Comparing the new rare design rainfalls with CRCFORGE estimates

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New rare design rainfalls were released for Australia in February 2017, for durations from one to seven days and probabilities from 1 in 100 Annual Exceedance Probability (AEP) up to 1 in 2000 AEP.

The differences between the previous rare design rainfalls using estimated Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE) method and the new rare design rainfall estimates vary with location, duration and probability. In this paper, these differences are explored spatially through the use of national maps, comparing percentage change between the two datasets for selected durations and probabilities. Before this comparison with the new rare design rainfalls could be completed, the State-based estimates had to be resampled and aggregated to form a national dataset for Australia.

For rare design rainfalls, it is often the catchment values that are required to determine the gross rainfall for design purposes. The impact of the revised areal reductions factors and rare design rainfalls is explored through case study catchments in Tasmania.

Keywords: Rare design rainfall; CRCFORGE; Intensity-Frequency-Duration (IFD)

Introduction

New rare design rainfalls were released for Australia in February 2017, for durations from one to seven days and probabilities from 1in 100 Annual Exceedance Probability (AEP) up to 1 in 2000 AEP. These are available through the Bureau of Meteorology website and are to be used in conjunction with the revised Australian Rainfall and Runoff (ARR 2016) design flood guidelines (Ball et. al, 2016). They replace the previous rare design rainfalls estimated in most States using the Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE) method.

In order to quantify the changes in rare design rainfall depths across Australia so that the impacts can be understood, it is necessary to compare against the previous rare design rainfall estimates. This was no easy task, with differences in file formats, grid spacing, projection and durations between each set of state CRC-FORGE estimates.

As with the new Intensity-Frequency-Duration (IFD) design rainfalls released previously, the updated rare design rainfalls differ from the previous design rainfalls. The increase in the spatial and temporal availability of rainfall data and the adoption of nationally consistent contemporary methods contributed to these changes. There is no systematic change evident; instead the differences vary spatially across all durations and throughout the rare design rainfall probability range. These differences are shown in the form of maps for selected key durations and probabilities.

For rare design rainfalls, it is often the catchment values that are more relevant to the design flood estimation process than point values. In order to quantify the risk for larger infrastructure, including dams, the previous CRC-FORGE extraction tools for most States incorporated an areal reduction factor (ARF) in the calculation of rare design rainfall estimates for catchments. With the release of ARR 2016, these ARF values have also been revised. Both of these are key inputs into the design flood estimation process. The changes are investigated in more detail using examples from Tasmanian locations and catchments.

Background

The CRCFORGE method was developed and first applied in Australia by Nandakumar et al. (1997) to derive the rare design rainfalls for Victoria. Since then it has been applied in all States between 1998 and 2012, with some overlap for the Northern Territory. The application of the method occurred over time and there are some differences between States, including period of rainfall record, gridding settings and anchoring point (Green et. al., 2016a).

As part of the ARR revision, the design rainfall suite was revised, including the rare design rainfalls from one day to seven day, for the standard probabilities from 1 in 100 AEP to 1 in 2000 AEP (Green et. al. 2015). Observed rainfall events from the daily read sites with more than 60 years of record within the quality controlled rainfall database collated for the IFD revision project were used to form the annual maximum series (AMS). A Generalised Extreme Value (GEV) distribution was fitted to the at-site AMS using LH-2 moments to represent the frequency distribution of the rare design rainfalls. This distribution is defined by three parameters, LH-CV (coefficient of variation), LH-SK (skewness) and an Index, and adds weight to the larger, less frequent events. For each site, a homogeneous region of influence based on several specific site characteristics was defined, using a minimum of 2000 station years. The GEV parameters were regionalised within each of the ROIs. These regionalised parameters were then gridded using the splining software ANUSPLIN to interpolate the values to the 0.025 degree grid used for the design rainfalls, by applying a spline incorporating latitude, longitude and elevation (Green et. al., 2016a). More detailed information on the derivation method for the new rare design rainfalls can be found in Green et. al (2016a) and (2016b).

