New Design Rainfalls for Australia – Lessons Learned...

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Abstract

The Australian Bureau of Meteorology recently released new design rainfalls for Australia. The new design rainfalls are based on a large rainfall data base which was analysed using 'state of the science' techniques. They are available for probabilities from 1 month Average Recurrence Interval (ARI) to 2000 year ARI and for durations from 1 minute to 7 days.

The derivation of the new design rainfalls was undertaken over eight years, involving fifty person years, at a cost of over six million dollars. The process of estimating the new design rainfalls involved the trialling of numerous approaches at each step. This included the quality controlling of rainfall data from numerous organisations; the selection of the most appropriate distribution and fitting method for the extreme value series; the identification of an optimal approach for regionalising the data; the assessment of methods to be used to extract short duration rainfall statistics from daily read rainfall stations; and the trialling of gridding techniques in order select the most suitable one.

The outcome of the considerable amount of time spent testing at each step was an overall method for deriving design rainfalls that was scientifically rigorous; defensible; and that could be applied across the whole of Australia and not just in data rich areas. The resultant method not only enabled new design rainfalls to be produced for Australia but also provides a tried and tested approach that can be applied by other countries, such as New Zealand, who are looking to estimate design rainfalls

1. INTRODUCTION

The Australian Bureau of Meteorology (the Bureau) has recently completed an 8 year project, which has provided new design rainfalls for Australia – the equivalent of the high intensity rainfalls provided by NIWA via the High Intensity Rainfall System (HIRDS). The new design rainfalls are based on a greatly expanded rainfall database which was analysed using more statistically rigorous methods that are most appropriate to Australian rainfall data. The new design rainfalls are provided for probabilities ranging from 12 Exceedances per Year (EY) to 1 in 2000 Annual Exceedance Probability (AEP) (equivalent to a range of 1 month to 2000 years Average Recurrence Interval (ARI)) and for durations from 1 minutes to 7 days.

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 Range	**Occurrence**
12 EY to 1 EY	Very frequent
1 EY to 10% AEP	Frequent
10% to 1% AEP	Infrequent
1 in100 AEP to 1 in 2000 AEP	Rare
< 1 in 2000 AEP	Extreme

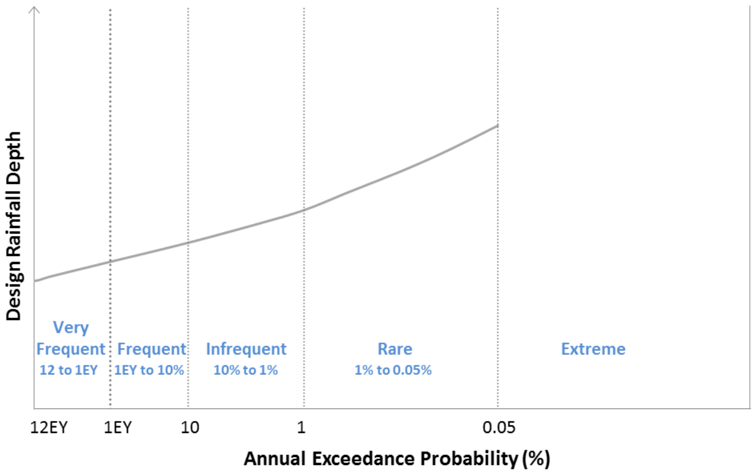

Figure 1 Types of design rainfall

In this paper, the focus will be on design rainfall estimates in the range from 12 EY used in Water Sensitive Urban Design (WSUD) to those with a probability of 1 in 2000 AEP used in bridge design and spillway adequacy assessment. These are the new design rainfalls that have been provided by the Bureau via the Bureau's website and which are discussed in more detail below. Section 2 provides an overview of the approaches adopted to produce new design rainfalls in these categories; Section 3 summarises the outcomes of the work; and Section 4 discusses the lessons that have been learned from the undertaking of the eight year project to derive new design rainfalls for Australia.

2. NEW DESIGN RAINFALLS

2.1. Overview

In deriving the new design rainfalls the same overall approach was adopted for the complete range of probabilities. The main steps included the collation of a quality controlled database, extraction of the extreme values series, frequency analysis, regionalisation and gridding processes. These steps are summarised in Figure 2 and were developed and initially applied to derive frequent and infrequent design rainfalls. In deriving the very frequent and rare design rainfalls the same overall approach was adopted in order to be derive design rainfalls that were consistent with the frequent and infrequent design rainfalls, however, modifications to the approach were necessary in order to address the different range of probabilities.

