Preparing for the Next Great Flood Using New Design Rainfalls

Janice Green
Project Director, IFD Revision Project, Bureau of Meteorology, Canberra, Australia

Catherine Beesley
Hydrologist, Bureau of Meteorology, Melbourne, Australia

Cynthia The
Hydrologist, Bureau of Meteorology, Sydney, Australia

Abstract:

Adequate preparation for the next great flood requires reliable information on the magnitude and frequency of rainfall events that will cause floods. This information on design rainfalls is necessary for use in the design of water bearing infrastructure; setting of planning levels; and in the forecasting of rainfall and flood events.

The previous Intensity-Frequency-Duration (IFD) design rainfall estimates for Australia were developed by the Bureau of Meteorology nearly 30 years ago. The estimates were based largely on data from the Bureau's network of daily-read and continuously-recording rainfall stations, using techniques for statistical data analysis that were considered appropriate at the time.

Design rainfalls for probabilities more frequent than one year Average Recurrence Interval, which are used primarily in Water Sensitive Urban Design and some stormwater applications, were not previously provided. Similarly although recently, one to five day rainfall estimates of rare design rainfalls have been generated their application on a state by state basis over a period of 15 years meant that there were inconsistencies between each state.

Introduction

The Bureau of Meteorology has recently completed an 8 year project which has produced new design rainfall estimates. The new design rainfall estimates are based on a greatly expanded database which incorporates rainfall data collected by organisations across Australia. These data have been analysed using contemporary statistical methods that are appropriate for Australian rainfall data. The new design rainfalls are provided for durations from 1 minute to 168 hours (7 days) and for probabilities from 12 Exceedances per Year (EY) (or 1 month ARI) to 0.05 % Annual Exceedance Probability (or 2000 year ARI) and are available from the Bureau's website for any location in Australia. They provide a clear, consistent point of reference for all hydraulic and hydrologic analyses in Australia necessary for preparing for the next great flood.

There are five broad types of design rainfalls that are currently used for design purposes, generally categorised by probability. These are summarised below and presented graphically in Figure 1.

Probability	Occurrence
12 EY to 1 EY	Very frequent
1 EY to 10% AEP	Frequent
10% to 1% AEP	Infrequent
1% to 0.05% AEP	Rare
Extreme	Extreme

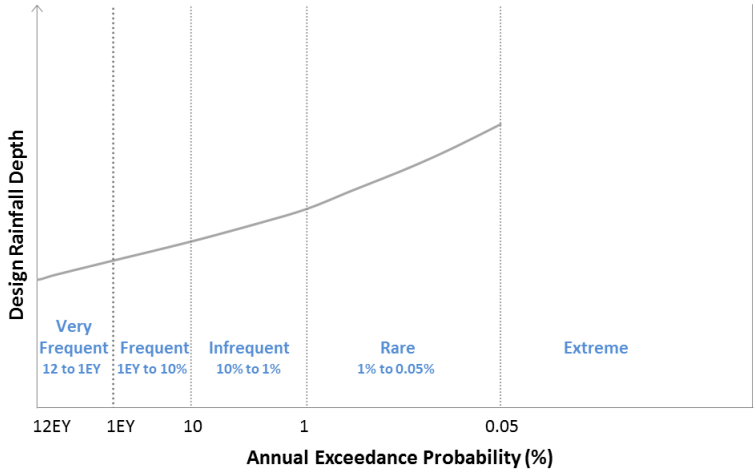

Figure 1 Types of design rainfall

The probability terminology adopted is the terminology adopted in the 2016 edition of Australian Rainfall and Runoff (ARR2016). In this new terminology the following terms are adopted:

- Exceedances per Year (EY) are adopted for probabilities less than or equal to the previous 1 year Average Recurrence Interval (ARI)
- Annual Exceedance Probability (AEP) expressed as a percentage is adopted for probabilities less frequent than 1 EY to 0.05% AEP.
- AEP expressed as 1 in x is adopted for probabilities less frequent than 0.05% AEP

In this paper, the focus is on design rainfall estimates in the range from 12 EY used in WSUD to those with a probability of 0.05% used in bridge design and spillway adequacy assessment. These are the new design rainfalls provided by the Bureau via the Bureau's website and which are discussed in more detail below. In Section 2 a background to previous estimates of very frequent, frequent and infrequent, and rare design rainfalls is provided. Section 3 provides an overview of the approaches adopted to produce new design rainfalls in these categories and Section 4 presents how the new design rainfalls and other information will be able to be obtained.

