28	83	92	1920-2011
422307	Kings Ck	Kings Ck	-27.90	151.91	334	43	1921-1966
422313	Emu Vale	Emu Ck	-28.23	152.23	148	64	1948-2011
422317	Rocky Pond	Glengallan Ck	-28.13	151.92	520	38	1954-1991
422319	Allora	Dalrymple Ck	-28.04	152.01	246	43	1969-2011
422321	Killarney	Spring Ck	-28.35	152.33	35	52	1960-2011
422326	Cranley	Gowrie Ck	-27.52	151.94	47	42	1970-2011
422334	Aides Br	Kings Ck	-27.93	151.86	516	42	1970-2011
422338	Leyburn	Canal Ck	-28.03	151.59	395	37	1975-2011
422341	Brosnans Barn	Condamine	-28.33	152.31	92	35	1977-2011
422394	Elbow Valley	Condamine	-28.37	152.14	325	39	1973-2011
915011	Mt Emu Plains	Porcupine Ck	-20.18	144.52	540	40	1972-2011
917104	Roseglen	Etheridge	-18.31	143.58	867	45	1967-2011
917107	Mount Surprise	Elizabeth Ck	-18.13	144.31	651	43	1969-2011
919005	Fonthill	Rifle Ck	-16.68	145.23	366	43	1969-2011
919013	Mulligan HWY	McLeod	-16.50	145.00	532	39	1973-2011
919201	Goldfields	Palmer	-16.11	144.78	533	44	1968-2011
919305	Nullinga	Walsh	-17.18	145.30	326	36	1957-1992
922101	Racecourse	Coen	-13.96	143.17	172	44	1968-2011

QLD

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
926002	Dougs Pad	Dulhunty	-11.83	142.42	332	41	1971-2011

Table A6 Selected catchments from Western Australia

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
602005	Anderson Farm	Chelgiup Ck	-34.89	118.01	48	34	1977 - 2010
602199	Black Cat	Goodga	-34.95	118.08	49.2	46	1964 - 2009
603003	Kompup	Denmark	-34.7	117.21	241.9	36	1974 - 2009
603005	Beigpiegup	Mitchell	-34.83	117.39	51.4	26	1986 - 2010
603008	Pardelup Prison Farm	Upper Hay Trib	-34.63	117.38	1.3	22	1989 - 2010
603013	Eden Rd	Cuppup	-35	117.49	61.1	23	1989 - 2011
603190	Woonanup	Yate Flat Ck	-34.7	117.29	56.3	49	1963 - 2011
606001	Teds Pool	Deep	-34.77	116.62	467.8	37	1975 - 2011
606002	Wattle Block	Weld	-34.69	116.52	24.2	28	1982 - 2009
606185	Dog Pool	Shannon	-34.77	116.38	407.6	35	1964 - 1998
606218	Baldania Ck Conflu	Gardner	-34.75	116.19	392.4	33	1966 - 1998
607004	Quabicup Hill	Perup	-34.33	116.46	666.7	38	1974 - 2011
607005	North Catch. B	Yerraminnup Ck	-34.14	116.32	2.4	23	1975 - 1997
607006	South Catch.B	Yerraminnup Ck	-34.15	116.34	2	23	1975 - 1997
607007	Bullilup	Tone	-34.25	116.68	983.1	34	1978 - 2011
607009	Pemberton Weir	Lefroy Brook	-34.44	116.02	253.6	30	1952 - 1981
607010	March Rd Catch.E	Six Mile Brook Trib	-34.48	116.33	2.9	24	1976 - 1999
607011	April Rd North Catch.F	Quininup Brook Trib	-34.5	116.35	2.5	23	1976 - 1998
607012	April Rd South Catch.G	Quininup Brook Trib	-34.51	116.35	1.6	24	1976 - 1999
607013	Rainbow Trail	Lefroy Brook	-34.43	116.02	249.4	33	1979 - 2011
607014	Netic Rd	Four Mile Brook	-34.3	116	13.1	20	1979 - 1998
607144	Quintarrup	Wilgarup	-34.35	116.35	460.5	51	1961 - 2011
607155	Malimup Track	Dombakup Brook	-34.58	115.97	118.5	39	1961 - 1999

WA

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
607600	Manjimup Research Stn	Smith Brook Trib	-34.37	116.21	0.5	42	1970 - 2011
608001	Upper Iffley	Barlee Brook	-34.21	115.77	159.1	28	1972 - 1999
608002	Staircase Rd	Carey Brook	-34.39	115.84	30.3	37	1975 - 2011
608004	Lewin North Catch C	Easter Brook Trib	-34.21	115.86	1.2	22	1976 - 1997
608006	Lease Rd	Carey Brook	-34.33	115.91	2.4	24	1976 - 1999
608151	Strickland	Donnelly	-34.33	115.78	782.1	60	1952 - 2011
608171	Boat Landing Rd	Fly Brook	-34.45	115.8	62.9	50	1962 - 2011
609002	Brennans Ford	Scott	-34.28	115.3	627.7	43	1969 - 2011
609003	Cambray	St Paul Brook	-33.9	115.66	161.6	26	1974 - 1999
609004	Dido Rd	St Paul Brook	-33.83	115.58	26	26	1974 - 1999
609005	Mandelup Pool	Balgarup	-33.91	117.14	82.4	37	1975 - 2011
609006	Balgarup	Weenup Ck	-33.95	117.21	13.3	25	1975 - 1999
609008	Millbrook	Apostle Brook	-33.8	115.63	27.6	24	1976 - 1999
609011	Padbury Rd	Balingup Brook Trib	-33.81	116	1.7	21	1978 - 1998
609016	Hester Hill	Hester Brook	-33.92	116.1	176.6	23	1983 - 2005
609017	Brooklands	Balingup Brook	-33.8	115.95	548.9	29	1983 - 2011
609018	Barrabup Pool	St John Brook	-33.94	115.69	552.3	29	1983 - 2011
610001	Willmots Farm	Margaret	-33.94	115.05	443	42	1970 - 2011
610005	Happy Valley	Ludlow	-33.68	115.62	109.2	26	1973 - 1998
610006	Woodlands	Wilyabrup Brook	-33.8	115.02	82.3	39	1973 - 2011
610007	Claymore	Ludlow	-33.74	115.7	9.5	22	1977 - 1998
610008	Whicher Range	Margaret R North	-33.81	115.44	15.5	23	1977 - 1999
611004	Boyanup Bridge	Preston	-33.48	115.73	808.4	32	1980 - 2011
611111	Woodperry Homestead	Thomson Brook	-33.63	115.95	102.1	54	1958 - 2011
611221	Pesconeris Farm	Coolingutup Brook	-33.53	115.87	3.9	43	1966 - 2008

WA

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
612004	Worsley	Hamilton	-33.31	116.05	32.3	40	1972 - 2011
612005	Mast View	Stones Brook	-33.37	115.94	12.9	27	1972 - 1998
612007	Dons Catchment	Bingham R Trib	-33.28	116.47	3.5	38	1974 - 2011
612009	Lemon Catchment	Pollard Brook Trib	-33.3	116.41	3.5	33	1974 - 2006
612010	Wights Catchment	Salmon Brook Trib	-33.42	115.98	0.9	34	1974 - 2007
612011	Salmon Catchment	Salmon Brook	-33.42	115.98	0.8	25	1974 - 1998
612012	Falcon Rd	Falcon Brook	-33.41	115.97	5.4	23	1974 - 1996
612014	Palmer	Bingham	-33.28	116.28	366.1	37	1975 - 2011
612016	Maxon Farm	Batalling Ck	-33.32	116.57	16.8	33	1976 - 2008
612019	Duces Farm	Bussell Brook	-33.46	116.02	37.5	22	1977 - 1998
612021	Stenwood	Bingham	-33.19	116.47	48.4	21	1978 - 1998
612022	Sandalwood	Brunswick	-33.22	115.92	116.2	32	1980 - 2011
612025	James Well	Camballan Ck	-33.46	116.43	170	30	1982 - 2011
612034	South Branch	Collie	-33.39	116.16	661.6	60	1952 - 2011
613002	Dingo Rd	Harvey	-33.09	116.04	147.2	42	1970 - 2011
613007	Waterous	Bancell Brook	-32.95	115.95	13.6	37	1975 - 2011
613018	Urquharts	McKnoes Brook	-32.89	115.97	24.4	22	1980 - 2001
613020	Mt William	Samson Brook	-32.93	116.03	4	21	1981 - 2001
613146	Hillview Farm	Clarke Brook	-33	115.92	17.1	50	1962 - 2011
614003	Brookdale Siding	Marrinup Brook	-32.7	115.97	45.6	40	1972 - 2011
614005	Kentish Farm	Dirk Brook	-32.42	116	35.1	30	1971 - 2000
614007	Del Park	South Dandalup Trib	-32.67	116.04	1.3	37	1975 - 2011
614017	Warren Catchment	Little Dandalup Trib	-32.59	116.03	0.9	35	1977 - 2011
614018	Bennetts Catchment	Little Dandalup Trib	-32.6	116.03	0.9	35	1977 - 2011
614019	Hansens Catchment	Little Dandalup Trib	-32.59	116.05	0.7	22	1977 - 1998

WA

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
614020	Higgens Catchment	Little Dandalup Trib	-32.58	116.09	0.6	21	1978 - 1998
614021	Lewis Catchment	North Dandalup Trib	-32.57	116.06	2	35	1977 - 2011
614024	Jones Catchment	North Dandalup Trib	-32.55	116.09	0.7	21	1978 - 1998
614025	Umbucks Catchment	Marrinup Brook Trib	-32.7	116	3.3	20	1979 - 1998
614028	Hopelands Rd	Dirk Brook	-32.43	115.91	63.8	22	1979 - 2000
614037	O'Neil Rd	Big Brook	-32.51	116.19	149.4	29	1983 - 2011
614047	Murray Valley Plntn	Davis Brook	-32.76	116.1	65.7	46	1956 - 2001
614060	Gordon Catchment	South Dandalup R Trib	-32.63	116.26	2.1	24	1988 - 2011
614062	Bates Catchment	Little Dandalup Trib	-32.58	116.03	2.2	23	1989 – 2011
614073	Mundlimup	Gooralong Brook	-32.35	116.04	51.5	47	1952 - 1998
616007	Byfield Rd	Rushy Ck (Manns Gully)	-31.96	116.21	39.2	30	1969 - 1998
616009	Slavery Lane	Pickering Brook	-31.98	116.19	29.4	27	1972 - 1998
616010	Hairpin Bend Rd	Little Darkin	-32.03	116.24	37.8	27	1972 - 1998
616012	Trewd Rd	Helena Brook	-31.92	116.28	26.7	27	1972 - 1998
616014	Furfaros Orchard	Piesse Brook	-31.95	116.08	55.2	24	1975- 1998
616022	Ceriani Farm	More Seldom Seen Ck	-32.25	116.08	3.4	42	1970 - 2011
616041	Vardi Rd	Wungong Brook	-32.25	116.11	80.8	30	1982 - 2011
616189	Railway Parade	Ellen Brook	-31.75	116.02	581.4	47	1965 - 2011
602015	Warren Rd	Mill Brook	-34.93	117.88	177.8	21	1992-2012
606195	Ordnance Rd Crossing	Weld	-34.81	116.58	250.2	49	1964-2012
607024	Stretch's Tree Farm	Chowerup Brook	-34.13	116.74	82.7	25	1988-2012
609001	Crouch Rd	Rosa Brook	-34	115.47	89.2	44	1969-2012
610009	Ludlow	Ludlow	-33.6	115.49	207.8	22	1991-2012
611007	South Western Hwy	Ferguson	-33.35	115.7	144.9	22	1991-2012
612032	Cross Farm	Brunswick	-33.25	115.75	509.4	23	1990-2012

WA

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
614064	Cameron West	Big Brook Trib	-32.59	116.24	2.1	22	1991-2012
614066	Cameron Central	Big Brook Trib	-32.59	116.25	4.9	21	1992-2012
616001	Karls Ranch	Wooroloo Brook	-31.73	116.12	514.7	48	1965-2012
616021	Travellers Arms	Seldom Seen Ck	-32.25	116.09	7.2	47	1966-2012
616178	National Park	Jane Brook	-31.88	116.09	73.4	50	1963-2012
802002	Mt Pierre Gorge	Mount Pierre Ck	-18.62	126.09	318.4	28	1971 - 1998
803001	Mt Joseph	Lennard	-17.37	125.11	1049.8	32	1967 - 2011
803002	Mt Herbert	Lennard	-17.17	125.23	441.4	31	1968 - 1998
803003	Dromedary	Fletcher	-17.12	124.99	67	31	1968 - 1998
806003	Crystal Head	Crystal Ck	-14.49	125.8	68.2	30	1969-1998
809310	Bedford Downs	Ord	-17.43	127.6	552.2	29	1970 - 1998
809312	Frog Hollow	Fletcher Ck Trib	-17.28	128.06	30.6	44	1968-2011
809314	Cockburn North	King R	-15.7	128.12	850.3	26	1986 - 2011

Table A7 Selected catchments for the Northern Territory

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
G8100189	Victoria HWY	Moriarty Ck	-16.065	129.1933	88	19	1967 - 1985
G8110004	Victoria HWY	East Baines	-15.7667	130	2342	46	1963 - 2008
G8110014	U/S Fig Tree Yard	Sullivan's Ck	-15.565	131.285	143	23	1970 - 1992
G8110110	V.R.D. Rd Crossing	Surprise Ck	-16.0783	130.8967	361	44	1960 - 2003
G8110263	1.5 Miles D/S Bore	Bullock Ck	-17.1317	131.4517	474	22	1971 - 1992
G8140008	Old Railway Br	Fergusson	-14.07	131.9767	1490	54	1958 - 2011
G8140061	Blue Hole	Copperfield Ck	-13.9933	131.9033	306	20	1958 - 1977
G8140063	D/S Old Douglas H/S	Douglas	-13.7967	131.3383	842	54	1958 - 2011
G8140086	D/S Stuart HWY	King	-14.6283	132.5883	484	23	1964 - 1986
G8140152	Dam Site	Edith	-14.1683	132.075	590	50	1962 - 2008
G8140158	Dam Site	McAdden Ck	-14.3483	132.3383	133	48	1964 - 2011
G8140159	Waterfall View	Seventeen Mile C	-14.2833	132.4	619	46	1963 - 2008
G8140161	Tipperary	Green Ant Ck	-13.7383	131.1033	435	46	1966 - 2011
G8140166	Gorge	Fish	-14.2367	130.9	992	23	1963 - 1985
G8150010	Batchelor Damsite	Finniss	-13.025	130.9533	360	37	1975 - 2011
G8150018	Stuart HWY	Elizabeth	-12.605	131.0733	101	57	1955 - 2011
G8150096	Cox Peninsula	Carawarra Ck	-12.5317	130.6683	38.5	45	1966 - 2011
G8150097	Rum Jungle +Ansto Eb4	East Finniss	-12.965	130.9683	71	44	1966 - 2009
G8150098	Tumbling Waters	Blackmore	-12.77	130.9483	174	51	1960 - 2010
G8150127	D/S McMillans Rd	Rapid Ck	-12.3933	130.8717	18.3	47	1964 - 2011
G8150151	U/S Darwin R Dam	Celia Ck	-12.91	131.0533	52	39	1972 - 2010
G8150180	Gitchams	Finniss	-12.97	130.7617	1048	47	1961 - 2007
G8150200	Rum Jungle Rd Crossing	East Finniss	-12.99	131	52	26	1982 - 2007

