Comparing CRCFORGE Estimates and the New Rare Design Rainfalls

J.H. Green[1]; C. Beesley[2]; C. The[3]; S. Podger[3] and A. Frost[3]

[1]*IFD Revision Project Director, Bureau of Meteorology, Canberra, Australia*
[2]*Hydrologist, Bureau of Meteorology, Melbourne, Australia*
[3]*Hydrologist, Bureau of Meteorology, Sydney, Australia*

The ability to estimate design rainfalls for probabilities rarer than 100 years or 1% Annual Exceedance Probability (AEP) is an essential part of dam hydrology. The earliest means of estimating rare events consisted of a pragmatic curve fitting procedure between the 50 and 100 year design rainfalls and the Probable Maximum Precipitation. In the 1990s a more rigorous method of estimating design rainfalls as rare as 2000 years was developed – the Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE) method. CRC-FORGE estimates were derived for Victoria in 1997 followed progressively by each of the other states. Over the subsequent two decades CRC-FORGE estimates were an integral part of the risk assessment of large dams – being used to determine the AEP of the Dam Crest Flood

The Bureau of Meteorology will soon release new rare design rainfall estimates for probabilities to 2000 years. The new rare design rainfalls are a significant improvement on the CRC-FORGE estimates as they have been derived using up to date data; contemporary analytical techniques and a method that is consistent across Australia.

However, there are differences between the CRC-FORGE estimates and the new rare design rainfalls. These differences do not constitute a systematic change to the CRC-FORGE estimates but rather vary with location; duration and probability. The results of a detailed comparison between the CRC-FORGE estimates and the new rare design rainfalls are presented together will an assessment of the possible impacts on previous estimates of the AEP of the Dam Crest Flood.

Keywords: *Rare design rainfalls; Intensity-Frequency-Duration (IFD); Annual Exceedance Probability; CRCFORGE*

Introduction

Rare design rainfalls are those design rainfalls which have probabilities rarer than 100 years Average Recurrence Interval (ARI) or 1% Annual Exceedance Probability (AEP) to 2000 years ARI or 1 in 2000 AEP as shown in Figure 1.

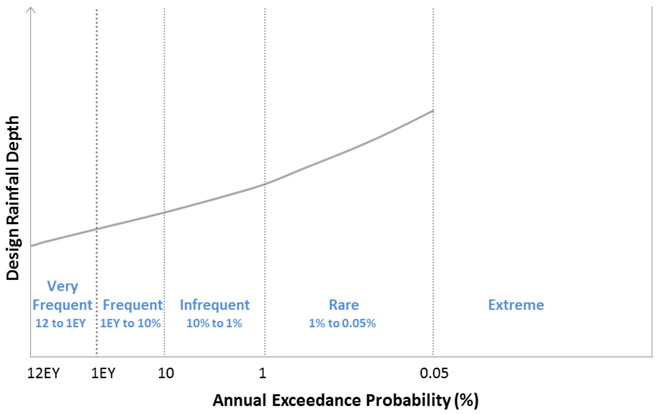

Figure 1 – Types of design rainfall

Design rainfalls in the rare range of probabilities are an essential part of dam hydrology as they enable more accurate definition of the design rainfall and flood frequency curves between the 1% AEP and Probable Maximum events (such of the Probable Maximum Precipitation, PMP). As the spillway adequacy of many existing dams lies within this range of probabilities, rare design rainfalls are integral to the determination of the Dam Crest Flood (DCF) as part of spillway adequacy assessments.

For this reason, methods for estimating rare design rainfalls have been provided since 1987. In the following sections, the methods for estimating rare designs will be discussed and a comparison made between the previous, Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE), estimates and the rare design rainfalls soon to be released by the Bureau of Meteorology.

Background

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).

More recently, 1 to 5 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) is based on the UK Institute of Hydrology FORGE concept (Reed and Stewart, 1989) 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 parts of the Northern Territory. The references for each of the state CRC-FORGE estimates are listed in Table 1.

Table 1 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

The CRC-FORGE estimates were provided for durations of 1, 2, 3, 4 and 5 days and for probabilities of 1 in 50; 100; 200; 500; 1000; and 2000 AEP. Although all the CRC-FORGE design rainfalls estimates were derived using essentially the same method, there were variations in the way in each state applied the method. These differences included:

- Differences in the cut-off period for data
- Differences in record length thresholds adopted for the various steps
- Development of separate quality controlled rainfall maxima databases by each state
- The adoption of different points for the 'anchoring' of the growth curves
- Consideration of seasonality
- Differences in gridding settings and smoothing processes.