CRCFORGE formats and spatial processing

CRCFORGE datasets and viewers were obtained for each State so that the grids could be extracted for comparison purposes. The level of documentation and support material varied in each case.

Table 1 summarises the spatial information for each of the CRC-FORGE design rainfall datasets for each State, including the new national grid, along with the reference to the supporting data source. The grid extent of each dataset shows a significant overlap in some cases to ensure consistency between States, most notably New South Wales which includes parts of South Australia and Queensland, and all of Victoria. In most cases the datasets are in the standard national geographic coordinate system for Australia; Geocentric Datum of Australia 1994 (GDA94), which is in latitude and longitude. Tasmania is projected to Australian Map Grid Zone 55 in metres, based on the previous datum Australian Geodectic Datum 1966 (AGD66). Queensland applied a local Albers Equal Area projected coordinate system in metres to a GDA94 datum, specified in a parameter file included with the software. As the format was a projected coordinate system, the grid spacing was also different for Queensland. The point inputs for all tools were in decimal degrees, except Tasmania which required eastings and northings.

Table 1: Summary of spatial information for each rare design rainfall dataset

State	Extent				Spacing	Coordinate system	Reference
	Top	Bottom	Left	Right			
Tasmania	-38.973	-44.005	144.015	149.148	0.025 degrees	AGD66	Gamble et al, 1998
Victoria	-33.775	-39.375	128.762	141.234	0.025 degrees	GDA94	Nandakumar et al, 1997
Western Australia	-10.5125	-35.9875	113.0125	130.0125	0.025 degrees	GDA94	Durrant et al, 2004
South Australia	-25.737	-38.113	128.762	141.234	0.025 degrees	GDA94	Hill et al, 2000
New South Wales	-24.9875	-40.0125	135.9875	153.6875	0.025 degrees	GDA94	Nandakumar et al, 2012
Queensland	-9.00	-30.00	137.00	154.00	2 kilometres	GDA94_Albers	Hargraves, 2004
IFD 2016	-9.00	-44.00	110.00	155.00	0.025 degrees	GDA94	Bureau of Meteorology, 2017

There are several notable differences between the CRCFORGE formats between the States in terms of the functionality and format. The datasets supporting CRCFORGE Western Australia, South Australia and Victoria were in a similar format and the viewing tool is essentially the same, although for WA included a seasonal component which has not currently been included in the new rare design rainfalls.

All of the CRCFORGE datasets have the same grid spacing as the new design rainfall suite except for Queensland. The centroids of the Victoria and New South Wales datasets align, with even grid spacing. Unfortunately this is offset from the standard grid used for the new design rainfall suite so resampling was required to align the grid cells. The data for all States was stored in point format, except for New South Wales which supplied gridded data in raster format. The point data was interpolated to a raster grid prior to analysis.

The datasets for each State were converted to ArcGIS raster format. These rasters were then reprojected and resampled to the same projection and resolution as the standard rare design rainfalls in order to undertake the comparison. The differences in projection and resolution resulted in some minor changes in the design rainfall value due to interpolation. While something to be aware of, this was not significant for the overall spatial comparison of differences. The grids were then clipped to State boundaries to exclude overlap and then merged to form a national dataset. These grids of design rainfall depths were then able to be compared directly to the new rare design rainfalls, with a percentage change metric used to highlight areas where there have been significant changes. No information was available for Northern Territory, apart from some overlap from neighbouring States

National comparison overview

The differences between the new rare design rainfalls and the CRCFORGE estimates have been calculated for each grid cell with a standard raster calculation using Equation 1.

$$\text{Percentage difference} = (\text{IFD2016} - \text{CRCFORGE}) \times 100 / \text{CRCFORGE} \qquad (1)$$

Maps of key durations and probabilities are shown in the following Figures 1 a through to f. These figures give a national overview of changes to the rare design rainfall grids for Australia. In general, Blue indicates areas where the new rare design rainfalls are greater than the CRCFORGE estimates. Red indicates areas where the new rare design rainfalls are less than the CRCFORGE estimates. Areas with no colour have had less than +/- 10% change in the rare design rainfalls.