NT

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
G8150233	McArthur Park	Palmerston Catch	-12.4883	130.975	1.4	20	1984 - 2003
G8160235	Damsite	Takamprimili	-11.7817	130.775	166	20	1967 - 1986
G8170002	Railway Br	Adelaide	-13.2417	131.1083	632	53	1954 - 2007
G8170020	Dirty Lagoon	Adelaide	-12.91	131.235	4325	49	1963 - 2011
G8170062	Eighty-Seven Mile Jump Up	Burrell Ck	-13.415	131.1517	36.8	28	1958 - 1985
G8170066	Stuart HWY	Coomalie Ck	-13.0133	131.1233	82	52	1958 - 2010
G8170075	U/S Manton Dam	Manton	-12.8783	131.13	28	46	1965 - 2010
G8170084	Tortilla Flats	Adelaide	-13.09	131.235	1246	52	1960 - 2011
G8170085	Stuart HWY	Acacia Ck	-12.7833	131.12	11	48	1964 - 2011
G8180026	El Sherana Rd Crossing	Mary	-13.6017	132.22	466	50	1962 - 2011
G8180069	near Burrundie	McKinlay	-13.5317	131.7183	352	51	1959 - 2009
G8180252	D/S El Sherana Rd	Harriet Ck	-13.6767	131.9867	122	46	1965 - 2010
G8190001	U/S Arnhem HWY	West Alligator	-12.7917	132.175	316	34	1977 - 2010
G8200045	El Sherana (C)	South Alligator	-13.5233	132.52	1300	52	1958 - 2009
G8200046	Coljon (C Part)	Deaf Adder Ck	-13.0983	133.0183	513	20	1972 - 1991
G8200049	near Nourlangie Rock	Koongarra Ck	-12.8767	132.83	15.4	28	1978 - 2005
G8200112	Kakadu HWY	Nourlangie Ck	-12.8183	132.7417	2220	45	1962 - 2006
G8210001	Nimbuwah (C)	Cooper Ck	-12.1867	133.3483	645	22	1971 - 1992
G8210009	D/S Jabiru	Magela Ck	-12.6417	132.9	605	40	1972 - 2011
G8210012	George Town Crossing	Gulungul Ck (Bog	-12.69	132.8933	47	21	1972 - 1992
G8210016	Mt. Borradaile	Cooper Ck	-12.08	132.9733	1650	27	1980 - 2006
G8210017	Jabiluka Billabong	Magela Ck Plains	-12.4617	132.875	1134	33	1974 - 2006
G8210019	Outflow Main Channel	Magela Plains	-12.2967	132.8217	1435	29	1976 - 2004
G8210024	D/S Nabarlek	Cooper Ck	-12.2933	133.34	225	28	1979 - 2006
G8260053	above Tidal Reach	Lower Latram	-12.3083	136.7783	85	21	1964 - 1984
G9030089	Rd Br	Waterhouse	-14.5617	133.1067	3110	39	1973 - 2011

NT

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record
G9030090	Wattle Hill	Chambers Ck	-14.5	133.3633	89	19	1974 - 1992
G8170020	Dirty Lagoon	Adelaide	-12.91	131.235	4325	49	1963 - 2011

Table A8 Selected catchments for the semi-arid and arid areas

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record	Average Annual Rainfall (mm)
001204A	Camooweal	Georgina	-19.93	138.11	2875	19	1971 - 1988	393.47
G0010005	Soudan Homestead	Ranken	-20.05	137.02	4360	45	1965 - 2009	381.07
A0040502	Terrapinna Springs	Hamilton Ck	-29.92	139.67	326	10	1984 - 1990	209.43
G0060003	Soil Erosion Project	Gillen Ck	-23.70	133.82	3.8	27	1967 - 1993	295.00
G0060008	South Rd Crossing	Roe Ck	-23.82	133.84	560	41	1967 - 2008	290.56
G0060009	Anzac Oval	Todd	-23.70	133.89	443	35	1973 - 2007	320.58
G0060012	Bond Springs (CSIRO Site 6	Stn Ck	-23.53	133.92	34	10	1974 - 1982	306.49
G0060015	Bond Springs	Stn Ck	-23.53	133.92	34	18	1979 - 1995	326.33
G0060017	U/S	Emily Ck	-23.69	133.98	60	28	1981 - 2008	318.05
G0060046	Wigley Gorge	Todd	-23.64	133.88	360	46	1963 - 2001	318.60
G0060047	Big Dipper	Charles	-23.65	133.86	52	14	1973 - 1986	304.96
G0060126	Heavitree Gap	Todd	-23.73	133.87	502	37	1973 - 2007	329.88
G0290240	Old Telegraph Stn	Tennant Ck	-19.56	134.23	72.3	37	1973 - 2007	391.42
G0290242	Stuart HWY	Attack Ck	-19.01	134.15	259	22	1967 - 1986	414.48
407236B	Mitiamo	Mount Hope Ck	-36.17	144.29	1629	41	1968 - 1996	425.60
409056	Aratula Rd	Tuppal Ck	-35.63	145.06	300	18	1986 - 2000	412.38
415257A	Donald	Richardson	-36.43	142.98	1831	40	1989 - 1999	433.74
422211A	Woolerbilla-Hebel Rd	Briarie Ck	-28.91	147.68	410	32	1968 - 2004	436.01
424202A	Yarronvale	Paroo	-26.79	145.34	1890	20	1968 - 1987	397.53
425016	Cobar	Box Ck	-31.46	145.81	15	35	1974 - 2008	407.93
425028	Quondong	Wireyards Ck	-32.13	141.85	50	16	1983 - 1999	243.02
601005	Cascades	Young	-33.54	120.97	88.9	25	1974 - 1998	442.92

Arid

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record	Average Annual Rainfall (mm)
602600	Hinkleys Farm	Jackitup Ck	-33.9	118.12	0.5	27	1972 - 1998	367.33
615011	Mooranoppin Rock	Mooranoppin Ck	-31.6	117.73	83.1	37	1975 - 2011	313.95
615222	Brookton Highway	Dale R South	-32.4	116.83	286	32	1967 - 1998	481.43
615600	North	Kunjin	-32.32	117.73	0.2	30	1969 - 1998	364.77
615604	Homestead	North Nungarin	-31.16	118.15	0.2	26	1972 - 1997	317.98
615605	Jollys Farm	South Nungarin	-31.18	118.15	0.2	27	1972 - 1998	305.64
912115A	Morestone	O Shannassy	-19.60	138.38	425	18	1971 - 1988	431.19
913005A	Damsite	Paroo Ck	-20.34	139.52	305	19	1969 - 1987	450.59
913009A	Flinders HWY	Gorge Ck	-20.69	139.65	248	17	1971 - 1987	444.20
915006A	Revenue Downs	Mountain Ck	-20.64	143.22	203	17	1972 - 1988	454.65
915203A	Cloncurry	Cloncurry	-20.67	140.49	5975	33	1969 - 1997	439.12
915203B	Cloncurry	Cloncurry	-20.70	140.50	5859	37	1969 - 2006	440.80
915204A	Damsite	Cloncurry	-21.08	140.42	4240	33	1969 - 1994	398.48
915205A	Black Gorge	Malbon	-21.06	140.08	425	17	1971 - 1987	423.63
915209A	Main Rd	Corella	-20.45	140.32	1587	17	1972 - 1987	442.72
915210A	Agate Downs	Cloncurry	-21.36	140.41	1089	17	1971 - 1987	411.71
915211A	Landsborough HWY	Williams	-20.87	140.83	415	36	1971 - 2006	417.56
A5090503	Old Kanyaka Ruins	Kanyaka Creek	-32.09	138.29	186.7	36	1977 - 2008	289.54
A5100502	Sugarloaf Hill	Mernmerna Creek	-31.75	138.45	346	18	1973 - 1989	302.34
A5100507	Maynards Well	Windy Ck	-30.64	138.65	170	15	1974 - 1988	288.09
A5100510	Leigh Creek	Windy Ck	-30.61	138.39	448	18	1986 - 2006	226.58
A5100511	Leigh Creek	Emu Ck	-30.62	138.39	224	18	1986 - 2006	226.58
701003	Nokanena Brook	-28.37	114.52	235.2	235.2	30	1972 - 2001	32.60
701005	Robb Crossing	Arrowsmith	-29.62	115.29	809.8	29	1972 - 2000	78.90
701006	Buller	Buller	-28.64	114.62	33.9	26	1975 - 2000	10.80

Arid

Station ID	Station Name	River Name	Lat (°S)	Long (°E)	Area (km^2)	Record Length (years)	Period of Record	Average Annual Rainfall (mm)
701601	Wearbe	Nokanena Brook Catch	-28.33	114.62	0.1	28	1971 - 1998	0.05
706207	Mt Samson	Hardey	-22.67	117.61	250.3	34	1967 - 2000	37.80
707001	Palra Springs	Robe	-22.06	117.06	174.3	31	1969 - 1999	30.60
708009	Fish Pool	Kanjenjie Ck Trib.	-21.66	117.33	41.1	28	1975 - 2002	11.50
708227	Recorder Pool	Portland	-21.45	116.88	553.4	34	1967 - 2000	48.60
709006	Blue Dog Pool	Tanberry Ck	-21.59	117.55	128.1	22	1975 - 1996	19.60
709007	Marmurrina Pool U-South	Harding	-21.3	117.07	49.4	24	1975 - 1998	14.60
709010	Pincunah	Turner	-21.23	118.83	885	24	1985 - 2008	56.50

Table A9 Summary statistics of the climatic and catchment characteristics for Region 1 (N = 558)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	0.90	1036.00	294.95	213.50	34.00	90.25	447.00	684.60
$I_{6,50}$ (mm/h)	3.95	22.40	8.69	7.47	5.05	5.85	10.40	14.55
$I_{6,2}$ (mm/h)	8.45	55.30	19.95	16.62	11.18	12.33	24.74	35.54
MAR (mm)	484.39	4546.00	1136.15	971.00	644.74	768.75	1330.50	1772.40
$I_{12,50}$ (mm/h)	2.61	15.92	5.74	4.93	3.27	3.83	6.74	9.99
shape factor	0.14	1.63	0.78	0.77	0.52	0.64	0.92	1.03
$I_{6,2}/I_{6,50}$	1.85	2.81	2.26	2.26	2.00	2.10	2.41	2.54

Table A10 Summary statistics of the climatic and catchment characteristics for Region 2 (N = 51)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	1.30	1900.00	320.51	158.10	18.40	44.80	437.90	756.30
$I_{6,50}$ (mm/h)	4.08	8.42	5.96	6.00	5.08	5.43	6.38	6.95
$I_{6,2}$ (mm/h)	7.83	17.63	11.46	11.10	9.55	10.34	12.67	13.28
MAR (mm)	520.20	3014.61	1364.04	1087.31	691.19	802.32	1881.90	2479.31
$I_{12,50}$ (mm/h)	2.65	6.02	4.14	4.14	3.45	3.66	4.52	4.78
shape factor	0.38	1.50	0.80	0.77	0.56	0.67	0.91	1.06
$I_{6,2}/I_{6,50}$	1.67	2.26	1.93	1.93	1.77	1.80	2.01	2.12

Table A11 Summary statistics of the climatic and catchment characteristics for Region 3 (N = 28)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	0.60	708.00	161.03	62.60	6.96	22.00	236.00	410.70
$I_{6,50}$ (mm/h)	4.05	5.78	4.97	5.03	4.32	4.52	5.28	5.60
$I_{6,2}$ (mm/h)	9.93	11.85	11.20	11.33	10.56	11.11	11.48	11.60
MAR (mm)	308.97	937.13	688.14	761.13	392.18	535.79	840.38	897.61
$I_{12,50}$ (mm/h)	2.53	3.94	3.26	3.31	2.74	2.93	3.50	3.72
shape factor	0.46	1.34	0.82	0.79	0.61	0.68	0.94	1.14
$I_{6,2}/I_{6,50}$	2.04	2.53	2.27	2.23	2.07	2.17	2.42	2.50

Table A12 Summary statistics of the climatic and catchment characteristics for Region 4 (N =58)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	1.40	4325.00	611.19	356.00	34.94	82.75	792.75	1451.50
$I_{6,50}$ (mm/h)	9.37	15.43	12.82	12.77	11.62	12.28	13.50	14.20
$I_{6,2}$ (mm/h)	19.72	33.13	25.80	25.70	23.11	24.02	27.03	29.02
MAR (mm)	504.52	1694.11	1260.04	1408.09	789.82	1029.77	1462.20	1541.77
$I_{12,50}$ (mm/h)	5.36	9.15	7.37	7.32	6.60	7.00	7.69	8.48
shape factor	0.38	1.15	0.72	0.73	0.50	0.60	0.82	0.98
$I_{6,2}/I_{6,50}$	0.38	1.15	0.72	0.73	0.50	0.60	0.82	0.98

Table A13 Summary statistics of the climatic and catchment characteristics for Region 5 (N = 103)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	0.50	983.10	139.94	45.60	1.36	3.70	160.35	501.08
$I_{6,50}$ (mm/h)	4.30	7.28	5.80	5.87	4.74	4.95	6.40	7.13
$I_{6,2}$ (mm/h)	9.68	13.82	11.91	12.18	9.97	10.83	13.01	13.31
MAR (mm)	515.66	1274.56	989.16	1010.64	769.84	871.14	1119.15	1188.07
$I_{12,50}$ (mm/h)	2.64	4.65	3.73	3.82	2.98	3.16	4.19	4.55
shape factor	0.32	1.60	0.75	0.70	0.46	0.57	0.85	1.10
$I_{6,2}/I_{6,50}$	1.82	2.56	2.07	2.04	1.89	1.96	2.14	2.36

Table A14 Summary statistics of the climatic and catchment characteristics for Region 6 (N =11)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	0.10	885.00	287.33	174.30	33.90	45.25	401.85	809.80
$I_{6,50}$ (mm/h)	4.72	9.30	7.16	7.42	4.82	5.31	8.96	9.27
$I_{6,2}$ (mm/h)	11.28	27.40	18.92	19.08	11.65	12.88	24.58	24.97
MAR (mm)	330.08	532.46	413.04	408.50	338.78	387.04	428.29	493.67
$I_{12,50}$ (mm/h)	2.90	5.64	4.38	4.45	2.97	3.27	5.50	5.62
shape factor	0.13	1.71	0.70	0.85	0.14	0.31	0.95	1.02
$I_{6,2}/I_{6,50}$	2.34	2.96	2.60	2.63	2.35	2.49	2.68	2.81

Table A15 Summary statistics of the climatic and catchment characteristics for Region 7 (N =44)

Variables	Min	Max	Average	Median	10th percentile	25th percentile	75th percentile	90th percentile
area (km^2)	0.20	5975.00	878.88	302.50	7.16	69.23	516.50	2579.50
$I_{6,50}$ (mm/h)	3.98	9.62	6.21	5.38	4.17	4.63	8.08	9.02
$I_{6,2}$ (mm/h)	10.22	22.72	16.35	17.01	10.76	12.37	19.56	21.90
MAR (mm)	209.43	481.43	364.51	386.25	288.53	306.28	427.00	442.86
$I_{12,50}$ (mm/h)	2.43	5.77	3.75	3.36	2.58	2.91	4.82	5.31
shape factor	0.32	2.16	0.88	0.78	0.58	0.68	0.98	1.19
$I_{6,2}/I_{6,50}$	2.27	3.18	2.68	2.51	2.38	2.42	3.00	3.16