These differences were exacerbated by the fact that the application of the CRC-FORGE to each of the states was undertaken over a period of 15 years with increasing length of record and availability of more advanced techniques and resulted in inconsistencies which are particularly apparent in overlapping state border areas. Also, currently there is no central point of dissemination and it is necessary to contact the individual or organisation responsible for preparing each of the state CRC-FORGE estimates for access. A summary of the differences between the applications of the CRC-FORGE method in each of the states is provided in Table 2.

Table 2 Comparison of application of CRC-FORGE method

	Victoria	South Australia	Queensland	New South Wales / ACT	Tasmania	Western Australia
Maxima series	Annual	Annual	Annual	Annual	Annual	Summer Winter
Period of record thresholds	≥30yrs index variable mapping; ≥60yrs homogeneity, distribution & growth curves; ≥100yrs Spatial Dependence Model (SDM)	>60yrs stationarity & growth curves; >100yrs homogeneity & SDM	≥70yrs SDM ≥30yrs all other CRCFORGE steps	≥30yrs index variable mapping; ≥60yrs homogeneity, distribution; ≥100ys SDM & growth curves	>20yrs stationarity; >25yrs concurrent SDM >60yrs homogeneity	>60 yrs distribution, homogeneity, SDM, & growth curves
Data cutoff	1993	1998	1997	2008	1997	2002
Homogenous regions	1 for SDM (192 station limit for pooling)	(All stations used for pooling)	1 for SDM 7 for pooling	1 (192 station limit for pooling)		4 (summer) and 5 (winter)
Anchoring of growth curves	CRC-FORGE growth curves rescaled to give a value of 1 at 2 % AEP ARR87 IFD estimates	CRC-FORGE growth curves rescaled to give a value of 1 at 2 % AEP ARR87 IFD estimates	CRC-FORGE estimates 2% AEP estimates adopted instead of ARR87 IFDs	CRC-FORGE growth curves rescaled to give a value of 1 at 2 % AEP ARR87 IFD estimates	CRC-FORGE growth curves rescaled to give a value of 1 at 2 % AEP ARR87 IFD estimates	Growth factors multiplied by mean seasonal maximum.

New Rare Design Rainfalls

In view of the issues with the existing CRC-FORGE estimates discussed above, the Bureau of Meteorology considered it important that new rare design rainfalls be provided as part of the continuum of new design rainfalls produced as part of the Intensity-Frequency-Duration (IFD) Revision Project (Green et al, 2015a). In deriving new rare design rainfalls, various options were considered including:

- Using the existing gridded CRC-FORGE data
- Applying the CRC-FORGE from scratch to the new IFD AMS database with some optimisation of methods including gridding / smoothing etc
- New / updated approach applied to the new IFD database.

More details on each of the options considered can be found in Green et al, 2015b. After testing each of the approaches, it was found that the third option was the most appropriate as it adopted a new approach which was more consistent with the new IFDs and overcame the limitations of the CRC-FORGE method especially with the spatial dependence model. The data and approach adopted are summarized in Table 3 and discussed in more detail below.

Table 3 Summary of rare design rainfall method

Step	Method
Number of rainfall stations	Daily read – 8074 for index value Daily read – 3955 for LCV and LSK
Period of record	All available records up to 2012
Length of record used in analyses	Daily read >= 30 years for index value Daily read >= 60 years for LCV and LSK
Source of data	Bureau of Meteorology
Extreme value series	Annual Maximum Series (AMS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using LH(2)-moments
Regionalisation	Region of influence
Gridding	Regionalised GEV parameters gridded using ANUSPLIN

Data

The quality controlled rainfall database established for the derivation of the more frequent design rainfalls was used as the basis for the database used for the rare design rainfalls. This database comprised daily read rainfall stations from all over Australia for their complete period of record, up to and including 2012. 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 to extract the LCV and LSK. This reduced the dataset to approximately 4000 stations, the locations of which are shown in Figure 2.