Background

In this section a history of the estimates of very frequent, frequent and large; and rare design rainfalls is provided to identify the approaches that are now superseded by the new design rainfalls.

Frequent and infrequent design rainfalls (IFDs)

Design rainfall estimates in the frequent to infrequent occurrence range were first made available in a consistent manner in Australia with the publication of the 1958 edition of Australian Rainfall and Run-off by the Institution of Engineers (1958). Since then these Intensity-Frequency-Duration (IFD) design rainfalls have been revised in 1977 and 1987 by the Bureau of Meteorology. Each successive set of IFDs has utilised the available data and methods to incorporate:

- Larger rain gauge networks and longer periods of record
- New statistical techniques
- More advanced methods for interpolating between rainfall gauge sites

In addition, significant advances in computing power have allowed more advanced approaches to be adopted with each successive revision.
The methods of disseminating each successive revision of IFDs has also changed from equations, map of isohyets that needed to be read and the values plotted manually; and, more recently, software and on-line dissemination.

Very frequent design rainfalls

To date, design rainfalls for probabilities more frequent than 1 EY (or the corresponding one year ARI), which are used primarily in WSUD and some stormwater applications, have not been provided. Although values for 0.25 year ARI and 0.5 year ARI for durations from one minute to three days were available for a fee from the Bureau, these were only available for sites where rain gauges were located; were at-site values rather than regional, gridded values; and were inconsistent from site to site due to difference in the available length of records.

In the absence of specific estimates or advice, agencies responsible for ensuring compliance to the relevant guidelines have provided their own advice on the approach to be adopted for estimating very frequent design rainfalls and consequent design floods. In particular, many stormwater quality or WSUD guidelines recommend a flow threshold of Q_{3month} (or 4 EY) for the design of stormwater quality treatment devices. Table 2 summarises some of the approaches adopted for estimating Q_{3month}.

Table 1. Summary of Australian practice for estimating very frequent design rainfalls

Source	Guideline	Method
Hastings Council Stormwater Management	Design Storm equivalent to a 3 month ARI storm event	40% of 1 year ARI storm event
Parramatta City Council Stormwater Asset Plan	3 month ARI storm event	0.5 x Q_{1year} (flow)
South Australia Government	3 month design flows	Logarithmic extrapolation of design flows from AR&R87
NSW State Government Stormwater Source Control	3 month ARI rainfall event	25% x 1 year ARI (rainfall)
Gold Coast City Council	Factors applied to 1 in 1 year ARI	3 month ARI = 0.50 x 1:1 year ARI
Queensland Urban Drainage Manual 2013	0.5 x 63% AEP (1 in 1 year) to replace the 3 month ARI terminology	0.5 x 63% AEP
WSUD Technical Design Guidelines for SEQld	3 month ARI storm event	0.5 x Q_{1year} (flow)

Rare design rainfalls

A method for deriving design rainfalls less frequent than 1% AEP was first provided in the 1987 edition of Australian Rainfall and Runoff (ARR87) (Institution of Engineers, 1987). This was a pragmatic, curve fitting procedure between the 1% and 2% AEP design rainfalls and the Probable Maximum Precipitation (PMP).