Appendix B Additional results from the data-rich regions

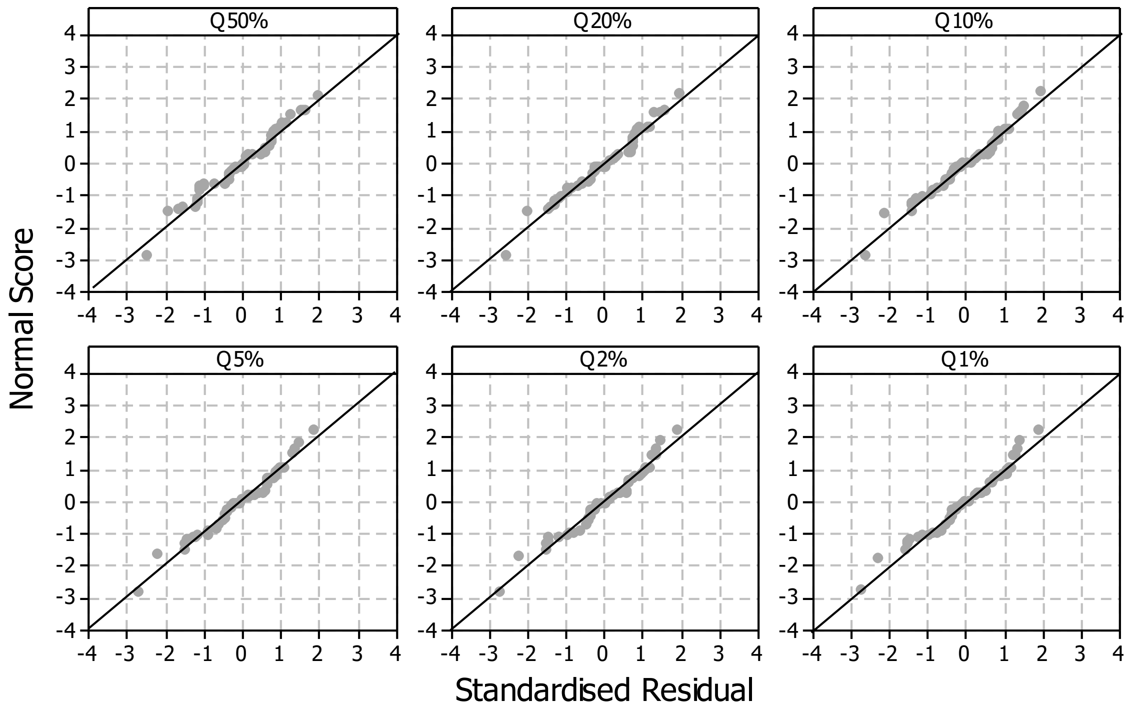

Figure B.1 Standardised residuals vs. Z score for AEPs of 50% to 1% for Region 2 (Tasmania)

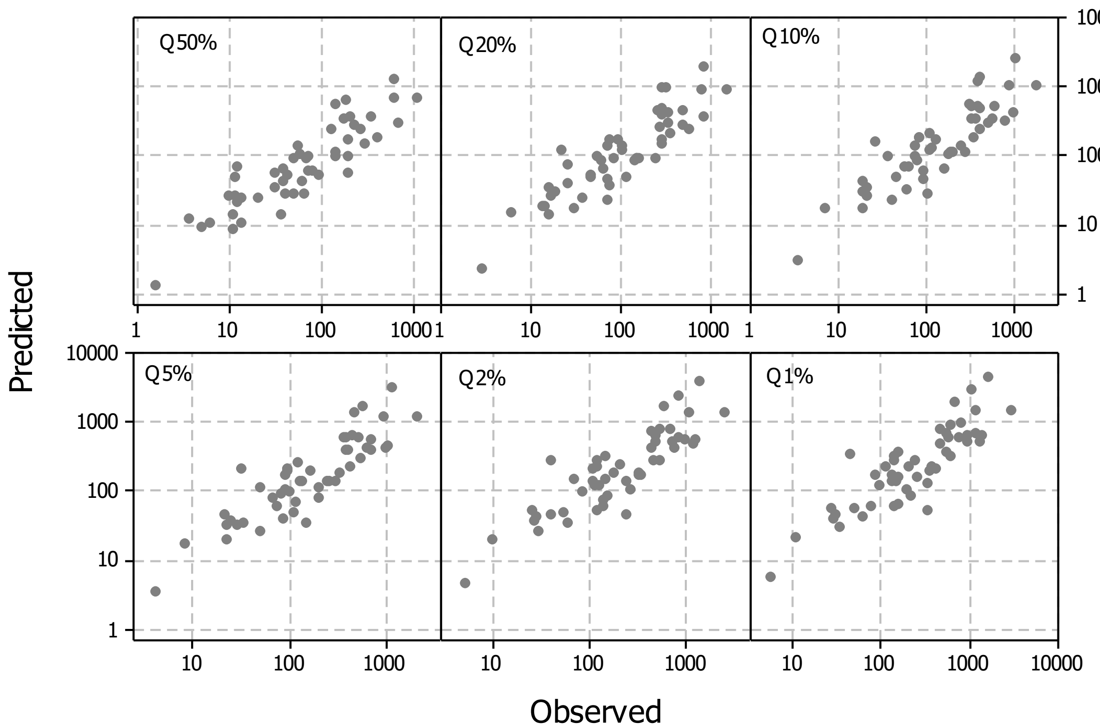

Figure B.2 Observed vs. predicted quantiles (in log space) for AEPs of 50% to 1% for Region 2 (Tasmania) (flood discharges are in m^3/s)

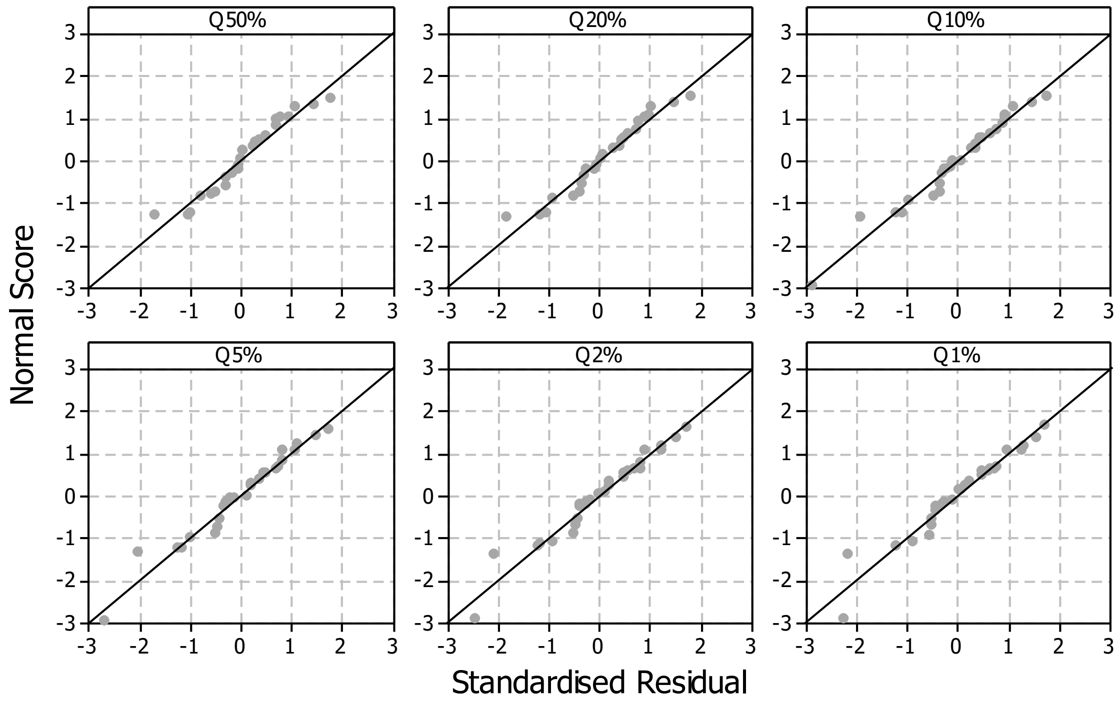

Figure B.3 Standardised residuals vs. Z score for AEPs of 50% to 1% for Region 3 (South Australia)

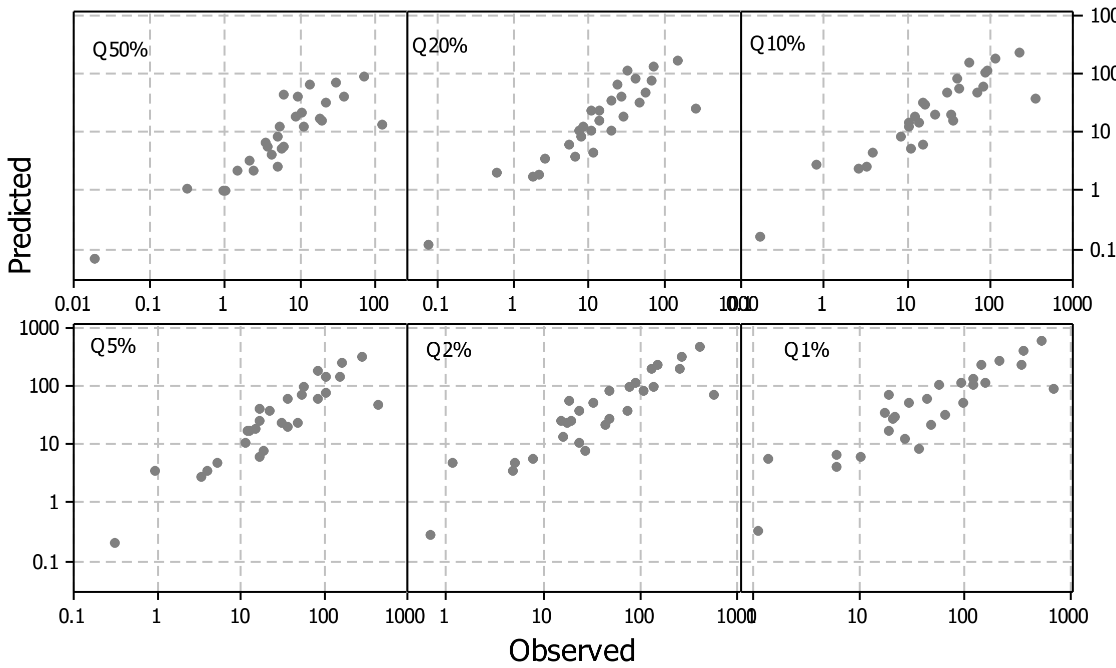

Figure B.4 Observed vs. predicted quantiles (in log space) for AEPs of 50% to 1% for Region 3 (South Australia) (flood discharges are in m^3/s)

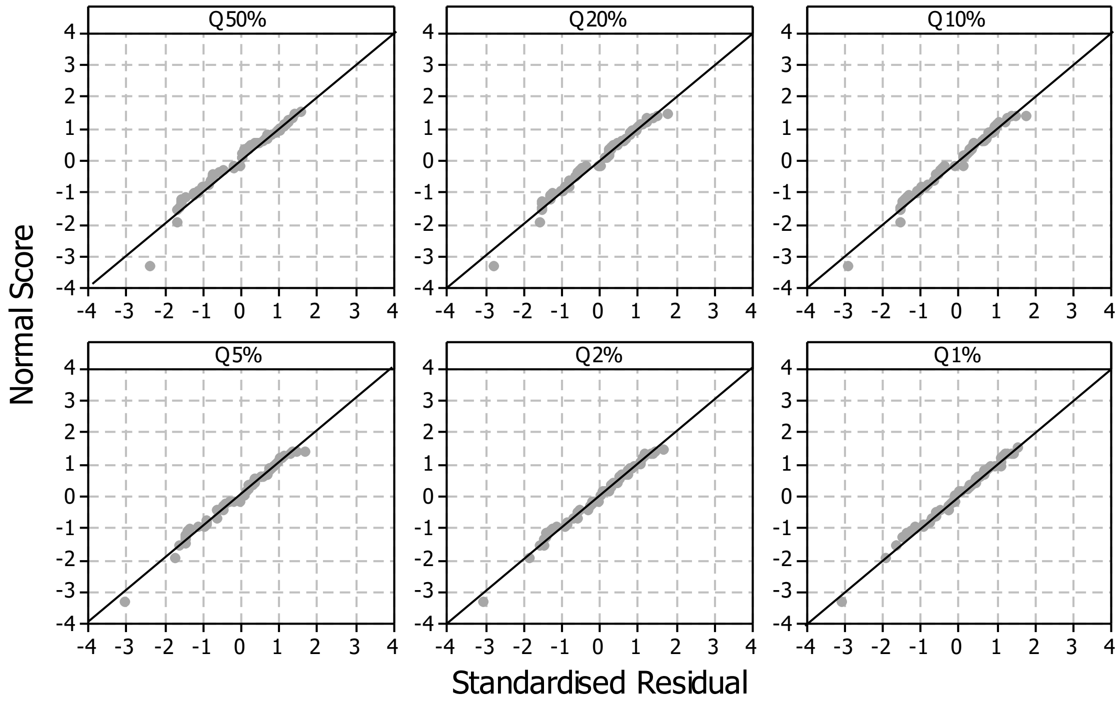

Figure B.5 Standardised residuals vs. Z score for AEPs of 50% to 1% for Region 4 (NT + Kimberley WA)

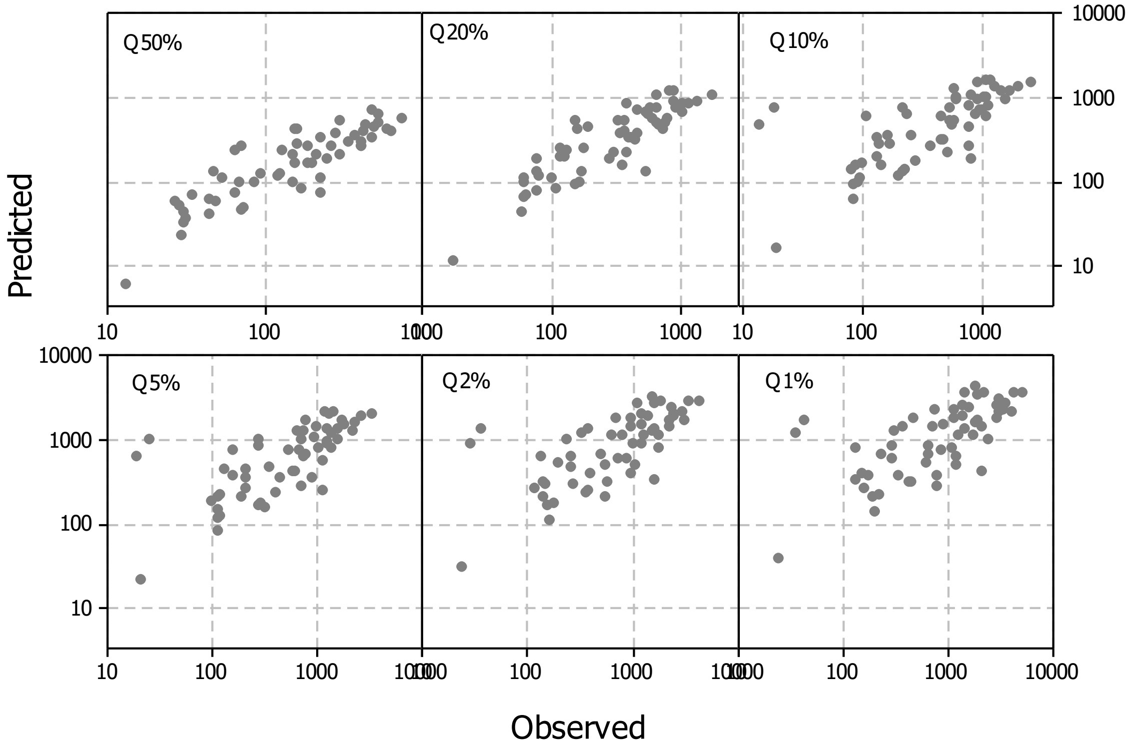

Figure B.6 Observed vs. predicted quantiles (in log space) for AEPs of 50% to 1% for Region 4 (NT + Kimberley WA) (flood discharges are in m^3/s)