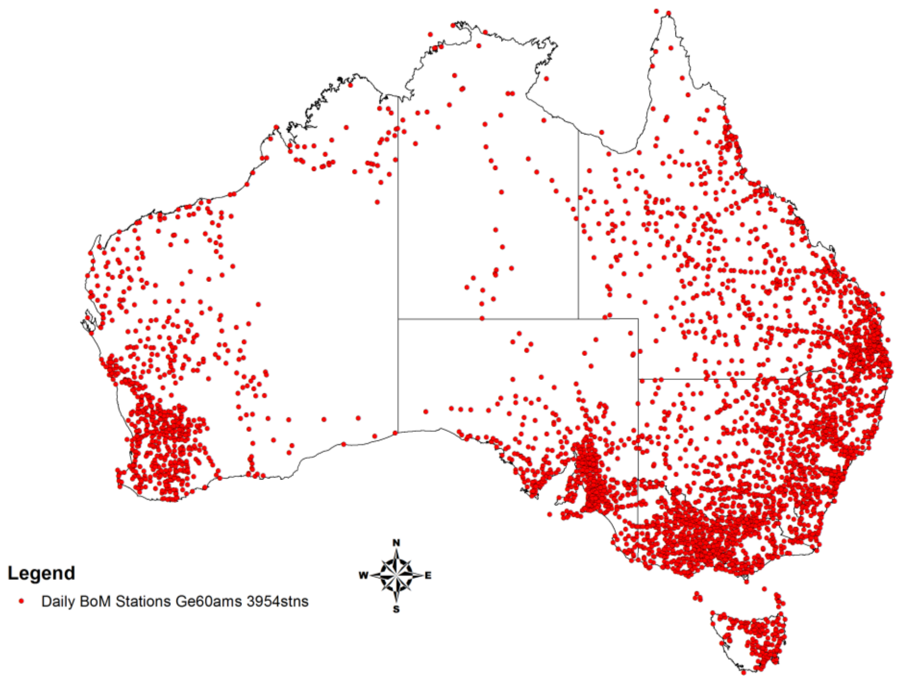

Figure 2 – Daily read rainfall stations used for LV and LSK

Index values were initially derived using the same set of stations as LCV and LSK, however it was found that this led to large differences compared to the new IFD values, therefore the index values were derived from the same dataset as the new IFDs. The locations of these stations are shown in Figure 3.

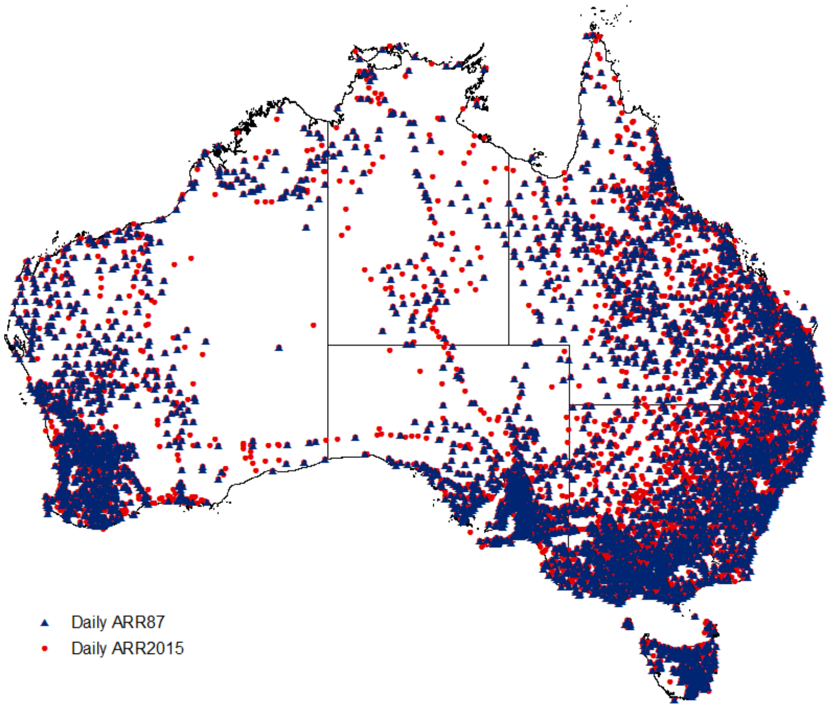

Figure 2 – Daily read rainfall stations used for Index value

The quality controlled database used for the new rare design rainfalls differed from those used for the CRCFORGE estimates in the following ways:

- the rainfall data were extracted for the whole of Australia, including the Northern Territory, rather than on a state by state basis
- a consistent cutoff date of 2012 was adopted for all the data in contrast to the range of cutoff dates from 1993 to 2002 adopted for the different states for the CRCFORGE estimates
- the periods of record thresholds adopted were consistent across Australia
- rigorous and consistent quality controlling of the rainfall data (Green et al, 2012) was undertaken rather than the separate quality controlling processes developed by each state.