Table 2. State CRC-FORGE estimates

State	Reference
New South Wales / ACT	Nandakumar *et al*, 2012
Queensland	Hargraves, 2004
South Australia	Hill *et al*, 2000
Tasmania	Gamble *et al*, 1998
Victoria	Nandakumar *et al*, 1997
Western Australia	Durrant *et al*, 2004

More recently, one to five day rainfall estimates in the large to rare range, have been generated using a method developed by the Cooperative Research Centre for Catchment Hydrology (CRCCH). The Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE) method (Nandakumar *et al*., 1997) was based on the UK Institute of Hydrology FORGE concept of using pooled rainfall data in a homogeneous region to derive growth curves at focal stations. Since its development and application to Victoria, the CRC-FORGE method has been applied to each state and some parts of the Northern Territory. The references for each of the state CRC-FORGE estimates are listed in Table 2.

New Design Rainfalls

The data and methods used to derive the new very frequent; frequent and infrequent; and rare design rainfalls are discussed below.

Frequent and infrequent design rainfalls (IFDs)

The revision of the IFDs was undertaken for a number of reasons:

- The availability of longer rainfall records (nearly 30 years more data)
- Access to expanded data sets incorporating rainfall data collected by organisations across Australia under the terms of the Water Regulations 2008
- New statistical analysis and gridding techniques
- The requirement of users for IFDs for shorter durations for use in urban studies and longer durations for use in the design of retarding basins.

Details of the data adopted for the new IFDs are summarised in Table 3 with a summary of the data used for the old ARR87 IFDs provided for comparison.

Figures 2 and 3 show the comparison between the location of the daily read and continuous stations used for the old and new IFDs.

Table 3. Comparison of Data used for New IFDs and ARR87 IFDs

Step	New IFDs	ARR87 IFDs
Number of rainfall stations	Daily read – 8074 Continuous – 2280	Daily read – 7500 Continuous – 600
Period of record	All available records up to 2012	All available records up to ~1983
Length of record used in analyses	Daily read > 30 years Continuous > 8 years	Daily read > 30 years Continuous > 6 years
Source of data	Organisations collecting rainfall data	Primarily Bureau of Meteorology

Figures 2 and 3 show the comparison between the location of the daily read and continuous stations used for the old and new IFDs.

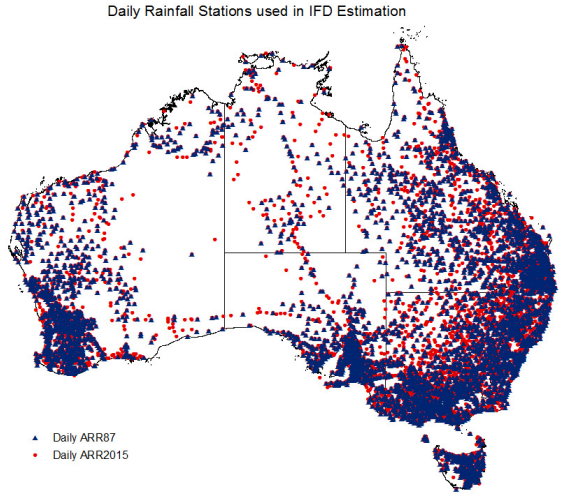

Figure 2 Comparison of daily read stations used for old IFDs (blue) and those used for new IFDs (red and blue)

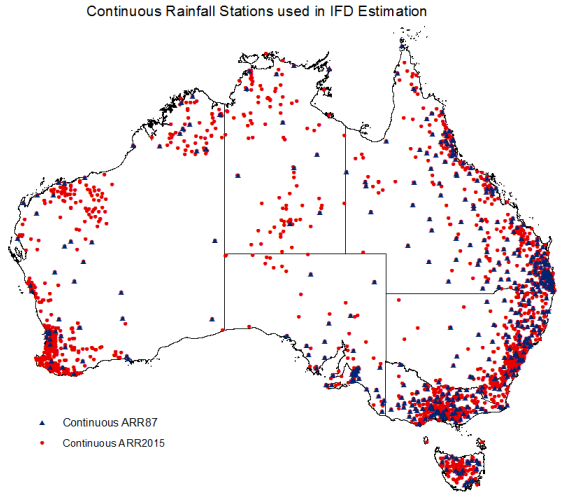

Figure 3 Comparison of continuous stations used for old IFDs (blue) and those used for new IFDs (red and blue)

As can be seen from Figure 3, significantly more continuous rainfall stations were used for deriving the new IFDs resulting in an improvement in the design rainfall estimates for durations less than one day.