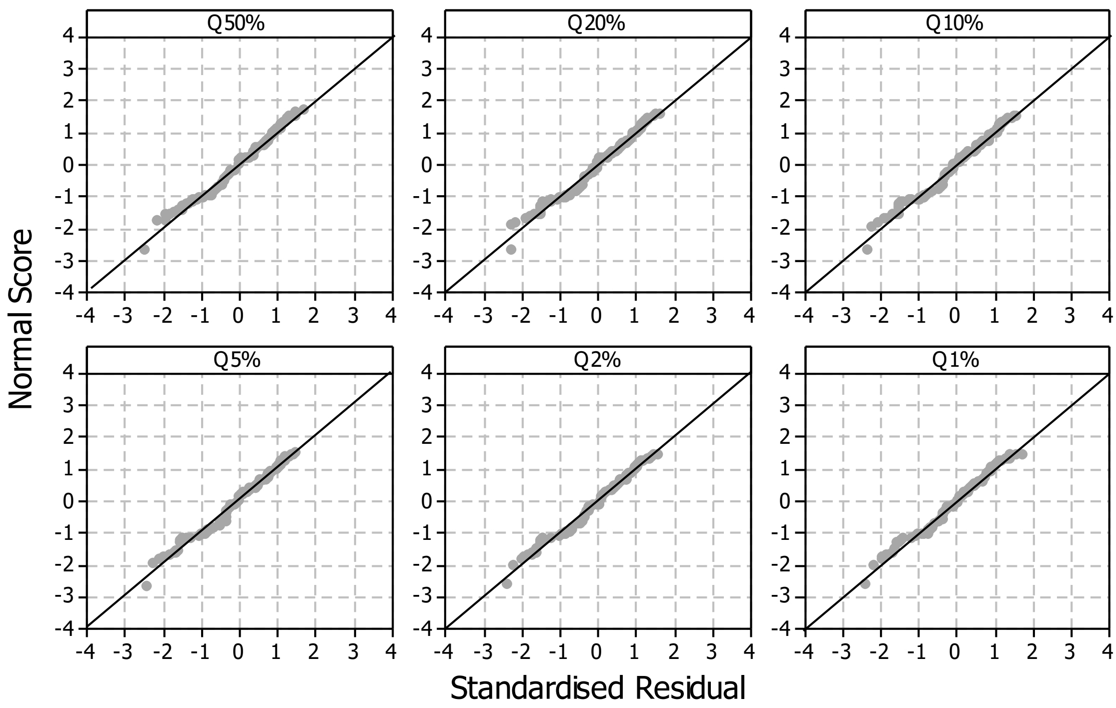

Figure B.7 Standardised residuals vs. Z score for AEPs of 50% to 1% for Region 5 (SW Western Australia)

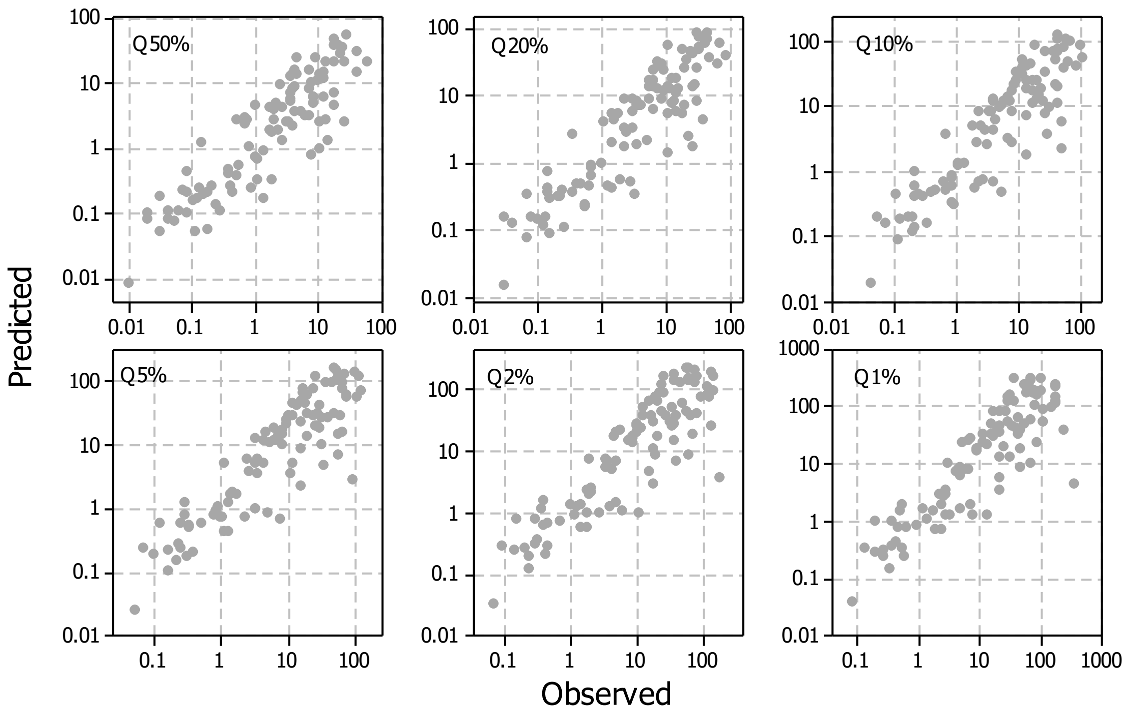

Figure B.8 Observed vs. predicted quantiles (in log space) for AEPs of 50% to 1% for Region 5 (SW Western Australia) (flood discharges are in m^3/s)

Appendix C Additional results from the arid regions

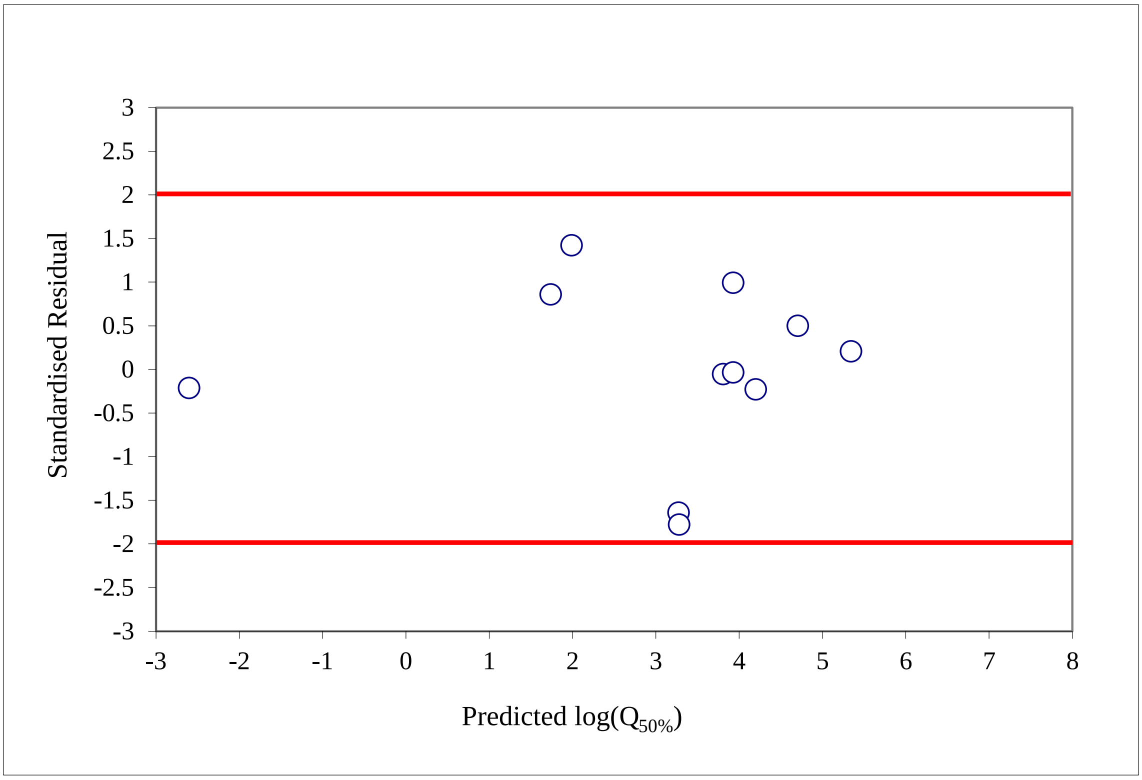

Figure C.1 Standardised residuals vs. predicted quantiles for 50% AEP (Region 6)

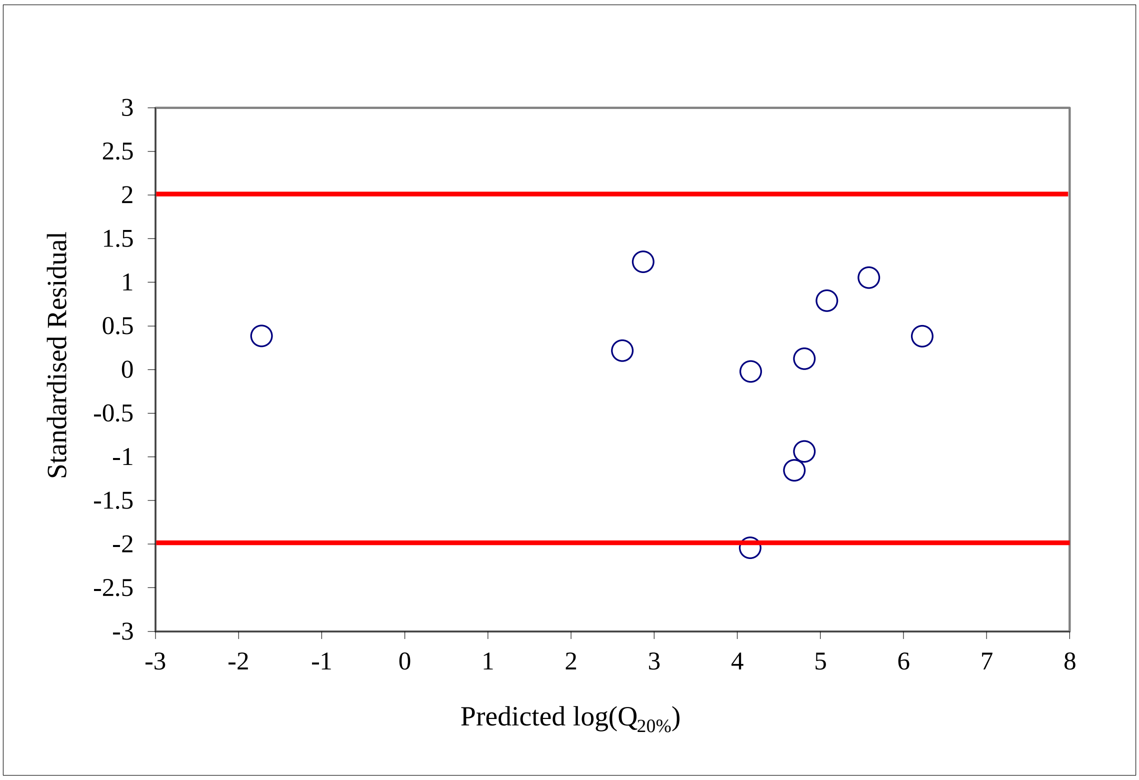

Figure C.2 Standardised residuals vs. predicted quantiles for 20% AEP (Region 6)

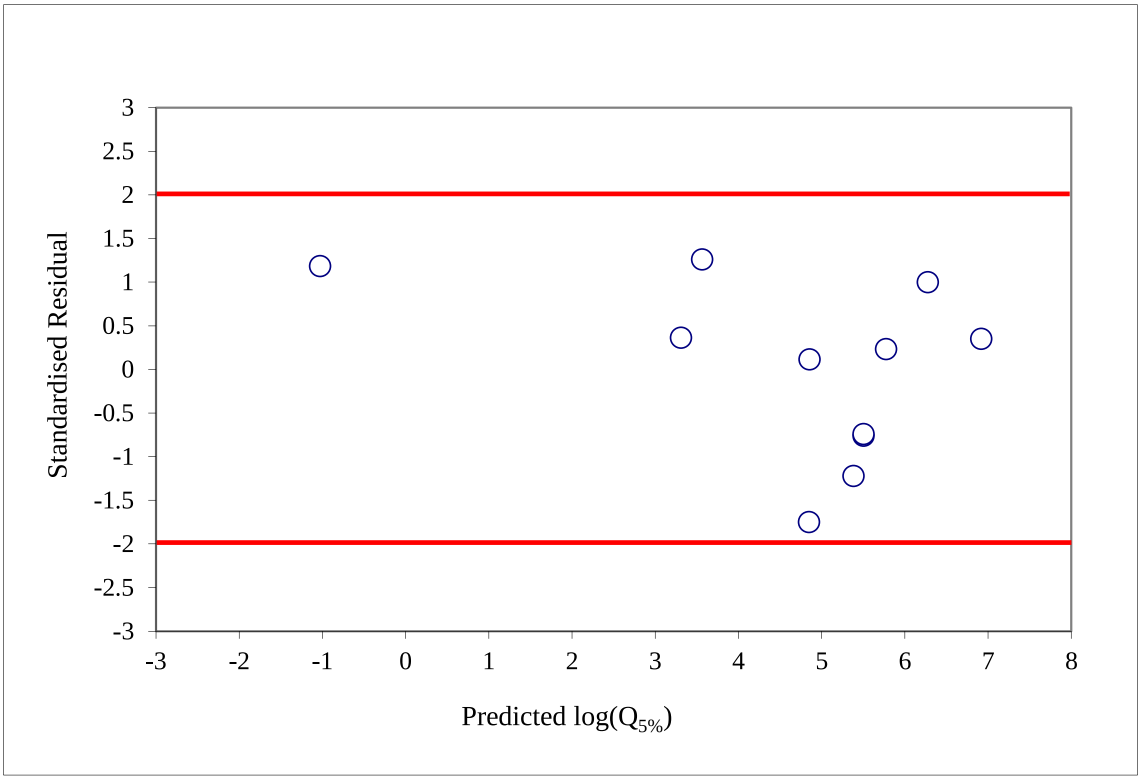

Figure C.3 Standardised residuals vs. predicted quantiles for 5% AEP (Region 6)