In the section below, the application of the broad approach to derive the frequent and infrequent design rainfalls will be discussed. How the broad approach was modified to derive the very frequent and rare design rainfalls will be presented in subsequent sections.

2.2. Frequent to infrequent design rainfalls

Details of how the overall approach was applied for the frequent and infrequent design rainfalls are summarized in Table 1. More details on each of the steps are provided below.

Data

Integral to the estimation of design rainfalls was the creation of a database containing data from all available rainfall stations across Australia. These rainfall data were collected at rainfall stations operated by various organisations using a range of types of collecting methods and instrumentation. The inclusion of rainfall data collected by organisations other than the Bureau was greatly facilitated by the terms of the Water Regulations 2008, which required water information (including rainfall data) collected by organisations around Australia to be provided to the Bureau. Although only a limited number of daily read rainfalls are operated by other organisations, the intense networks of continuous rainfall stations operated by urban water utilities provided data for three times the number of continuous rainfall stations operated by the Bureau. The locations of the daily read rainfall stations are shown in Figure 3 and the locations of the continuous rainfalls stations in Figure 4.

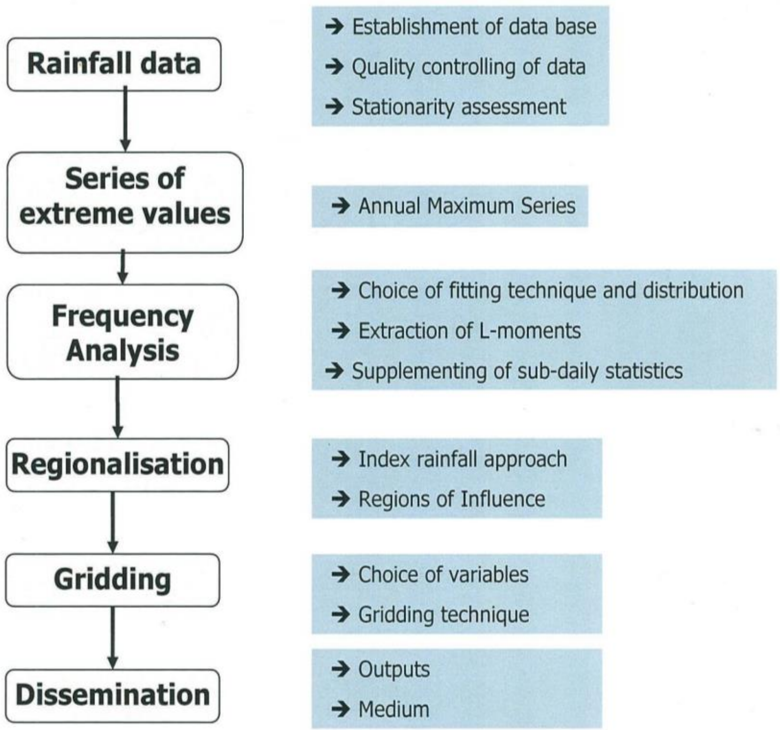

Figure 2 Steps adopted in deriving new design rainfalls

Table 1 Summary of Frequent and Infrequent Design Rainfall Method

Step	**Method**
Number of rainfall stations	Daily read – 8074 Continuous – 2280
Period of record	All available records up to 2012
Length of record used in analyses	Daily read >= 30 years Continuous > 8 years
Source of data	Organisations collecting rainfall data across Australia
Extreme value series	Annual Maximum Series (AMS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using L-moments
Extension of sub-daily rainfall statistics to daily read stations	Bayesian Generalised Least Squares Regression (BGLSR)
Regionalisation	Region of influence (ROI)
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN

Quality Controlling of Data
In light of the volume of data that needed to be quality controlled and the disparate sources of the data, automated procedures were developed for the identification of suspect data and, as far as possible, the correction of these data. However, the quality controlling of the data could only be automated so far and a significant amount of data was required to be manually checked. Detailed descriptions of the quality controlling undertaken can be found in Green *et al* (2011; 2012a).