In addition to a greatly expanded data base, the new IFDs used contemporary methods for the analysis of the rainfall data. The methods used to derive the ARR87 IFDs relied on subjective, manual interpolation to fill in areas with limited rainfall data. Additional computing capacity now available allowed more objective gridding techniques to be used, which provided a consistent, repeatable interpolation method across Australia. In addition, there have been developments in the statistical analysis of data since the estimation of the ARR87 IFDs, such as the use of L-moments in fitting a probability distribution to the data, which are considered to be more reliable. Table 4 provides a summary of the methods used for deriving the new IFDs and gives a comparison to those methods used in the estimation of the ARR87 IFDs.

Table 4. Comparison of Methods used for New IFDs and ARR87 IFDs

Step	New IFDs	ARR87 IFDs
Extreme value series	Annual Maximum Series (AMS)	Annual Maximum Series (AMS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using L-moments	Log-Pearson Type III (LPIII) distribution fitted using method of moments
Extension of sub-daily rainfall statistics to daily read stations	Bayesian Generalised Least Squares Regression (BGLSR)	Principal Component Analysis
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Maps hand-drawn to at-site distribution parameters, digitised and gridded using an early version of ANUSPLIN

The data and method summarised above produced new IFDs estimates across Australia for the standard durations and standard probabilities listed in Table 5. The durations for which the new IFDs are provided include durations shorter than five minutes and longer than three days. In addition, the IFDs for durations shorter than one hour are provided in five minute increments rather than six minute increments as this is more keeping with the time step commonly adopted in hydrologic modelling.

As is to be expected, there are differences between the old and new IFDs which vary across Australia and with duration and AEP. Some of the difference is due to increased data availability in locations that previously had limited data, and some is due to the different methods for statistical analysis and interpolation used for the new IFDs. Examples of the differences between the old and the new IFDs for each capital city are provided on the new IFD webpage.

Table 5. IFD Outputs

Output	Values	Units
Standard durations	1, 2, 3, 4, 5, 10, 15, 30 1, 2, 3, 6, 12 1, 2, 3, 4, 5, 6, 7	Minutes Hours Days
Standard probabilities	63.2%, 50%, 20%, 10%, 5%, 2%, 1%	AEP

Very frequent design rainfalls

The data base adopted for the very frequent design rainfalls was the data base adopted for the new IFDs as discussed above. However, as very frequent design rainfall estimates are required for the more frequent probabilities of 12, 6, 4, 3, and 2 EY, additional stations with shorter record lengths were also included. The advantage of the inclusion of rainfall stations with shorter periods of records was to improve the

spatial coverage of the data. A comparison of the data used for the new IFDs and the data used for the very frequent design rainfalls is presented in Table 6.

Table 6. Comparison of data used for new IFDs and very frequent design rainfalls

Step	New IFDs	Very frequent
Number of rainfall stations	Daily read – 8074 Continuous – 2280	Daily read – 15 364 Continuous – 2722
Period of record	All available records up to 2012	All available records up to 2012
Length of record used in analyses	Daily read > 30 years Continuous > 8 years	Daily read > 5 years Continuous > 5 years
Source of data	Organisations collecting rainfall data	Organisations collecting rainfall data

The location of the daily read and continuous rainfall stations used in deriving the very frequent design rainfalls is shown in Figure 4.