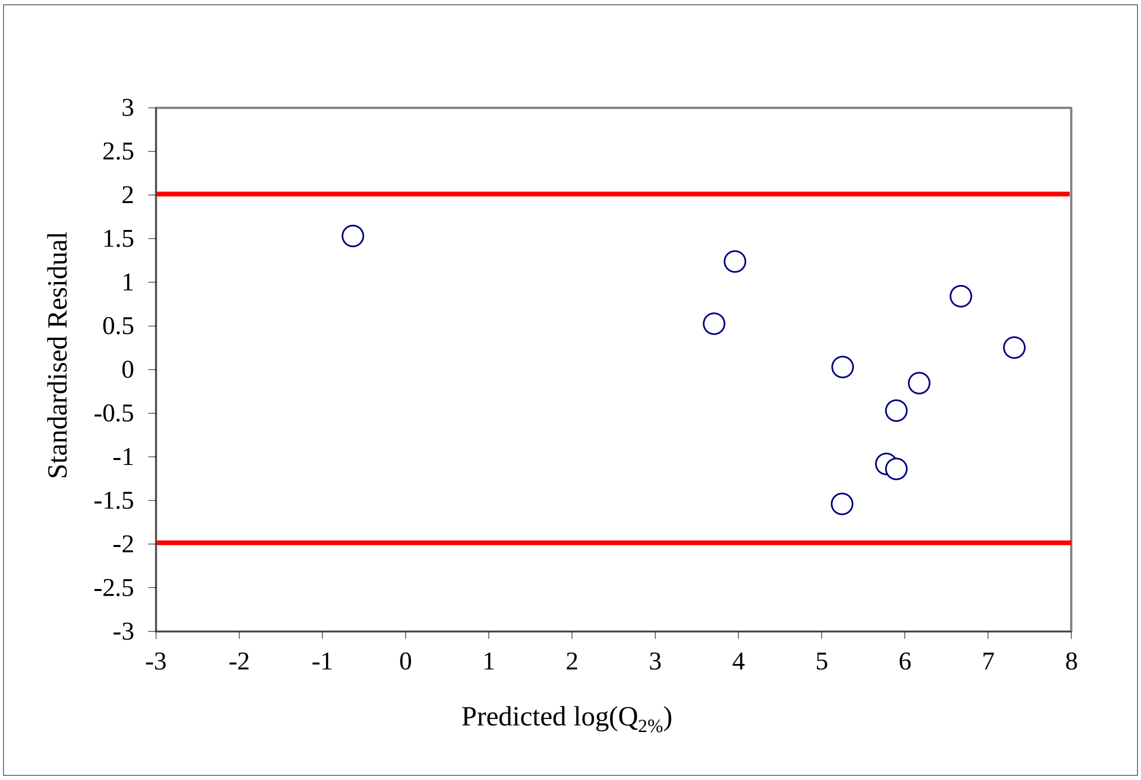

Figure C.4 Standardised residuals vs. predicted quantiles for 2% AEP (Region 6)

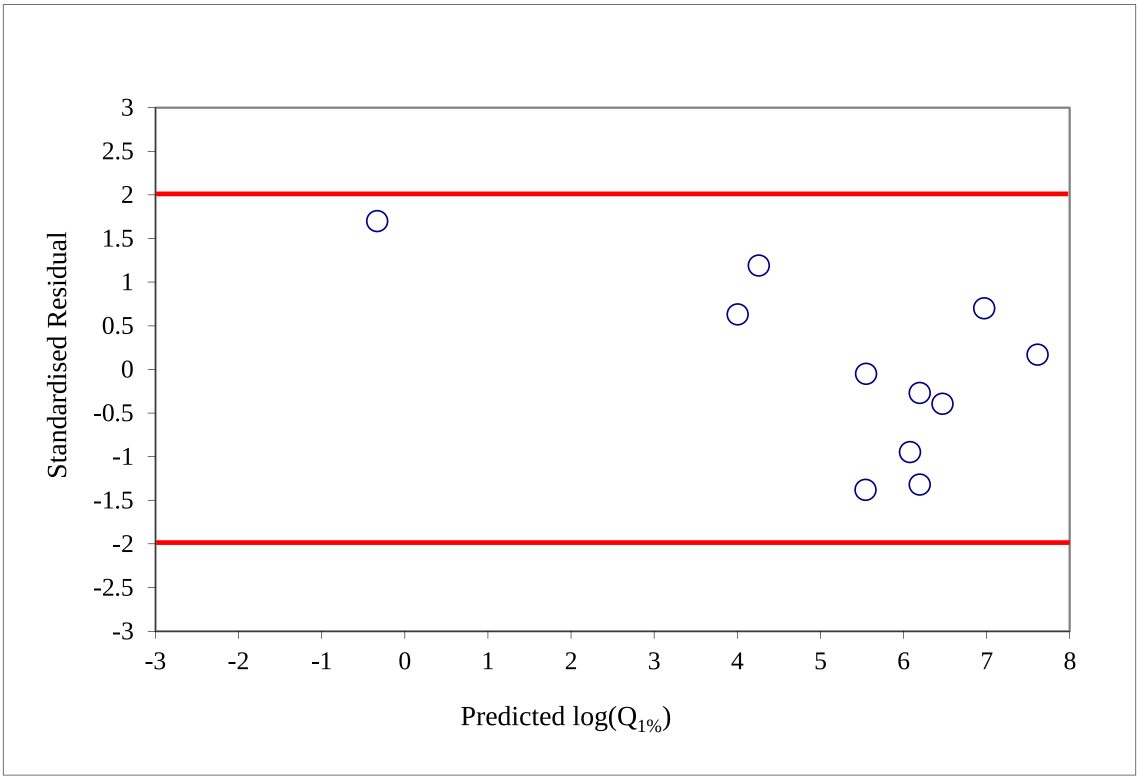

Figure C.5 Standardised residuals vs. predicted quantiles for 1% AEP (Region 6)

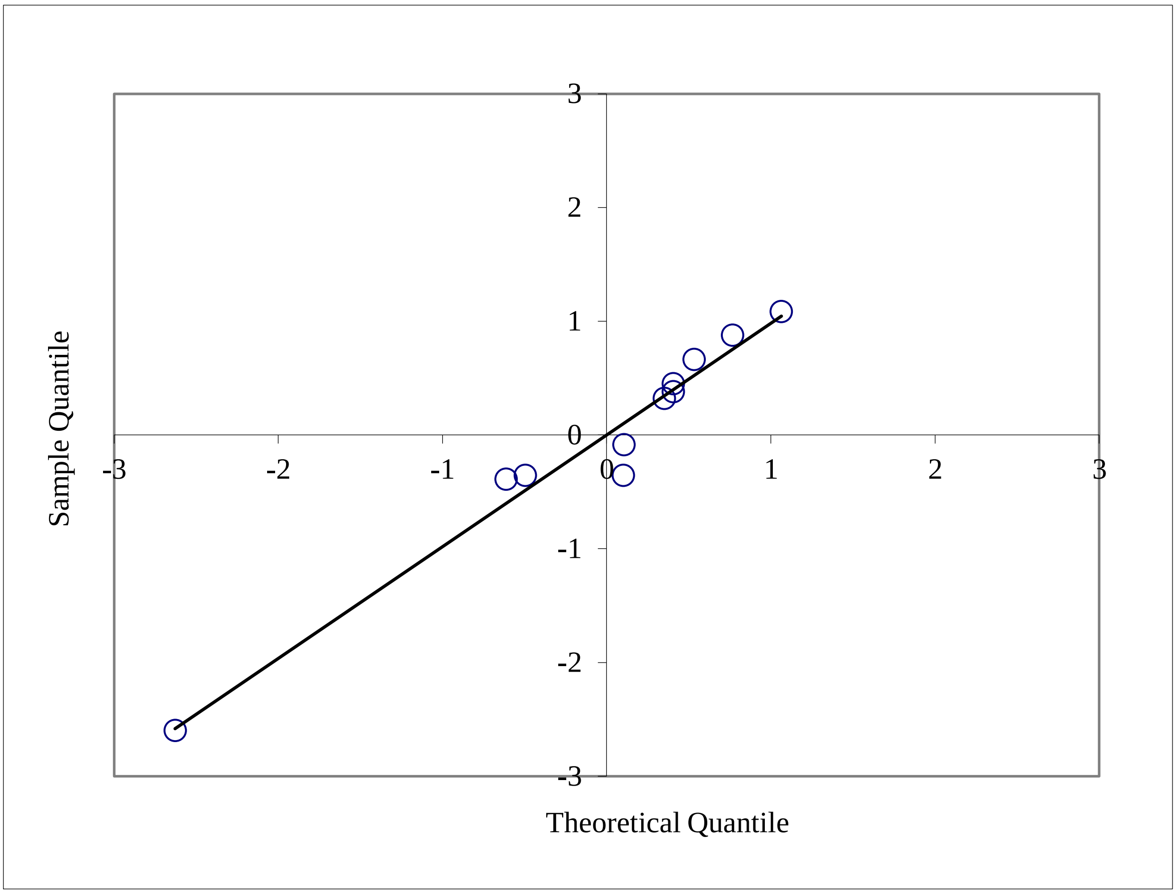

Figure C.6 QQ-plot of the standardised residuals for 50% AEP (Region 6)

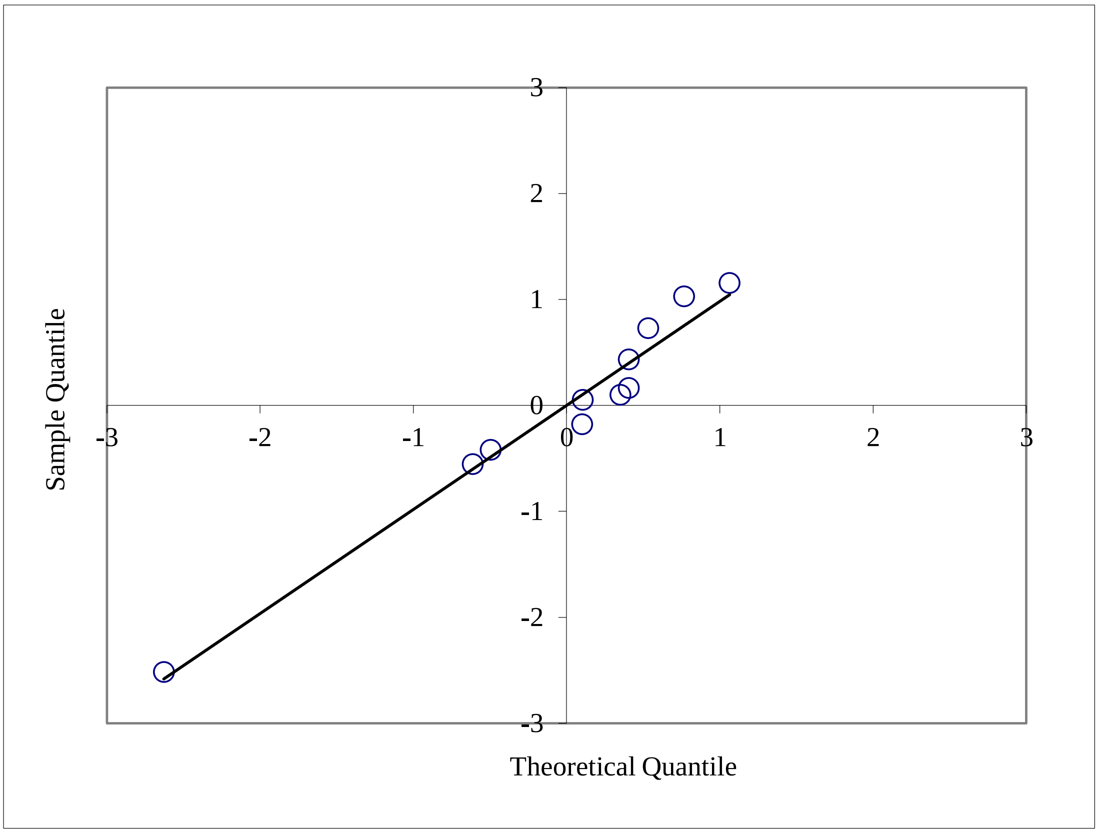

Figure C.7 QQ-plot of the standardised residuals for 20% AEP (Region 6)

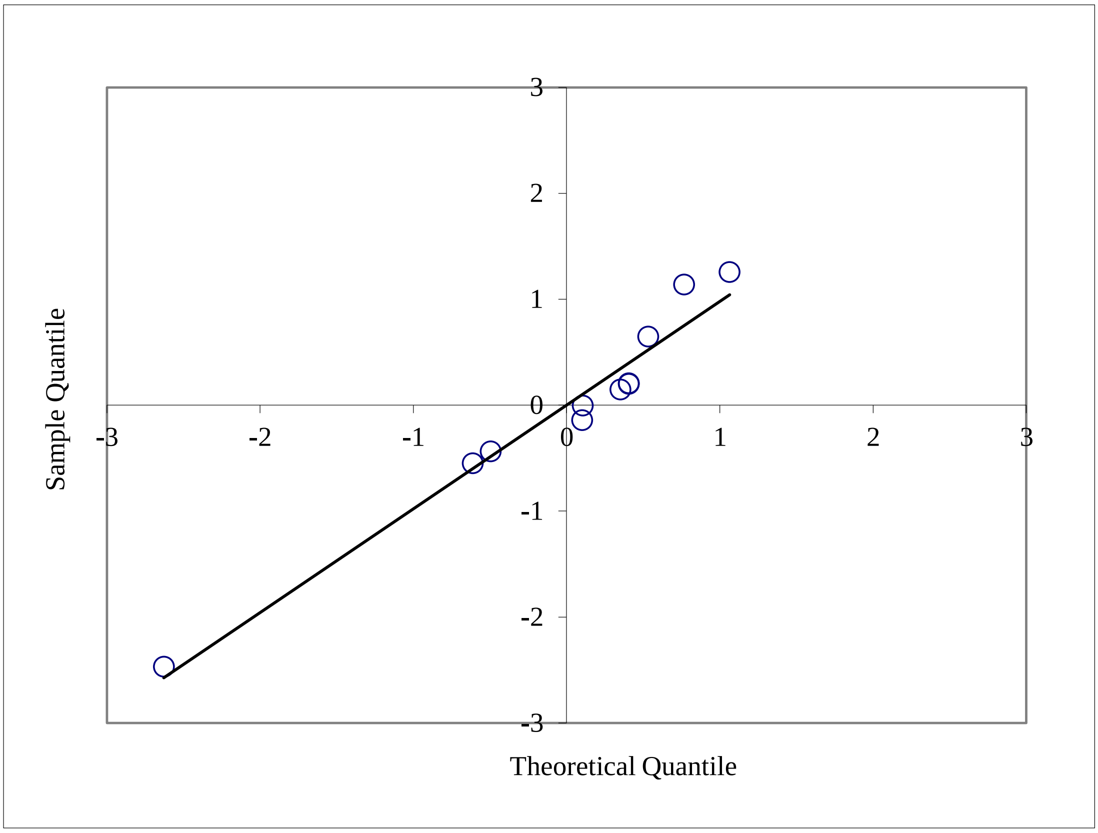

Figure C.8 QQ-plot of the standardised residuals for 5% AEP (Region 6)

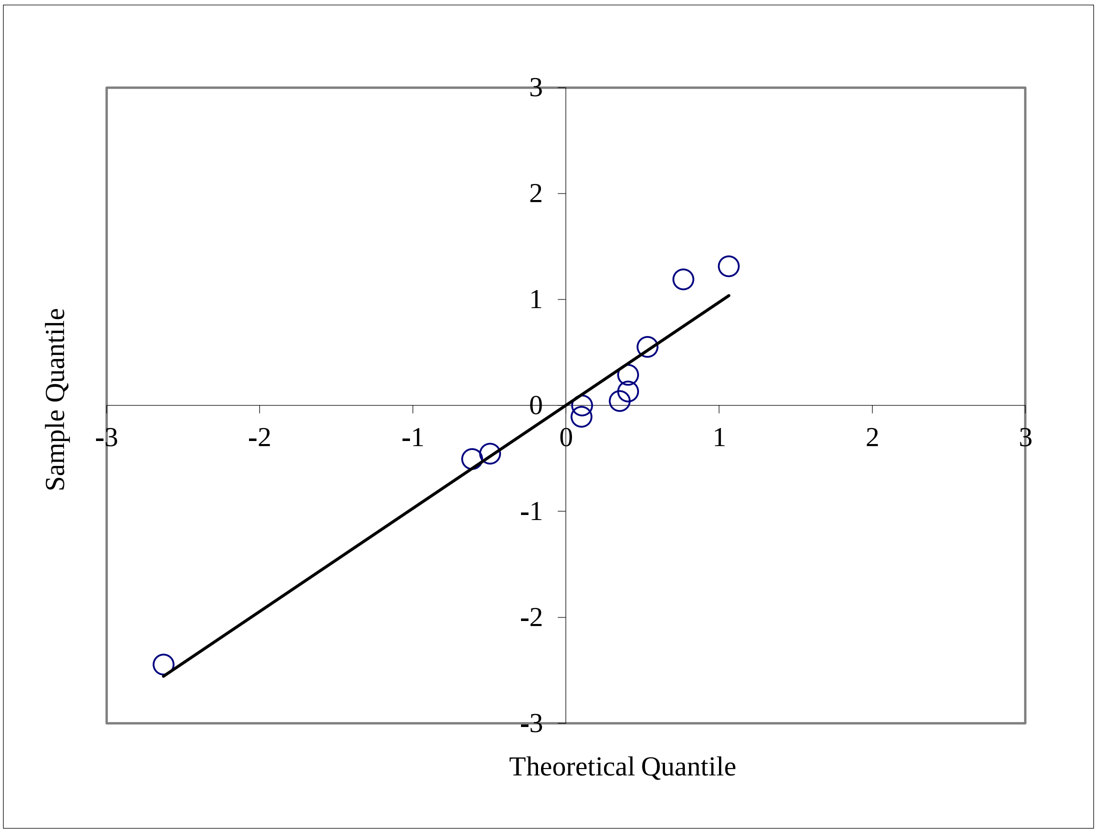

Figure C.9 QQ-plot of the standardised residuals for 2% AEP (Region 6)