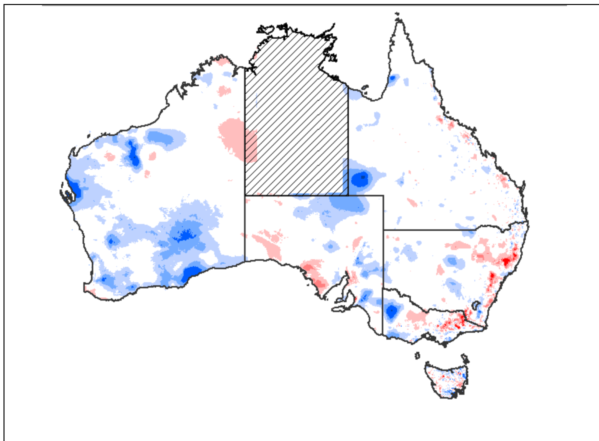


Figure 1a: Design rainfalls for 1 day, 1 in 200 AEP

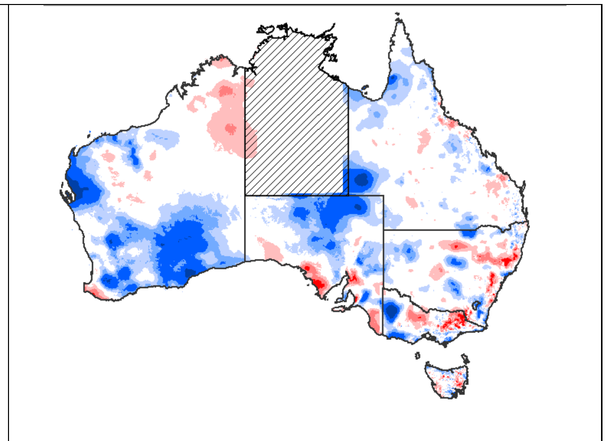


Figure 1b: Design rainfalls for 1 day, 1 in 2000 AEP

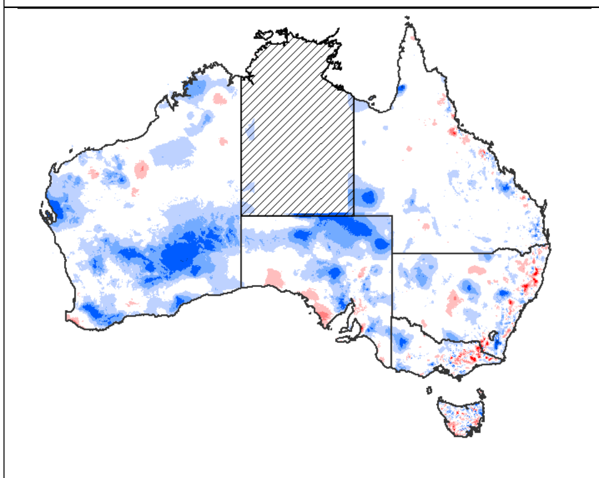


Figure 1c: Design rainfalls for 3 day, 1 in 200 AEP

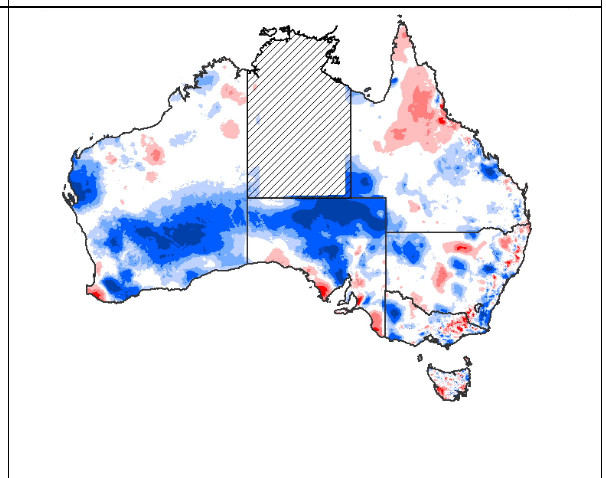


Figure 1d: Design rainfalls for 3 day, 1 in 2000 AEP

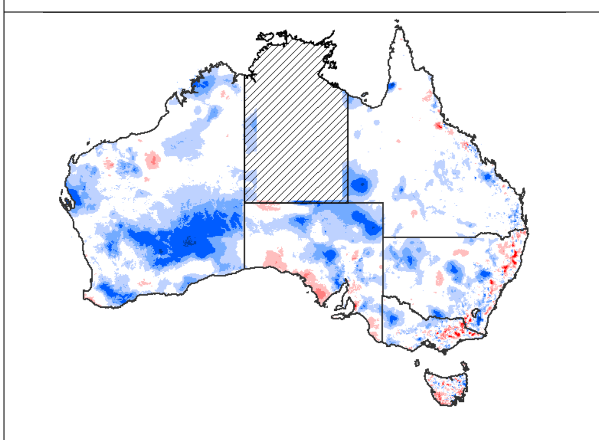


Figure 1e: Design rainfalls for 5 day, 1 in 200 AEP

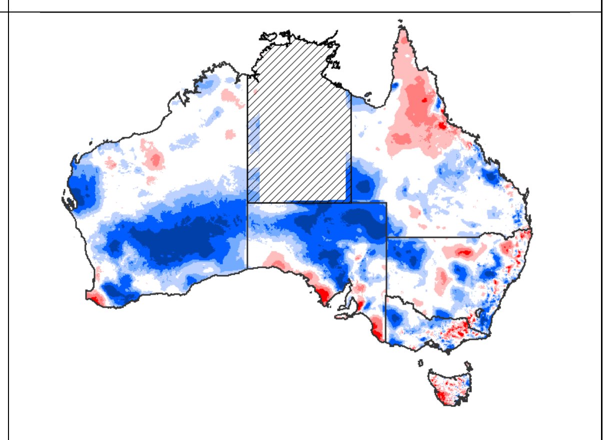
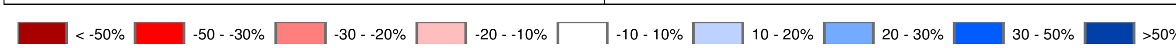


Figure 1f: Design rainfalls for 5 day, 1 in 2000 AEP



It can be seen that there are areas where there are significant differences, particularly at the less frequent probabilities. In the arid areas in central Australia, the new rare design rainfalls are greater than the previous CRCFORGE estimates, while in northern Queensland, the new rare design rainfalls are less than CRCFORGE estimates. The differences are more variable along the coast where topography results in more variable spatial rainfall patterns. It is unclear why this is as both methods included elevation in the interpolation, although fitting a spline to a national dataset rather than a State based dataset may have affected the topographic fit in some areas. The additional record length at many sites is also likely to have had an impact.

Examples of changes for Tasmania

To explore the changes for Tasmania in more detail, a selection of four catchments and four point locations was made. The details of these are summarised in Table 2. These locations represent different climatologies around the State. For the catchment, the latitude and longitude refers to the catchment centroid.

Table 2: Metadata for selected catchments and locations in Tasmania

Location	Type	Latitude	Longitude	Area (km^2)
Mersey	Catchment	-41.5585	146.3197	1917
Upper Derwent	Catchment	-42.2530	146.4324	3527
South Esk	Catchment	-41.6407	147.7350	3347
Little Swanport	Catchment	-42.3440	147.7629	887
Hobart	Point	-42.8897	147.3278	n/a
Launceston Airport	Point	-41.5492	147.2144	n/a
St Helens	Point	-41.3381	148.2792	n/a
Strathgordon	Point	-42.7681	146.0461	n/a

Rare design rainfall estimates were extracted for the one and three day durations for 1 in 200 and 1 in 2000 AEP. The two standard durations selected relate to the general time of concentration for the catchments in Tasmania. The CRCFORGE point and catchment estimates were extracted from FORGE Viewer Version 1.1, developed by Survey & Geographic Information Services Department within Hydro Tasmania. The new IFDs were extracted from the grids underlying the IFD website.