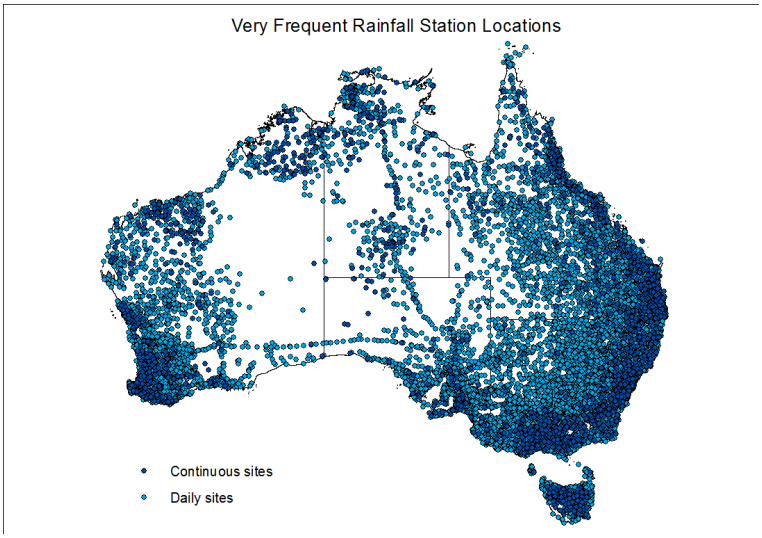

Figure 4 Daily read stations (light blue) and continuous stations (dark blue) used for very frequent design rainfalls

To ensure consistency between the very frequent design rainfalls and the IFDs, the overall approach adopted for the sub-annual IFDs was similar to that used for the new IFDs. However some changes were necessary because of the increased frequency of occurrence. These changes are summarised below but are discussed in more detail in The *et al* (2015).

Table 7. Comparison of method used for new IFDs and very frequent design rainfalls

Step	New IFDs	Very frequent
Extreme value series	Annual Maximum Series (AMS)	Partial Duration Series (PDS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using L-moments	Generalised Pareto (GPA) distribution fitted using L-moments
Extension of sub-daily rainfall statistics	Bayesian Generalised Least Squares Regression (BGLSR)	Ratios
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Regionalised at-site distribution parameters gridded using ANUSPLIN

The data and method described above produced very frequent design rainfall estimates across Australia for the following standard durations and probabilities.

Table 8. Very frequent design rainfall outputs

Output	Values	Units
Standard durations	1, 2, 3, 4, 5, 10, 15, 30 1, 2, 3, 6, 12 1, 2, 3, 4, 5, 6, 7	Minutes Hours Days
Standard probabilities	12, 6, 4, 3, 2, 1, 0.5, 0.2	EY

In order to be able to compare the methods previously adopted for estimating the 4 EY (3 month ARI), the ratio of the new 4 EY very frequent design rainfall to the new 1 EY IFD were made and are shown in Table 9 for durations of 1, 2, and 3 days.

Table 9. Summary of Australian practice for estimating very frequent design rainfalls

Source	Guideline	Method	Ratio 4 to 1 EY - 1 day	Ratio 4 to 1 EY - 3 day	Ratio 4 to 1 EY - 5 day
Hastings Council Stormwater Management	Design Storm equivalent to a 3 month ARI storm event	40% of 1 year ARI storm event	0.42	0.4	0.38
Parramatta City Council Stormwater Asset Plan	3 month ARI storm event	0.5 x Q_{1year} (flow)	0.41	0.4	0.38
South Australia Government	3 month design flows	Logarithmic extrapolation of design flows from AR&R87	NA	NA	NA
NSW State Government Stormwater Source Control	3 month ARI rainfall event	25% x 1 year ARI (rainfall)	Majority of state >0.3		
Gold Coast City Council	Factors applied to 1 in 1 year ARI	3 month ARI = 0.50 x 1:1 year ARI	0.37	0.37	0.36
Queensland Urban Drainage Manual 2013	0.5 x 63% AEP (1 in 1 year) to replace the 3 month ARI terminology	0.5 x 63% AEP	Majority of state <0.45		
WSUD Technical Design Guidelines for SE Queensland	3 month ARI storm event	0.5 x Q_{1year} (flow)	NA	NA	NA

Rare design rainfalls

Unlike the derivation of very frequent, frequent and infrequent design rainfalls which are based on observed rainfall events that lie within the range of probabilities being estimated, rare design rainfalls are an extrapolation beyond observed events. As a consequence the methods adopted need to be based on assumptions that are reasonable and which are consistent with the methods used to derive more frequent design rainfalls.