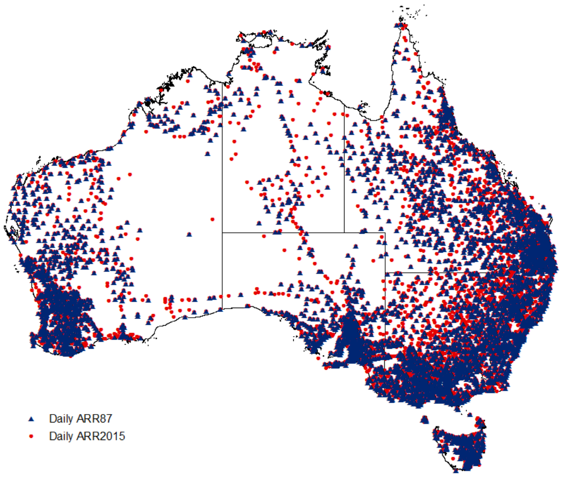

Figure 3 Daily Read Rainfall Stations

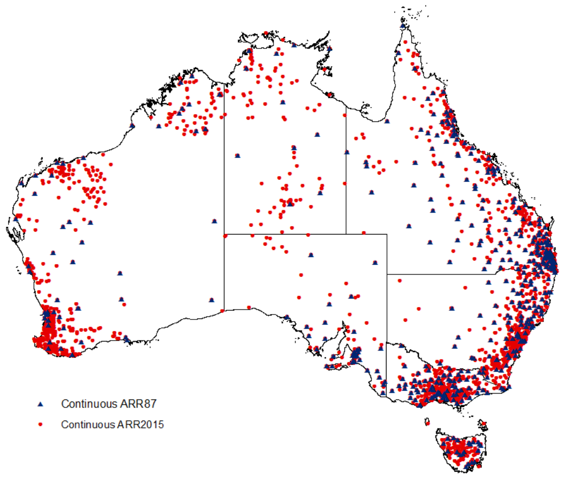

Figure 4 Continuous Rainfall Stations

Extreme value series
For the frequent and infrequent design rainfalls the Annual Maxima Series (AMS) was used to define the extreme value series.

Frequency analysis
The Generalised Extreme Value (GEV) distribution was fitted to the AMS as this has been found to be the most appropriate distribution to be used with Australia rainfall data. L-moments were used in fitting the GEV distribution to the data, as they are considered to be more reliable than the previously adopted method of moments (Hosking and Wallace, 1997)

Extension of sub-daily rainfall statistics to daily read stations
Bayesian Generalised Least Squares Regression (BGLSR) (Reis et al 2012) was adopted in order to infer sub-daily rainfall statistics from daily read rainfall data (Johnson et al, 2012b).

Regionalisation
The regionalisation of the data was undertaken using a Region of Influence (ROI) approach (Johnson et al, 2012a) in order to remove bias caused by stations with short periods of records.

Gridding
The translation from point to gridded design rainfall estimates was carried out with thin plate smoothing splines which were implemented using ANUSPLIN (Hutchinson 2013 The et al, 2012, 2014).

Table 2 Frequent and Infrequent 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	1 50%, 20%, 10%, 5%, 2%, 1%	EY AEP

2.3. Very frequent design rainfalls

As discussed, to ensure consistency between the very frequent design rainfalls and the frequent and infrequent design rainfalls, the same overall approach was adopted. 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 3 Comparison of approach used for frequent & infrequent and very frequent design rainfalls

Step	Frequent & infrequent	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
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 to daily read stations	Bayesian Generalised Least Squares Regression (BGLSR)	Ratios
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Regionalised at-site distribution parameters gridded using ANUSPLIN

Data
The data base adopted for the very frequent design rainfalls was the data base adopted for the frequent and infrequent design rainfalls 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.

Frequency analysis
A partial duration series (PDS) approach was adopted to estimate probabilities for events occurring more frequently than once a year. The advantage of using the PDS is that it extracts as much information as possible about large events and produces direct estimates for probabilities more frequent than the 10% AEP.

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

Table 4 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	EY

2.4. Rare design rainfalls

As for the very frequent design rainfall, the same overall approach that was adopted for the frequent and infrequent design rainfalls was used for the rare design rainfalls. However because of the rarity of the design rainfalls some changes were necessary. These changes are summarised below but are discussed in more detail in Green *et al* (2015).

Data
As the estimation of rare design rainfalls relies on long term records, only those stations with more than 60 years of record were selected to extract the LCV and LSK.

Table 5 Comparison of approach used for frequent & infrequent and rare design rainfalls

Step	Frequent & infrequent	Rare
Number of rainfall stations	Daily read – 8074	Daily read – 8074 for index value Daily read – 3955 for LCV and LSK
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 >= 30 years for index value Daily read >= 60 years for LCV and LSK
Source of data	Organisations collecting rainfall data	Bureau of Meteorology
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
Regionalisation	Region of Influence	Region of Influence
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Regionalised at-site distribution parameters gridded using ANUSPLIN

Frequency analysis
For the rare design rainfalls LH-moments with a shift 2 (η=2) were adopted (Wang, 1997) as they more accurately fit the upper tail (rarer probabilities) of the distribution.