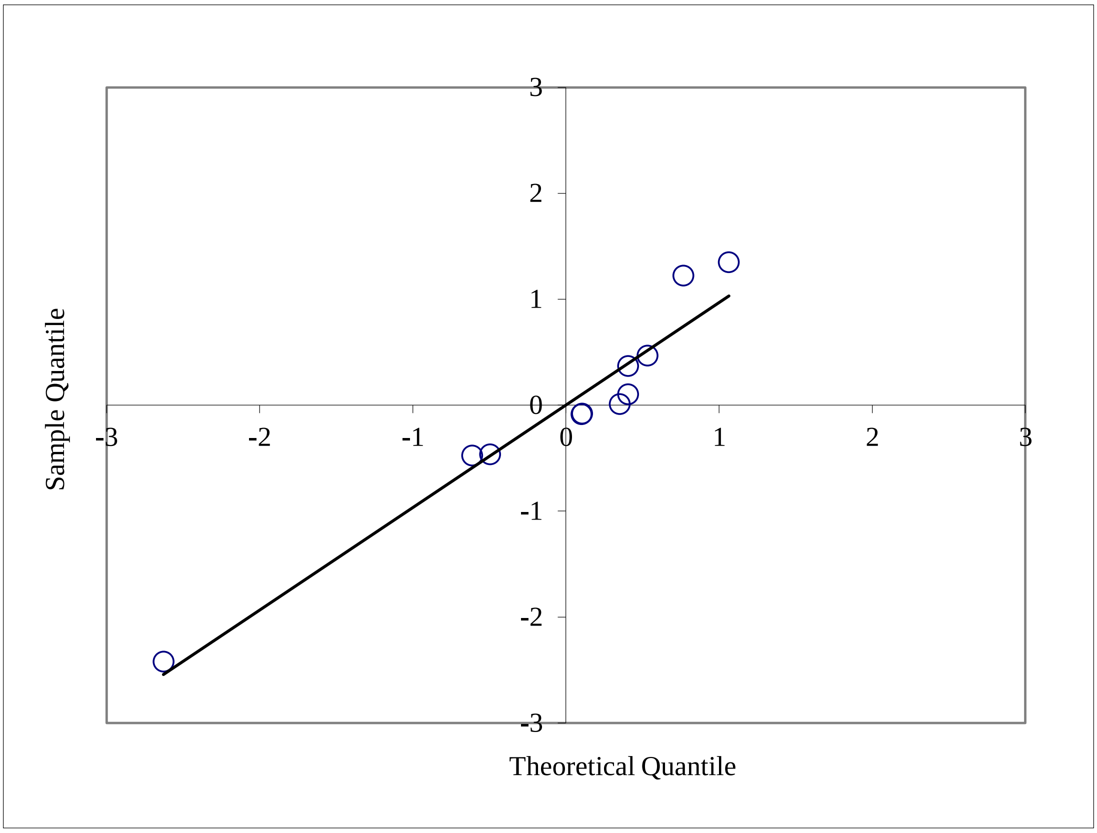

Figure C.10 QQ-plot of the standardised residuals for 1% AEP (Region 6)

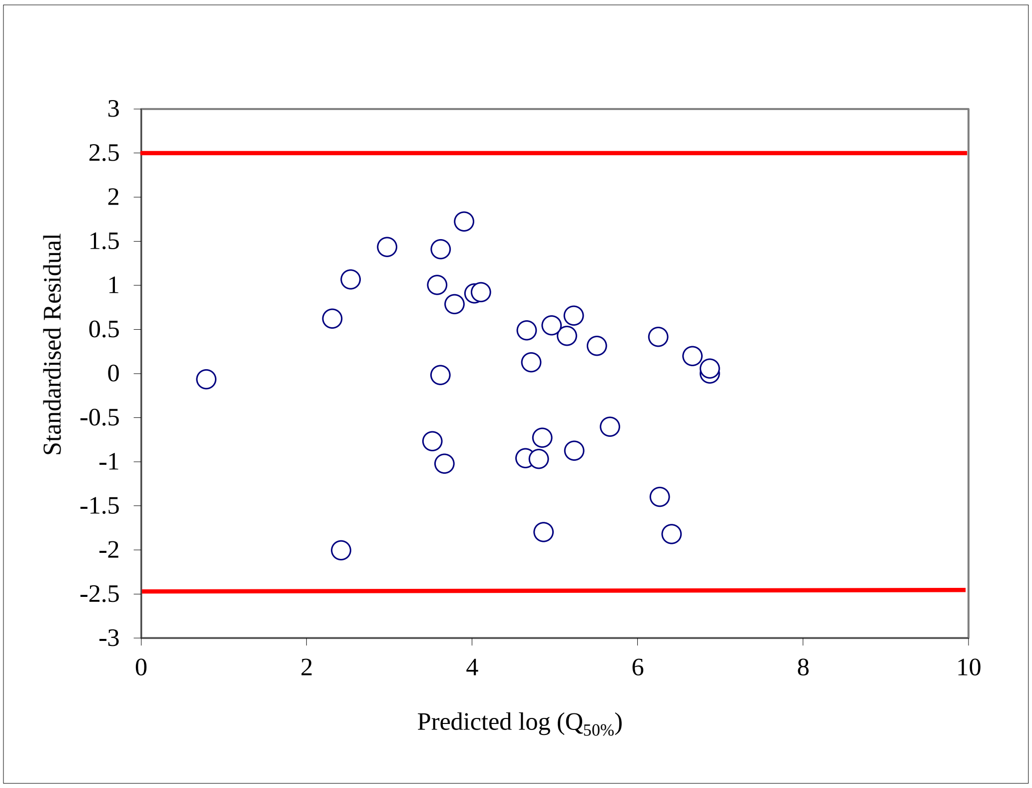

Figure C.11 Standardised residuals vs. predicted quantiles for 50% AEP (Region 7)

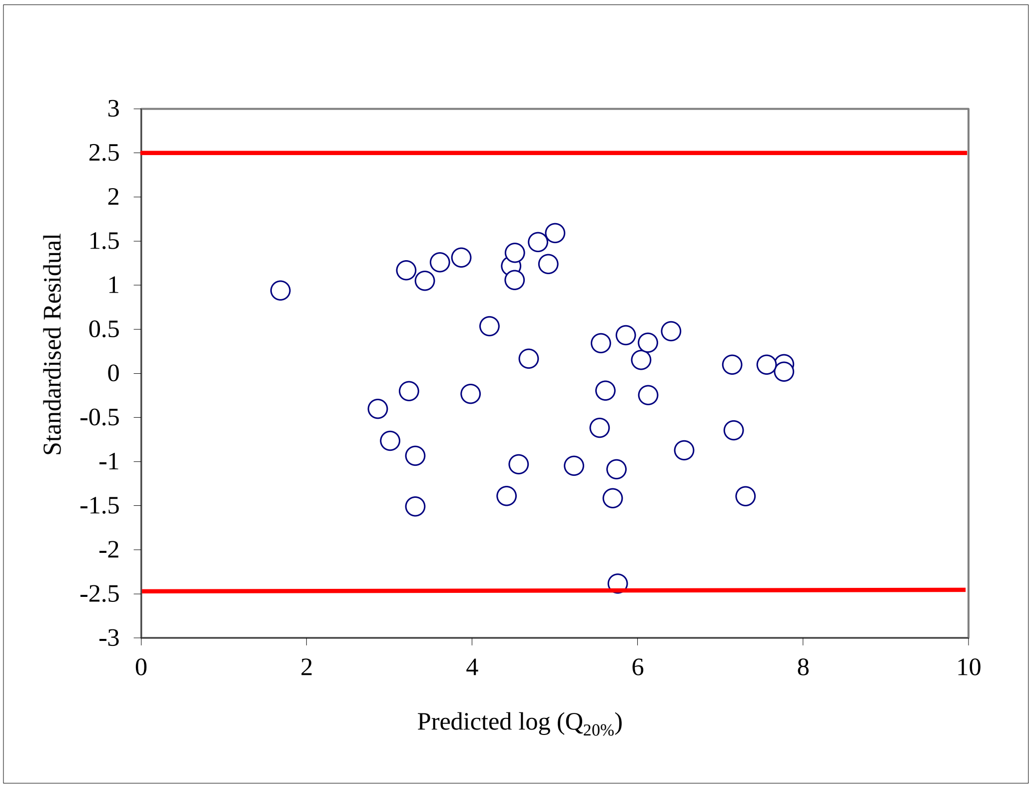

Figure C.12 Standardised residuals vs. predicted quantiles for 20% AEP (Region 7)

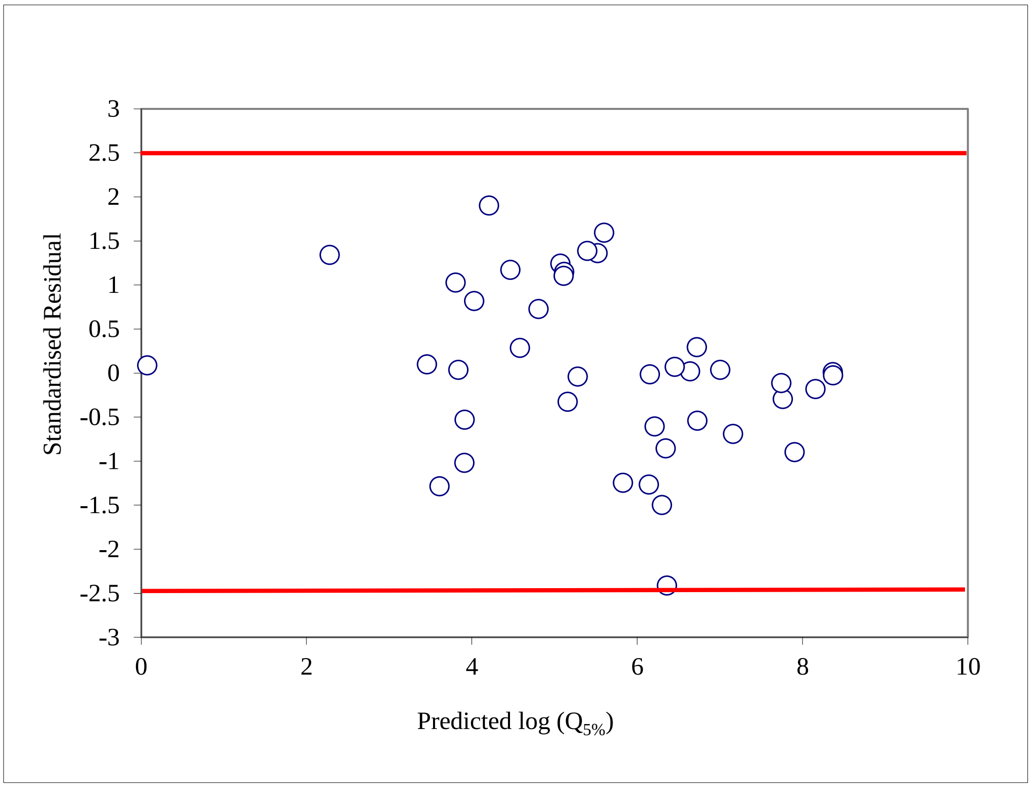

Figure C.13 Standardised residuals vs. predicted quantiles for 5% AEP (Region 7)

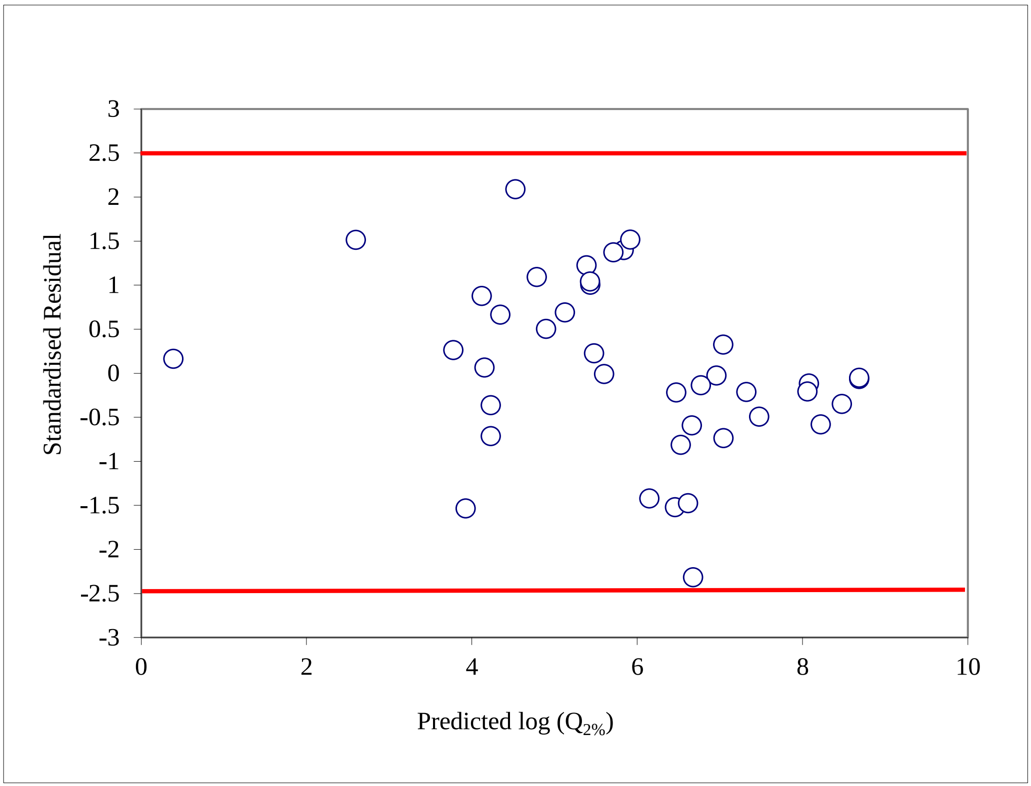

Figure C.14 Standardised residuals vs. predicted quantiles for 2% AEP (Region 7)