The new rare design rainfall tool available on the Bureau of Meteorology website (Bureau of Meteorology, 2017) returns the value directly from the underlying grid cell with no interpolation; therefore any points located within the same grid cell will have the same rare design rainfall values. The point rainfall extracted from Tasmanian FORGE Viewer is interpolated using an inverse distance weighting method based on the neighbouring points from the underlying 0.025 degree grid. Neighbouring points can therefore have different rare design rainfall values, particularly in areas with high spatial variability. For comparison purposes the catchment values are taken as catchment averages of the rare design rainfall grids as a way of accounting for the spatial variation of the rare design rainfalls across the catchment. This is the method suggested in Jordan et. al. (2016) and previously in Canterford et. al. (1998).

The ARF were also calculated for the catchments, using the methods current at the time. For the CRCFORGE, this was the method developed by Siriwarden and Weimann (1996) for Victorian catchments, as none were available specifically for Tasmania. The equation developed is a function of catchment area in square kilometres, storm duration in hours and average recurrent interval as a percent. Grayson et. al. (1996) note that there are statistically significant differences across Victoria, although on average the ARF values are up to 10% lower than those calculated for similar areas in the United States by the National Weather Service (Nathan and Weinmann, 1998). It was decided that for this comparison, these Victorian values would be more representative of the Tasmania conditions.

For the new rare design rainfalls, the revised ARF equation was used, as described in Podger et. al. (2015). For durations from one day to seven days a single equation has been derived across Australia, with nine regional coefficients used to adjust for spatial variability. For Tasmania, the regional coefficients are included here in Table 3. The ARF calculated using the method in Siriwarden and Weimann (1996), were less than those calculated using the revised method, although the difference generally reduced with longer durations and lower probabilities.

Table 3: ARF coefficients for Tasmania for Durations 24 to 168 hours

Region	a	b	c	d	e	f	g	h	i
Tasmania	0.0605	0.347	0.2	0.283	0.00076	0.347	0.0877	0.012	-0.00033

Tables 4 to 7 summarise the differences for the Tasmanian selected catchments and locations in Table 2. These results reinforce the spatial differences from the maps in Figure 1. The spatial variability across the State is similar to the differences in the IFD probability range found in Jolly et. al. (2015).

The new rare design rainfalls are significantly higher around the elevated areas in north east of Tasmania, shown by the changes for the South Esk catchment and the township of St Helens. The new rare design rainfalls are generally less than the CRCFORGE estimates for the western districts across all durations and probabilities, particularly for the rarer or less frequent events. This is also the case for the midlands region.

Table 4: Design rainfalls for 1 day, 1 in 200 AEP

Catchment	CRCFORGE estimates			IFD2016 rare design rainfalls			Change (%)
	ARF	IFD (mm)	Rainfall (mm)	ARF	IFD (mm)	Rainfall (mm)	
Mersey	0.803	193.0	155.0	0.853	188.1	160.5	**3.6**
Upper Derwent	0.772	148.5	114.7	0.823	148.6	122.3	**6.6**
South Esk	0.775	191.5	191.5	0.826	206.4	170.4	**14.8**
Little Swanport	0.837	210.0	210.0	0.881	171.9	151.4	**-13.8**
Hobart	n/a	155.7	155.7	n/a	151	151	**-3.0**
Launceston Airport	n/a	105.2	105.2	n/a	104	104	**-1.1**
St Helens	n/a	220.3	220.3	n/a	266	266	**20.7**
Strathgordon	n/a	208.8	208.8	n/a	183	183	**-12.4**

Table 5: Design rainfalls for 1 day, 1 in 2000 AEP

Catchment	CRCFORGE estimates			IFD2016 rare design rainfalls			Change (%)
	ARF	IFD (mm)	Rainfall (mm)	ARF	IFD (mm)	Rainfall (mm)	
Mersey	0.788	287.6	226.6	0.831	283.8	235.7	**4.0**
Upper Derwent	0.753	216.6	163.1	0.797	216.9	173.0	**6.0**
South Esk	0.756	292.9	221.5	0.801	294.6	235.9	**6.5**
Little Swanport	0.826	317.0	261.7	0.860	238.3	204.8	**-21.7**
Hobart	n/a	271.4	271.4	n/a	216	216	**-21.4**
Launceston Airport	n/a	157.2	157.2	n/a	154	154	**-2.0**
St Helens	n/a	331.1	331.1	n/a	393	393	**18.7**
Strathgordon	n/a	317.0	317.0	n/a	270	270	**-14.8**