Table 6 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

3. LESSONS LEARNED

The derivation of the new design rainfalls by the Australian Bureau of Meteorology was undertaken over eight years, involving fifty person years, at a cost of over six million dollars. The outcomes from the project provide new design rainfall estimates for probabilities from 12 EY to 1 in 2000 AEP. These design rainfall estimated are based on a comprehensive rainfall data base comprising data collected by the Bureau and organisations around Australia which have been analysed using the latest methods. They provide a clear, consistent point of reference for all hydraulic and hydrologic analysis in Australia.

In addition, the work undertaken provides a tried and tested approach that can be applied by other countries, such as New Zealand, who are looking to estimate or revise design rainfalls. However, over the course of the project a number of lessons have been learned which are also of value.

1. As discussed in Section 2, initially only the frequent and infrequent design rainfalls were derived; the estimation of the very frequent and rare design rainfalls was undertaken as second phase. Although there were efficiencies in using an existing data base and overall approach, a certain amount of reworking was required, especially with the quality controlling of the data. Further, in estimating the rare design rainfalls it was recognized that the approach adopted produced better estimates of the 1 in 50 and 1 in 100 AEP design rainfalls than the 2% and 1% AEP infrequent design rainfalls and necessitated the updating of the new design rainfalls.

   In hindsight it would have been better to have scoped the project for the full range of probabilities from the outset.

2. While it was important to learn from work undertaken overseas in the derivation of design

rainfalls (especially in the United States and the United Kingdom) it was equally important to recognize that Australia has a very different hydroclimate and therefore it was not appropriate to just adopt a method used overseas.

3. Similarly, while value was gained by leveraging off research undertaken into various aspects of the project, it was important to recognize that the work being undertaken was a project and not research and that there were diminishing returns from spending too much time investigating relatively small aspects of the work.

4. In developing the approach that was finally adopted, a lot of value was gained from testing options on small areas of differing climatic regimes and data density.

5. The estimation of uncertainty estimates for the new design rainfalls was undertaken at the end of the project which required rerunning processes. A better approach would have been to have developed the uncertainty framework at the same time as the overall method was being developed.

6. The approach adopted had to be appropriate for both data rich and data sparse areas. As a consequence, at times it was not possible to use more sophisticated techniques or data sources because they could not be applied across the whole of Australia or the complete length of record. One possible solution to overcome this would have been to have partitioned the country into those areas which were data rich and highly populated and those which weren't and apply different approaches to the different areas.

7. Over four years (or half the project time) was spent on quality controlling of the data. While it was recognized that this was an essential step and the value of the time spent on it paid off in later stages of the project, it made the work in the first few years of the project very tedious with little to demonstrate the amount of work being undertaken. Therefore it was important to automate as much of the quality controlling processes as possible while recognizing that only about 80% of the process could be automated. The engagement of university students over summer to undertake the more manual quality controlling proved very effective – both in terms of the volume of data checked and the break it provided for the project team.

8. The quality controlling of the data and understanding of rainfall data was greatly enhanced by project team members taking part in maintenance visits to various raingauges as it provided them with a better understanding of the limitations of collecting rainfall data.

9. Although some use was made of secondary data sources, such as historic data and data from raingauges that did not meet operational standards, there would have been benefit from spending more time investigating these data sources – especially in data sparse areas.

10. A lot of value was gained from having a project team that included meteorologists; statistical hydrologists; and engineers who had experience using design rainfalls as they each provided different but complementary knowledge. In addition, as most of the project team were based in different states they were able to bring local knowledge to the project.

11. One of the main difficulties encountered was due to 30 years having elapsed since design rainfalls were last estimated. To avoid this in the future, the procedures and software used to produce the new design rainfalls have been set up to facilitate the updating of the design rainfalls every five or years.

4. CONCLUSIONS

The Australian Bureau of Meteorology has recently completed an eight year project to provide new design rainfalls for Australia. The new design rainfalls are based on a comprehensive rainfall data base comprising data collected by the Bureau and organisations around Australia which have been analysed using the latest methods. The new design rainfalls are provided for durations from 1 minute to 7 days and for probabilities from 12 Exceedances per Year to 1 in 2000 AEP and are available for any location in Australia. The new design rainfalls are available from a one stop shop on 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.

The project also provides a tried and tested approach that can be applied by other countries, such as New Zealand, who are looking to estimate design rainfalls. In addition the lessons learned during the course of the project will assist others undertaking similar work.

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