Frequency analysis

The Annual Maximum Series (AMS) was extracted from all daily read rainfall stations with 60 or more years of record. The AMS was used to define the extreme value series for the rare design rainfalls as the focus here is on the largest recorded events. As was done for the more frequent design rainfalls, the GEV distribution was adopted for the rare design rainfalls. However, where L-moments were used to fit the GEV distribution to the AMS for the more frequent design rainfalls, for the rare design rainfalls LH-moments were adopted (Wang, 1997) as they more accurately fit the upper tail (rarer probabilities) of the distribution. In applying LH moments a shift of 2 (η=2) was adopted as a compromise between providing a better fit to the tail of the at-site distribution without giving too much influence to the high outliers.

Although the CRCFORGE application by each state adopted the AMS and the GEV distribution, the GEV distribution was fitted using L-moments rather than LH moments.

Regionalisation

For the rare design rainfalls, the Region of Influence (ROI) approach adopted for the more frequent design rainfalls was used to reduce the uncertainty in the estimated LH-moments by regionalising the station point estimates. However, whereas for the more frequent design rainfalls, 500 station years was found to be an optimum pool size, as the rare design rainfalls are provided for probabilities out to 1 in 2000 AEP, the ROI needed to be increased. Based on testing for the pool size that reduced uncertainty without introducing significant homogeneity, a minimum of 2000 station years was adopted.

Gridding

The Index, regionalised LH-CV and LH-SK values for all durations and AEP's were gridded using the splining software ANUSPLIN (Hutchinson 2013) that was adopted for the more frequent design rainfalls. To determine the most appropriate method to adopt for the gridding of the moments a range of tests was undertaken of combinations of different knot sets. The final case adopted was a spline that incorporated latitude, longitude and elevation using 3750 knots for the Index (as was adopted for the more frequent design rainfalls) and 2200 knots for the regionalised LH-CV and LH-SK values. The 0.025 degree Digital Elevation Model (DEM) of Australia was used to provide the elevation data which was the same as that used in the derivation of the IFD grids (The et al, 2014).

Anchoring

In order to provide consistent design rainfall estimates across all durations and probabilities, a suitable method was required to integrate the rare design rainfalls with the more frequent design rainfalls. After testing of various 'anchor' points, the rare design rainfalls were anchored to the more frequent design rainfalls at the 5% AEP (20 year ARI) as it was considered that the rare design rainfalls provide a better estimate of the upper tail of the distribution down to the 5% AEP.

This differs from the anchoring adopted for the CRCFORGE application where most states (except for Queensland and Western Australia) anchored the CRCFORGE estimates to the 2% AEP (50 year ARI) ARR87 IFD estimates.

Outputs

The method described above produced rare design rainfall estimates across Australia for the following standard durations and standard probabilities:

Table 4 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

These outputs differ from the outputs from the CRCFORGE estimates because the CRCFORGE estimates are only provided for durations of one to five days. The longer durations are provided for the rare design rainfalls in order to be consistent with the more frequent design rainfalls as well as to meet the requirements for tailing dams and other volume dependent dams such as flood mitigation dams.

Dissemination

The rare design rainfalls are incorporated into the Bureau of Meteorology's new design rainfall website (http://www.bom.gov.au/water/designRainfalls/ifd/). By entering the co-ordinate of a location of interest, users can obtain rare design rainfall estimates as either depths or intensities for durations from 24 to 168 hours for any point in Australia in a single query.

This differs from the CRCFORGE estimates where it is necessary to contact the individual or organisation responsible for preparing each of the state CRC-FORGE estimates for access.

Comparing the new rare design rainfalls and the CRCFORGE estimates

As discussed above, there are significant differences in the data and method adopted for the new rare design rainfalls compared to the data and method adopted for the CRCFORGE estimates. These differences are exacerbated by the fact that the application of the CRC-FORGE to each of the states was undertaken over a period of 15 years and in varying ways as summarised in Table 2. As a result the differences between the new rare design rainfalls and the CRC-FORGE estimates are not systematic but rather vary with location, duration and probability.

To enable users to compare the new rare design rainfalls to the CRC-FORGE estimates for specific locations, comparisons are provided on the Bureau of Meteorology's new design rainfall website on a catchment basis.

Examples of two such comparisons are provided below for the Gwydir River catchment in NSW Figure 4 and the Fitzroy River catchment in Western Australia in Figure 5 where rare design rainfalls (RDR) depths are compared to CRC-FORGE (CRC) depths for durations of 1, 2, 3, 4 and 5 days and probabilities of 1 in 50; 1 in 100; 1 in 200; 1 in 500; 1 in 1000 and 1 in 2000.

As can be seen from Figures 4 and 5, there is no consistent pattern to the differences between the new rare design rainfalls and the CRCFORGE estimates. The differences between the two sets of estimates are different between the NSW and the WA catchment; between the durations for each catchment and between the probabilities for each catchment.