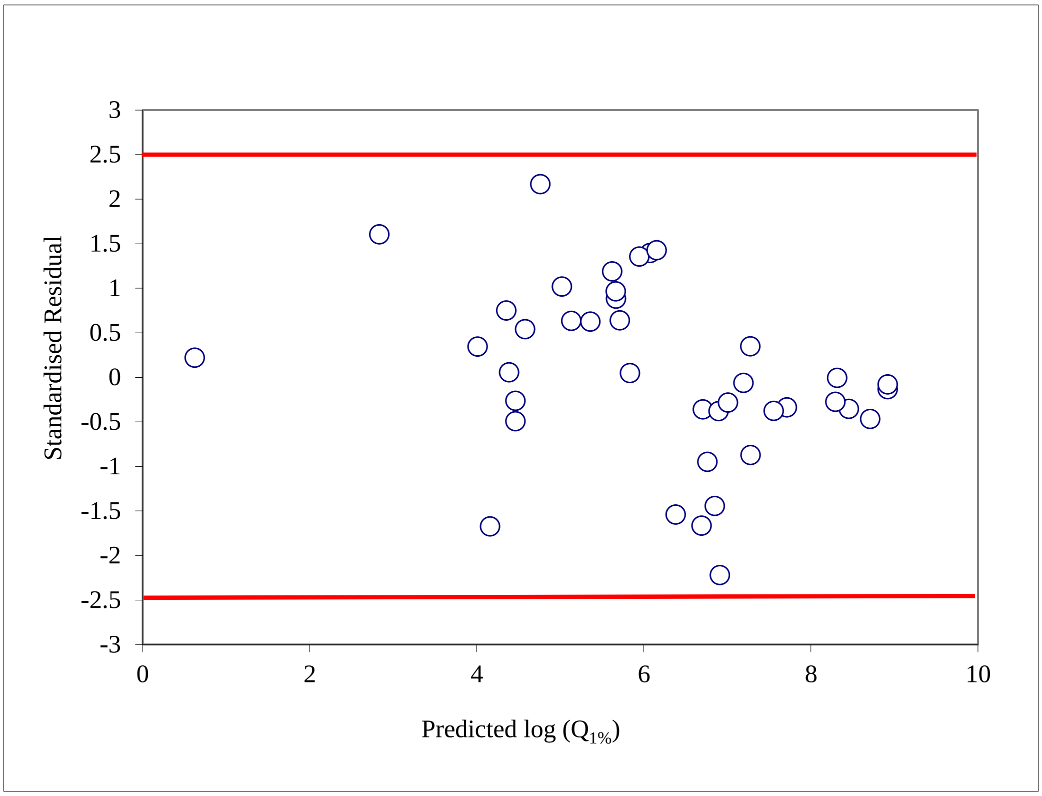

Figure C.15 Standardised residuals vs. predicted quantiles for 1% AEP (Region 7)

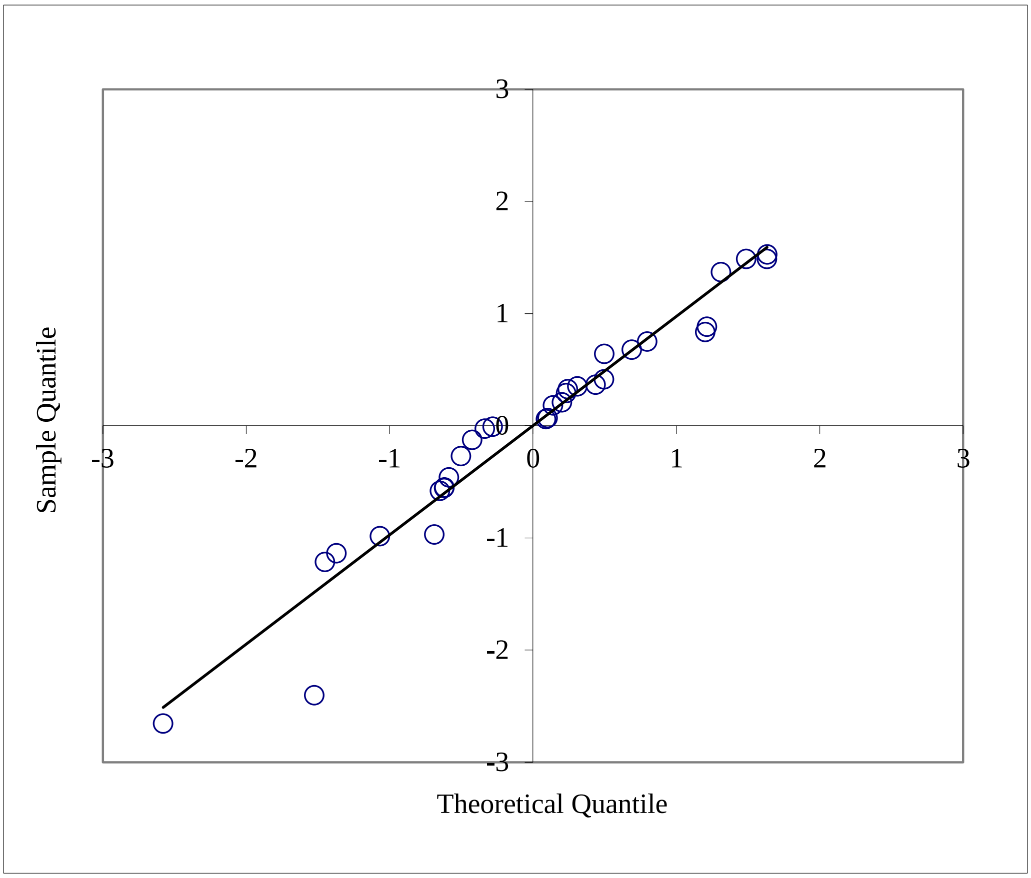

Figure C.16 QQ-plot of the standardised residuals for 50% AEP (Region 7)

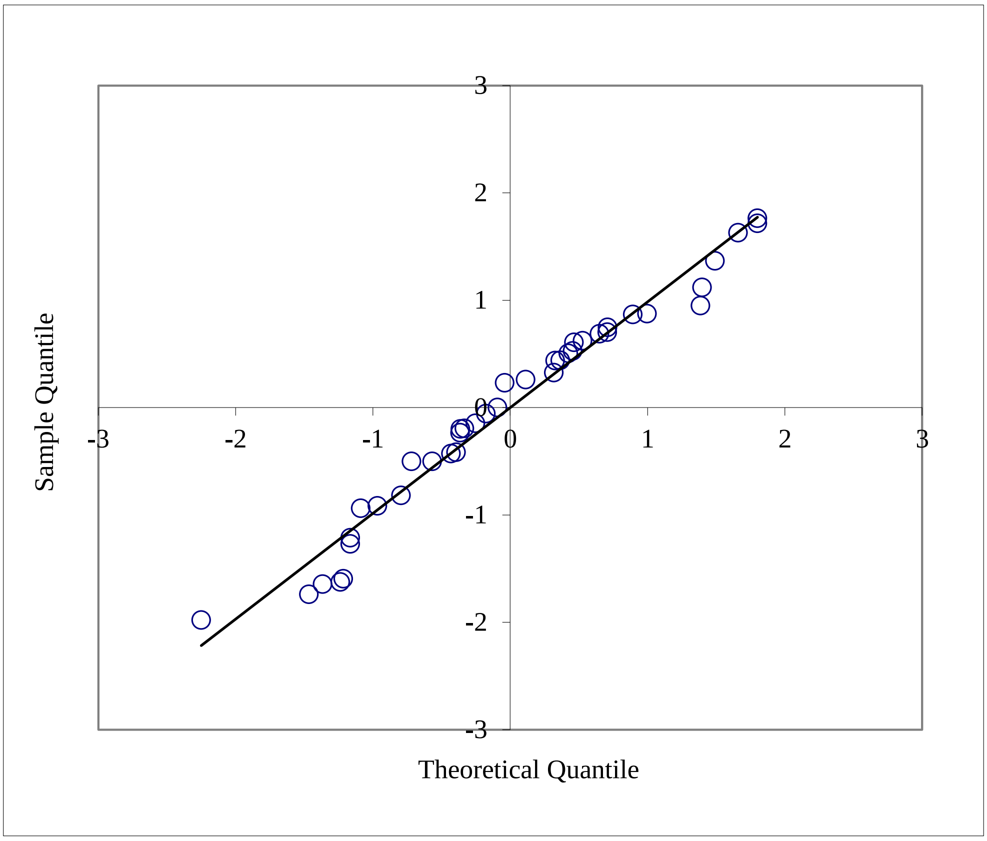

Figure C.17 QQ-plot of the standardised residuals for 20% AEP (Region 7)

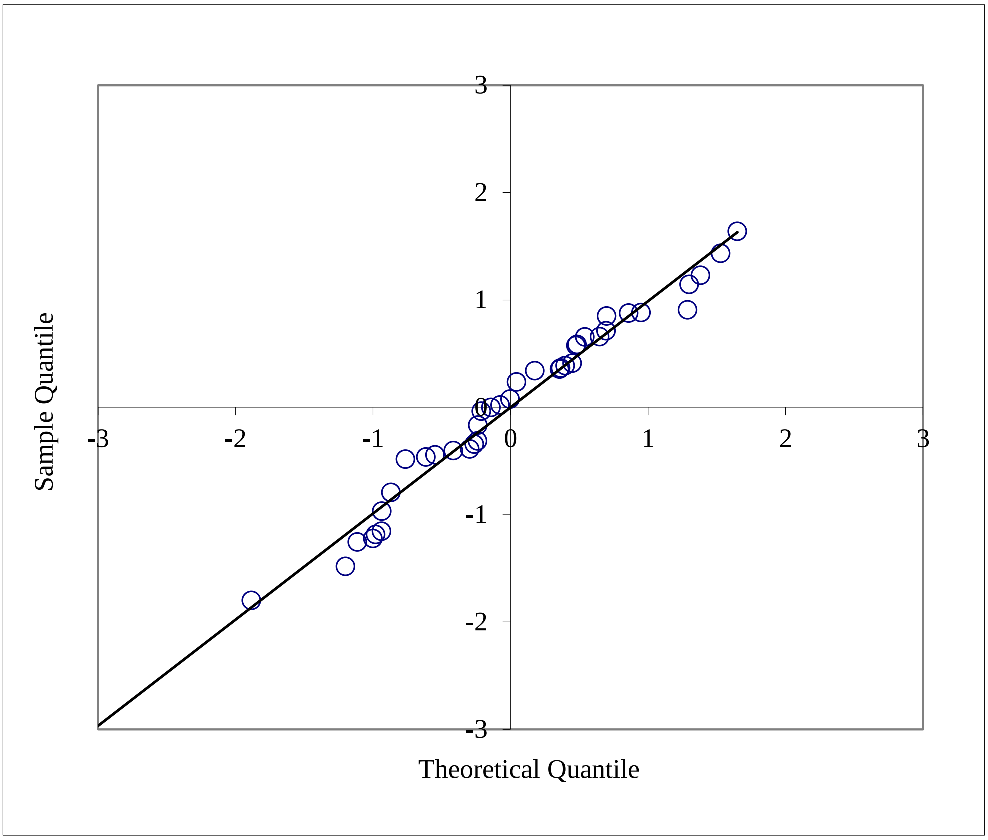

Figure C.18 QQ-plot of the standardised residuals for 5% AEP (Region 7)

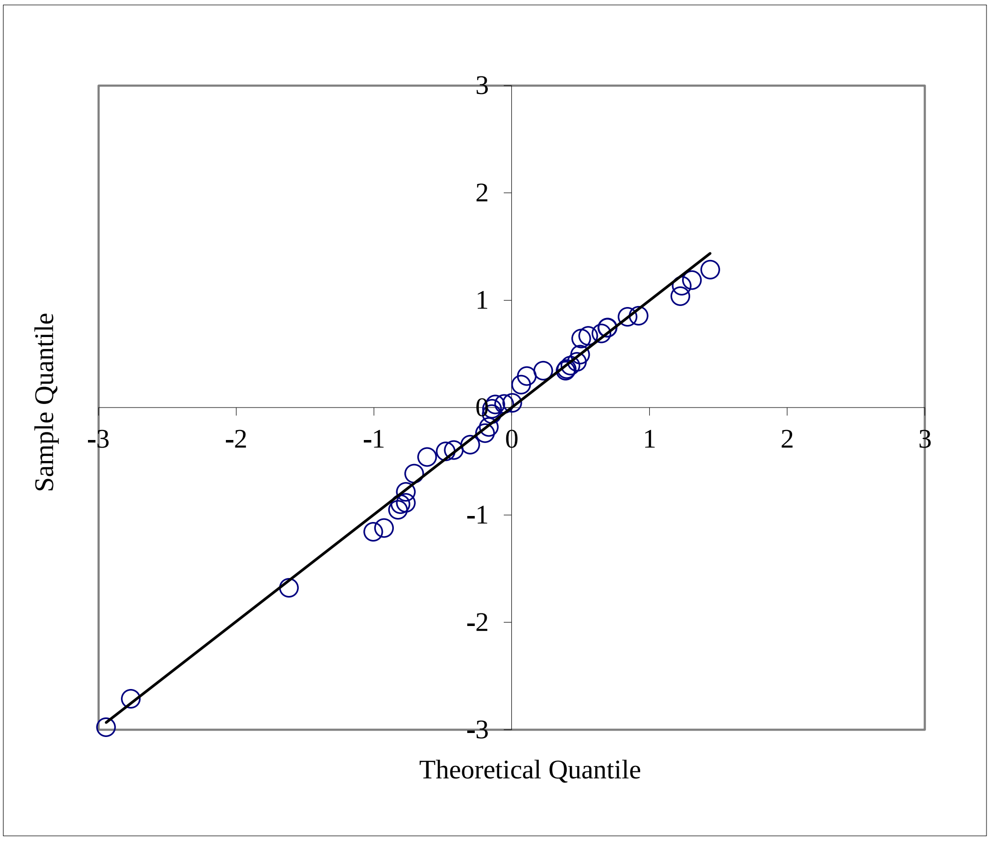

Figure C.19 QQ-plot of the standardised residuals for 2% AEP (Region 7)

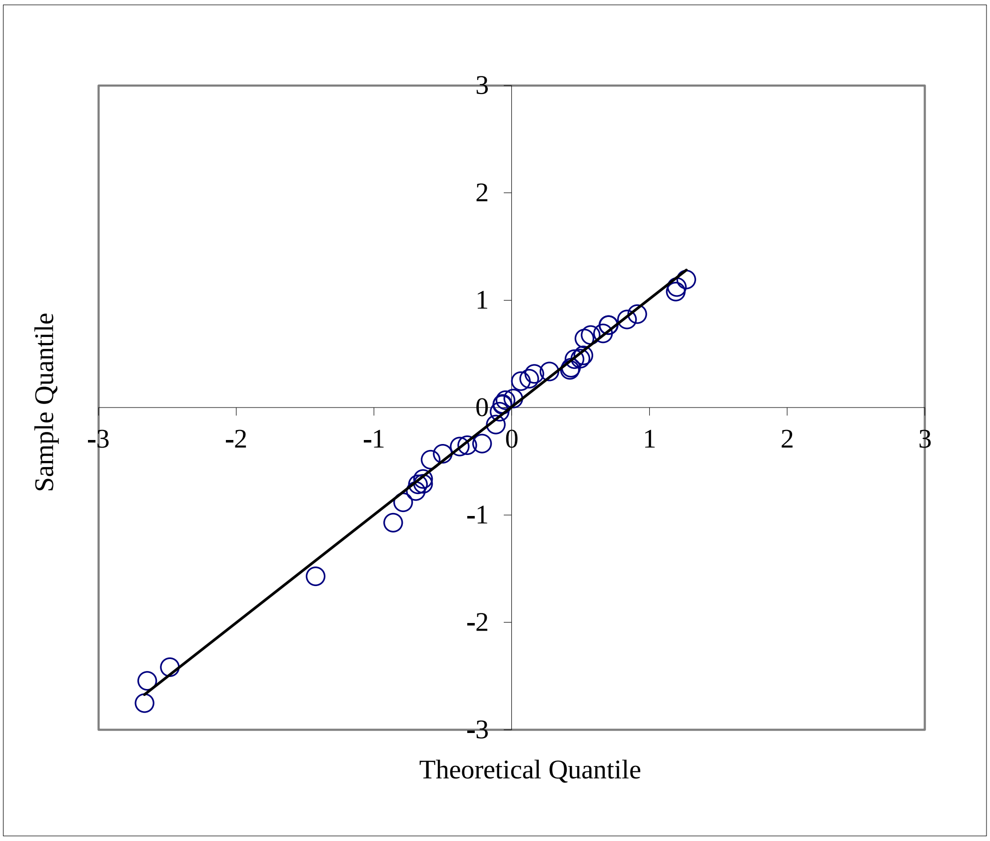

Figure C.20 QQ-plot of the standardised residuals for 1% AEP (Region 7)