Table 6: Design rainfalls for 3 day, 1 in 200 AEP

Catchment	CRCFORGE estimates			IFD2016 rare design rainfalls			Change (%)
	ARF	IFD (mm)	Rainfall (mm)	ARF	IFD (mm)	Rainfall (mm)	
Mersey	0.871	274.5	239.2	0.882	262.0	231.1	**-3.4**
Upper Derwent	0.845	226.4	191.3	0.854	229.8	196.2	**2.6**
South Esk	0.847	267.0	226.3	0.857	298.2	255.4	**12.9**
Little Swanport	0.899	297.0	267.0	0.908	238.5	216.5	**-19.0**
Hobart	n/a	248.0	248.0	n/a	197	197	**-20.6**
Launceston Airport	n/a	139.4	139.4	n/a	161	161	**15.5**
St Helens	n/a	318.4	318.4	n/a	351	351	**10.2**
Strathgordon	n/a	325.4	325.4	n/a	269	269	**-17.3**

Table 7: Design rainfalls for 3 day, 1 in 2000 AEP

Catchment	CRCFORGE estimates			IFD2016 rare design rainfalls			Change (%)
	ARF	IFD (mm)	Rainfall (mm)	ARF	IFD (mm)	Rainfall (mm)	
Mersey	0.848	408.2	346.0	0.860	385.8	331.9	**-4.1**
Upper Derwent	0.815	344.1	280.3	0.827	331.5	274.1	**-2.2**
South Esk	0.818	382.6	312.9	0.830	425.1	352.9	**12.8**
Little Swanport	0.882	413.4	364.4	0.890	327.1	291.0	**-20.2**
Hobart	n/a	363.8	363.8	n/a	282	282	**-22.5**
Launceston Airport	n/a	206.9	206.9	n/a	195	195	**-5.8**
St Helens	n/a	457.1	457.1	n/a	523	523	**14.4**
Strathgordon	n/a	529.3	529.3	n/a	395	395	**-25.4**

Conclusions

The new design rainfalls, including the new rare design rainfalls, have been derived using an expanded database and a consistent, contemporary method and as such represent better estimates than the previous estimates. There are significant advantages to having a nationally consistent dataset for the design rainfalls across Australia, particularly in terms of comparisons and analysis of large catchments that overlap State boundaries. The new rare design rainfalls are available through the Bureau of Meteorology website, replacing the state-based CRCFORGE estimates. They can now be used seamlessly with the methods described in the ARR2016 guidelines for the estimation of very rare to extreme rainfall and floods.

The comparisons shown in this paper clearly indicate that the differences in the new rare design rainfall estimates vary with location, duration and probability, consistent with previous findings on the frequent and infrequent design rainfalls undertaken previously. It will be important to consider these changes in the context of the revised ARR2016 design guidelines. This will be of particular relevance to those involved in the assessment and design of large dams and associated infrastructure.

Future work

Currently the rare design rainfalls grids are only available for durations from one to seven days. While this range is suitable for design of dams and other infrastructure in larger catchments, there is other high risk and critical infrastructure located in smaller catchments with critical durations of less than one day. There is currently interim guidance provided in ARR 2016 to estimate subdaily rare design rainfalls using growth curve factors derived by Jordan et. al. (2005) using regional frequency analysis of standardised heavy rainfall bursts from ten long term Bureau pluviograph sites.

To complete the suite of design rainfalls for Australia, work is currently being undertaken by the Bureau of Meteorology to derive subdaily rare design rainfalls for the standard subdaily IFD durations. This work is based on a much larger rainfall database than previous studies, including the available quality controlled rainfall database and the associated regionalised design rainfall grids developed as part of the new IFDs

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