The data base that was adopted for the rare design rainfalls was also based on that used for the frequent and infrequent design rainfalls. However, as the estimation of rare design rainfalls relies on long term records, only those stations with more than 60 years of record were selected. A comparison of the data used for the new IFDs and the data used for the rare design rainfalls is presented in Table 10.

Table 10. Comparison of data used for new IFDs and rare design rainfalls

Step	New IFDs	Rare
Number of rainfall stations	Daily read – 8074 Continuous – 2280	Daily read – 3955
Period of record	All available records up to 2012	All available records up to 2012
Length of record used in analyses	Daily read > 30 years Continuous > 8 years	Daily read > 60 years
Source of data	Organisations collecting rainfall data	Bureau of Meteorology

The location of the daily read stations used to derive the rare design rainfalls is shown in Figure 5

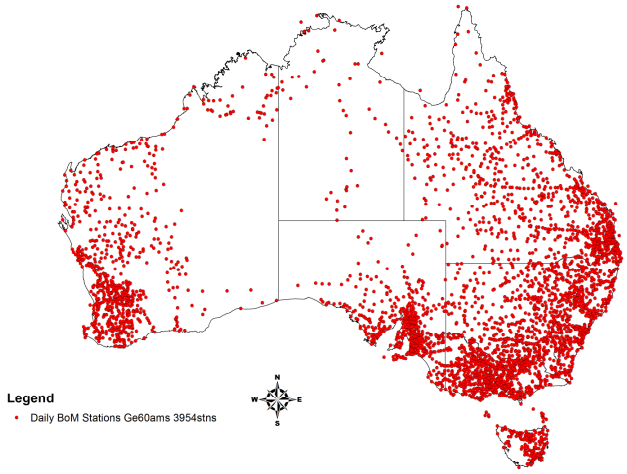

Figure 5 Daily read stations used for rare design rainfalls

The method adopted for deriving the rare design rainfalls was based on the method adopted for the more frequent design rainfalls but places more weight on the largest observed rainfall events. The approach adopted is summarized in Table 11 and compared to the method used for the new IFDs. More detail can be found in Green et al (2016).

The data and method described above produced rare design rainfall estimates across Australia for the standard durations and probabilities listed in Table 12.

Table 11. Comparison of method used for new IFDs and very frequent design rainfalls

Step	New IFDs	Rare
Extreme value series	Annual Maximum Series (AMS)	Annual Maximum Series (AMS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using L-moments	Generalised Extreme Value (GEV) distribution fitted using LH(2)-moments
Extension of sub-daily rainfall statistics to daily read stations	Bayesian Generalised Least Squares Regression (BGLSR)	N/A
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Regionalised at-site distribution parameters gridded using ANUSPLIN

Table 12. Rare design rainfall outputs

Output	Values	Units
Standard durations	1, 2, 3, 4, 5, 6, 7	Days
Standard probabilities	1 in 100; 1 in 200; 1 in 500; 1 in 1000; 1 in 2000	AEP

Dissemination

The new design rainfalls are provided for durations from 1 minute to 7 days and for probabilities from 12 Exceedances per Year (or 1 month Average Recurrence Interval) to 1 in 2000 AEP and are available for any location in Australia. The new design rainfalls are available from the Bureau's website at http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml. The new design rainfalls are provided both as a table – which can be downloaded as a .csv file to facilitate their incorporation into models – and as a chart – which can be downloaded as a .jpg file.

Conclusion

The Bureau of Meteorology has released new design rainfalls for Australia. The new design rainfalls are based on rainfall data collected nationally from all agencies. The methods adopted to derive the new design rainfalls reflect 'state of the science' practices that extract as much information on large rainfall events as possible from the available data.

The new design rainfalls are provided for a range of durations and AEPs that reflect the change in focus from large rural catchments to small urban catchments and which better meet the needs of users. The information is available from a one stop shop on the Bureau's website in a format that best facilitates access and use by practitioners. The new design rainfalls provide better estimates to assist in preparing for the next great flood.

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