Appendix D List of publications originated from Project 5

Journal papers and book chapter published from Project 5 (till Dec 2014)

1. Aziz. K., Rahman, A., Fang, G., Shreshtha, S. (2014). Application of artificial neural networks in regional flood frequency analysis: A case Study for Australia, Stochastic Environment Research & Risk Assessment, 28, 3, 541-554.
2. Haddad, K., Rahman, A., Ling, F. (2014). Regional flood frequency analysis method for Tasmania, Australia: A case study on the comparison of fixed region and region-of-influence approaches, Hydrological Sciences Journal, DOI:10.1080/02626667.2014.950583.
3. Haddad, K., Rahman, A., Zaman, M., Shrestha, S. (2013). Applicability of Monte Carlo cross validation technique for model development and validation using generalised least squares regression, Journal of Hydrology, 482, 119-128.
4. Haddad, K. and Rahman, A. (2012). Regional flood frequency analysis in eastern Australia: Bayesian GLS regression-based methods within fixed region and ROI framework – Quantile Regression vs. Parameter Regression Technique, Journal of Hydrology, 430-431 (2012), 142-161.
5. Haddad, K., Rahman, A., and Stedinger, J.R. (2012). Regional Flood Frequency Analysis using Bayesian Generalized Least Squares: A Comparison between Quantile and Parameter Regression Techniques, Hydrological Processes, 26, 1008-1021.
6. Haddad, K., Rahman, A., and Kuczera, G. (2011). Comparison of ordinary and generalised least squares regression models in regional flood frequency analysis: A case study for New South Wales, Australian Journal of Water Resources, 15, 2, 59-70.
7. Haddad, K. and Rahman, A. (2011). Regional flood estimation in New South Wales Australia using generalised least squares quantile regression. Journal of Hydrologic Engineering, ASCE, 16, 11, 920-925.
8. Haddad, K., Rahman, A. and Weinmann, P.E. (2011). Estimation of major floods: applicability of a simple probabilistic model, Australian Journal of Water Resources, 14, 2, 117-126.
9. Haddad, K. and Rahman, A. (2011). Selection of the best fit flood frequency distribution and parameter estimation procedure – A case study for Tasmania in Australia, Stochastic Environmental Research & Risk Assessment, 25, 415-428.
10. Haddad, K., Rahman, A., Weinmann, P.E., Kuczera, G. and Ball, J.E. (2010). Streamflow data preparation for regional flood frequency analysis: Lessons from south-east Australia. Australian Journal of Water Resources, 14, 1, 17-32.
11. Haddad, K., Zaman, M. and Rahman, A. (2010). Regionalisation of skew for flood frequency analysis: a case study for eastern NSW. Australian Journal of Water Resources, 14, 1, 33-41.
12. Ishak, E., Rahman, A. (2014). Detection of changes in flood data in Victoria, Australia over 1975-2011, Hydrology Research, doi:10.2166/nh.2014.064.
13. Ishak, E., Rahman, A., Westra, S., Sharma, A. and Kuczera, G. (2013). Evaluating the non-stationarity of Australian annual maximum floods. Journal of Hydrology, 494, 134-145.
14. Ishak, E., Haddad, K., Zaman and Rahman (2011). Scaling property of regional floods in New South Wales Australia, Natural Hazards, 58: 1155-1167.
15. Micevski, T., Hackelbusch, A., Haddad, K., Kuczera, G., Rahman, A. (2014).

Regionalisation of the parameters of the log-Pearson 3 distribution: a case study for New South Wales, Australia, Hydrological Processes, DOI: 10.1002/hyp.10147.

16. Palmen, L.B., Weeks, W.D. (2011), Regional flood frequency for Queensland using the quantile regression technique, Australian Journal of Water Resources, 15, 1, 47-57.
17. Rahman, A., Haddad, K., Kuczera, G., Weinmann, P.E. (2014). Regional flood frequency estimation, Australian Rainfall and Runoff, Book 3, Engineers Australia (Under review).
18. Rahman, A., Zaman, M.A., Haddad, K., Adlouni, S. E., Zhang, C. (2014). Applicability of Wakeby distribution in flood frequency analysis: a case study for eastern Australia, Hydrological Processes, DOI: 10.1002/hyp.10182.
19. Rahman, A., Haddad, K., Kuczera, G., and Weinmann, P.E. (2013). Accumulation of knowledge: Revision of Australian Rainfall & Runoff for Improved Flood Predictions, In: Runoff Prediction in Ungauged Basins**:** Synthesis across Processes, Places and Scales, Editor: G Blöschl, M Sivapalan, T Wagener, Cambridge University Press, ISBN 9781107028180.
20. Rahman, S.A., Rahman, A., Zaman, M., Haddad, K., Ashan, A. and Imteaz, M. A. (2013). A study on selection of probability distributions for at-site flood frequency analysis in Australia, Natural Hazards, 69, 1803-1813.
21. Rahman, A., Haddad, K., Zaman, M., Kuczera, G. and Weinmann, P.E. (2011). Design flood estimation in ungauged catchments: A comparison between the Probabilistic Rational Method and Quantile Regression Technique for NSW. Australian Journal of Water Resources, 14, 2, 127-137.
22. Zaman, M., Rahman, A., and Haddad, K. (2013). Application of empirical scale correction factors with regional flood prediction equations: A case study for eastern Australia, Australian Journal of Water Resources, 16, 2, 141-150.
23. Zaman, M., Rahman, A., Haddad, K. (2012). Regional flood frequency analysis in arid regions: A case study for Australia. Journal of Hydrology, 475, 74-83.

Conference papers published from Project 5

1. Aziz, K., Sohail, R., Rahman, A. (2014). Application of Artificial Neural Networks and Genetic Algorithm for Regional Flood Estimation in Eastern Australia, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.
2. Aziz, K., Rahman, A., Shamseldin, A., Shoaib, M. (2013). Regional flood estimation in Australia: Application of gene expression programming and artificial neural network techniques, 20th International Congress on Modelling and Simulation, 1 to 6 December, 2013, Adelaide, Australia, 2283-2289.
3. Aziz, K., Rahman, A., Fang, G. Shrestha, S. (2012). Comparison of Artificial Neural Networks and Adaptive Neuro-fuzzy Inference System for Regional Flood Estimation in Australia, Hydrology and Water Resources Symposium, Engineers Australia, 19-22 Nov 2012, Sydney, Australia.
4. Aziz, K., Rahman, A., Fang, G. and Shrestha, S. (2011). Application of Artificial Neural Networks in Regional Flood Estimation in Australia: Formation of Regions Based on Catchment Attributes, The Thirteenth International Conference on Civil, Structural and Environmental Engineering Computing, Crete, Greece, 6-9 September, 2011, 13 pp.
5. Aziz, K., Rahman, A., Shrestha, S., Fang, G. (2011). Derivation of optimum regions for ANN based RFFA in Australia, 34th IAHR World Congress, 26 June – 1 July 2011, Brisbane, 17-24.

6. Aziz, K., Rahman, A., Fang, G., Haddad, K. and Shrestha, S. (2010). Design flood estimation for ungauged catchments: Application of artificial neural networks for eastern Australia, World Environmental and Water Resources Congress 2010, American Society of Civil Engineers (ASCE), 16-20 May 2010, Providence, Rhode Island, USA, pp. 2841-2850.
7. Hackelbusch, A., Micevski, T. Kuczera, G., Rahman, A. and Haddad, K. (2009). Regional Flood Frequency Analysis for Eastern New South Wales: A Region of Influence Approach using Generalized Least Squares log-Pearson 3 parameter regression. In Proc. 32nd Hydrology and Water Resources Symp., 30 Nov to 3 Dec, Newcastle, Australia, pp 603-615.
8. Haddad, K., Rahman, A., Weinmann, P.E., Kuczera, G. (2014). Development and Application of a Large Flood Regionalisation Model for Australia, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.
9. Haddad, K., Rahman, A., Kuczera, G, Weinmann, P. E. (2012). A New Regionalisation Model for Large Flood Estimation in Australia: Consideration of Inter-site Dependence in Modelling, Hydrology and Water Resources Symposium, Engineers Australia, 19-22 Nov 2012, Sydney, Australia.
10. Haddad, K., Rahman, A., Weeks, W., Kuczera, G. and Weinmann, P.E. (2011).Towards a new regional flood frequency analysis method for Western Australia, The 19th International Congress on Modelling and Simulation, 12-16 Dec 2011, Perth, Australia, 3788-3795.
11. Haddad, K., Uddin, J., Rahman, A., Kuczera, G., and Weinmann, P.E. (2011). A new flood regionalisation model for large flood estimation in Australia, 11th International Multidisciplinary Scientific Geo-Conference and Expo SGEM 2011, Bulgaria, 19-25 June, 2, 761-768.
12. Haddad, K., Rahman, A., Ling, F. and Weinmann, P.E. (2011). Towards a new regional flood frequency analysis method for Tasmania, 34th IAHR World Congress, 26 June – 1 July 2011, Brisbane, 170-177.
13. Haddad, K., Rahman, A., Kuczera, G. and Micevski, T. (2011). Regional Flood Frequency Analysis in New South Wales Using Bayesian GLS Regression: Comparison of Fixed Region and Region-of-influence Approaches, 34th IAHR World Congress, 26 June – 1 July 2011, Brisbane, 162-169.
14. Haddad, K., Zaman, M. Rahman, A. and Shrestha, S. (2010). Regional Flood Modelling: Use of Monte Carlo cross-validation for the Best Model Selection. World Environmental and Water Resources Congress 2010, American Society of Civil Engineers (ASCE), 16-20 May 2010, Providence, Rhode Island, USA, pp. 2831-2840.
15. Haddad, K., Pirozzi, J., McPherson, G., Rahman, A. and Kuczera, G. (2009). Regional Flood Estimation Technique for NSW: Application of Generalised Least Squares Quantile Regression Technique. In Proc. 32nd Hydrology and Water Resources Symp., 30 Nov to 3 Dec, Newcastle, Australia, pp. 829-840.
16. Haddad, K., Aziz, K., Rahman, A., and Ishak, E.H. and Weinmann, P.E. (2009). A Probabilistic Model for Estimation of Large Floods in Ungauged Catchments: Application to South-east Australia. In Proc. 32nd Hydrology and Water Resources Symp., 30 Nov to 3 Dec, Newcastle, Australia, pp. 817-828.
17. Haddad, K., Rahman, A. and Weinmann, P. E. (2008). Development of a Generalised Least Squares Based Quantile Regression Technique for design flood estimation in Victoria, 31st Hydrology and Water Resources Symp., Adelaide, 15-17 April 2008, 2546-2557.
18. Haddad, K., Rahman, A. and Weinmann, P.E. (2008). Streamflow Data Preparation for

Regional Flood Frequency Analysis: Important Lessons from a Case Study. 31st Hydrology and Water Resources Symp., Adelaide, 15-17 April 2008, 2558-2569.

19. Hossain, M.S., Haque, M., Rahman, A. (2014). Trend Analysis of Annual Maximum Flood Series in South East Australia Using Most Up-To-Date Flood Data, 35th Hydrology and Water Resources Symposium, Engineers Australia, 24-27 Feb, 2014.

20. Hossain, M.S., Rahman, A., Haddad, K., Ishak, E.H. (2013). Trend analysis of flood data in Australia: A case study for Victoria, 20th International Congress on Modelling and Simulation, 1 to 6 December, 2013, Adelaide, Australia, 2318-2324.

21. Hossain, A., Rahman, A. and Haddad, K. (2009). Design streamflow estimation for ungauged catchments in Victoria: Uncertainty analysis using boot strapping. 2nd International Conference on Water & Flood Management (ICWFM-2009), 15-17 March, 2009, Dhaka, 2, 669-676. ISBN 984-300-003354-5.

22. Ishak, E., Rahman, A., Westra, S., Sharma, A., Kuczera, G. (2014). Trend Analysis of Australian Annual Maximum Flood Data: Exploring Relationship with Climate and Catchment Characteristics, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.

23. Ishak, I., Rahman, A., Westra, S., Sharma, A. and Kuczera, G. (2011). Trends in Peak Streamflow Data in Australia: Impacts of Serial and Cross-correlation, 34th IAHR World Congress, 26 June – 1 July 2011, Brisbane, 766-773.

24. Ishak, E.H., Rahman, A., Westra, S., Sharma, A. and Kuczera, G. (2010). Preliminary analysis of trends in Australian flood data. World Environmental and Water Resources Congress 2010, American Society of Civil Engineers (ASCE), 16-20 May 2010, Providence, Rhode Island, USA, pp. 120-124.

25. Ishak, E.H., Aziz, K., Rahman, A. and Haddad, K. (2009). Scaling Behaviour of Regional Floods in New South Wales Australia. In Proc. 32nd Hydrology and Water Resources Symp., 30 Nov to 3 Dec, Newcastle, Australia, 400-408.

26. Palmen, L.B., Weeks, W.D. (2009). Regional flood frequency for Queensland using the Quantile Regression Technique, Proc. 32nd Hydrology and Water Resources Symp., Newcastle.

27. Pirozzi, J. and Rahman, A. (2010). Design Streamflow Estimation for Ungauged Catchments in Eastern NSW: Identification of Important Predictor Variables, Australian Water Association National Conference, Ozwater 2010, 8-10 March, Brisbane.

28. Pirozzi, J., Ashraf, M., Rahman, A., and Haddad, K. (2009). Design Flood Estimation for Ungauged Catchments in Eastern NSW: Evaluation of the Probabilistic Rational Method. In Proc. 32nd Hydrology and Water Resources Symp.,30 Nov to 3 Dec, Newcastle, Australia, pp. 805-816.

29. Rahman, A. S., Haddad, K., Rahman, A. (2014). Identification of Outliers in Flood Frequency Analysis: Comparison of Original and Multiple Grubbs-Beck Test, International Conference on Environmental Systems Science and Engineering, 15 -16 Dec 2014, Sydney, Australia.

30. Rahman, A., Haddad, K., Kuczera, G., Weinmann, P.E., Weeks, W., Stensmyr, P., Babister, M. (2014). An Overview of the Development of the New Regional Flood Frequency Estimation (RFFE) Model for Australia, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.

31. Rahman, A., Haddad, K., Rahman, A.S., Haque, M.M. Kuczera, Weinmann, P.E. (2014). An Overview of Preparation of Streamflow Database for ARR Project 5 Regional Flood Method, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.

32. Rahman, A., Haque, M.M., Haddad, K., Rahman, A.S., Kuczera, G., Weinmann, P.E. (2014). Assessment of the Impacts of Rating Curve Uncertainty on At-Site Flood Frequency Analysis: A Case Study for New South Wales, Australia, 35th Hydrology and Water Resources Symposium, Perth, Engineers Australia, 24-27 Feb, 2014.

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