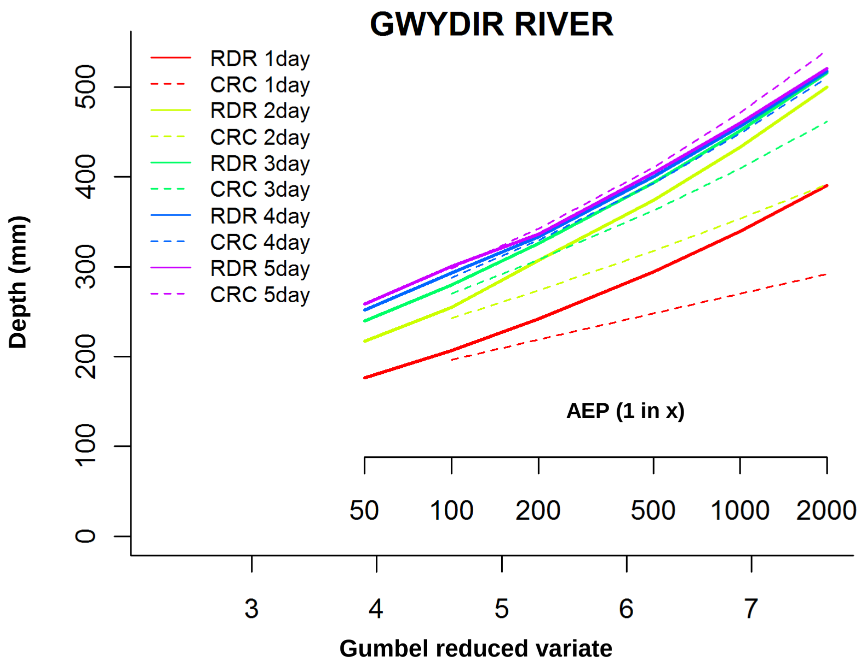

Figure 4 – Rare design rainfall vs CRCFORGE depths Gwydir River Catchment NSW

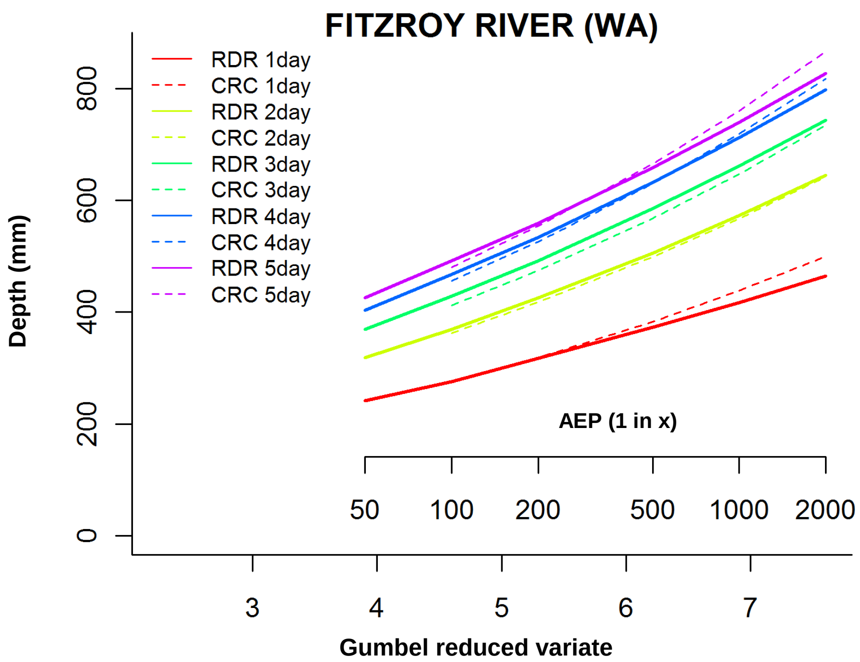

Figure 5 – Rare design rainfall vs CRCFORGE depths Fitzroy River Catchment WA

Conclusions

The Bureau of Meteorology will soon release new rare design rainfall estimates for probabilities from 1 in 100 to 1 in 2000 AEP and durations from 1 to 7 days. These rare design rainfall estimates are based on a comprehensive, quality controlled rainfall database which has been analysed in a consistent manner for the whole of Australia using the latest methods. The new rare design rainfalls will provide improved estimates for any point in Australia which can be accessed from Bureau's website and, as such, will replace the state based CRC-FORGE estimates.

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