Comparison of catchment average rainfall IFD analysis to 2013 IFD and ARFs

Peter Stensmyr
Senior Engineer, WMA Water, Sydney, Australia
E-mail: stensmyr@wmawater.com.au

Mark Babister
Director, WMA Water, Sydney, Australia
E-mail: babister@wmawater.com.au

Abstract

As part of Australian Rainfall and Runoff (ARR) Revision Project 2: Spatial Patterns of Rainfall, a procedure for estimating catchment average design rainfall has been developed. The method uses an empirical approach based on 2D grid interpolation. All historic rainfall events are gridded at various durations for a given catchment. Annual Maxima Series of catchment average rainfall can then be constructed for each duration of interest, from which design rainfall quantiles can be derived on a catchment basis.

Using this method, sets of design rainfall quantiles were calculated for catchments in the Brisbane River basin as well as in the Hawkesbury-Nepean River basin. Corresponding design quantiles were also calculated using ARR2013 Intensity Frequency Duration (IFD) data and the currently recommended methods for deriving areal reduction factors. The quantiles were then compared to assess the advantages and shortcomings of the empirical approach; and to highlight any significant differences in design rainfall estimates between the two approaches.

1. INTRODUCTION

In a typical scenario, design rainfall is provided to practitioners on a point basis, using IFD data from the Bureau of Meteorology (BoM). For larger catchments, this point design rainfall requires translation to catchment design rainfall. Traditionally this is done by either averaging the point IFD values within the catchment or spatially distributing them and applying an Areal Reduction Factor (ARF). Both methods produce the same catchment average rainfall loading.

The ARF is applied to transform the point design rainfall to areal design rainfall. ARFs account for the fact that a rare rainfall event will not occur over the whole catchment simultaneously. Using an ARF makes it possible to account for a real physical phenomenon, but the way it is implemented is simply as a correction factor to adjust the design rainfall closer to the true value. It is a pragmatic approach that is not overly concerned with the underlying spatial and temporal pattern variability.

An alternative to the conventional is to determine catchment-specific IFDs using historical rainfall, in a similar way to how the IFDs are determined for a point location. An Annual Maxima Series of catchment average rainfall can be determined using historical rainfall data for the region. The Generalized Extreme Value (GEV) distribution can then be fitted to the Annual Maxima Series, from which IFD rainfall quantiles can be extracted at different probabilities. With this approach, there is no need for ARFs as the rainfall quantiles are spatial by nature.

The BoM 2013 IFDs, developed as part of the Australian Rainfall and Runoff (ARR) Revision Project 1, represent a significant update on the design rainfall input for flood estimation. For the Hawkesbury-Nepean catchment, the updated IFDs resulted in decreased design rainfall depths, which would have a significant impact on flood extents. As part of ARR Project 2: Spatial Patterns of Rainfall and the Hawkesbury-Nepean Flood Study, the approach described above was applied to independently verify and test the robustness of the updated IFD estimates. This initial verification produced results similar to the updated IFDs, and the method was subsequently applied, in a more comprehensive manner, to the Brisbane River catchment as well.

The catchment-based approach described in this study uses interpolated historical rainfall surfaces to determine catchment average rainfall, a method first developed for pluviograph data in a study for ARR on short duration ARFs (Stensmyr & Babister, 2013). This method can easily be adapted to use daily rainfall stations, for durations longer than 24 hours.

2. METHOD

2.1. Overview

The method for developing catchment design rainfall curves consists of the following main steps:

1. Convert pluviograph records to equivalent daily records (9am to 9am rainfall totals)
2. Interpolate a rainfall surface that covers the whole catchment of interest, for each day between 1887 and 2011 (where enough rainfall gauge data is available),
3. Use the grids created in step 2 to construct areal Annual Maximum Series for the catchments of interest,
4. Apply restricted to unrestricted rainfall conversion factor,
5. Fit the Generalised Extreme Value (GEV) distribution using L-Moments to each areal Annual Maximum Series and extract rainfall quantiles at different AEPs
6. Compare these rainfall quantiles to those calculated using BoM IFDs and the current recommended ARFs

The analysis was done for catchments in the Brisbane River and Hawkesbury-Nepean River basins. This method produces areal design rainfall estimates. The quantile estimates were then compared to catchment average IFDs created based on the conventional, using the BoM 2013 IFDs with Areal Reduction Factors as provided by the ARR Spatial Patterns of Rainfall project – Interim Report (SKM, 2013).

This is in contrast to the conventional, which uses the following steps:

1. Get point 2013 IFDs for all cells within the catchment from the BoM IFD website. The IFDs are provided at a 0.025 degree resolution, which is equal to around 6.25 km^2 per grid cell.
2. Calculate the average point IFD from all the point values.
3. Apply the appropriate ARF using equations varying by region, AEP, duration and catchment area (SKM, 2013).

2.2. Data

The Hawkesbury-Nepean and the Brisbane River basins where initially selected because the authors had access to the extensive rain gauge data sets of the BoM and local water authorities. Slight differences were found when this data set was compared to that used by the BoM for the IFD revision (Green, 2012). To aid comparison to ARR and to eliminate rainfall data as a source of difference the results presented in this paper are based on the BoM IFD data set as used in ARR Project 2. For the Hawkesbury-Nepean basin only daily gauges were used while for more in depth study on the Brisbane River Basin, pluviographs were also used. In order to fit within the framework, these were aggregated to daily rainfall totals (9 am – 9 am). Figure 1 shows the distribution of gauges for the Brisbane and Hawkesbury-Nepean River basins. In both cases, a buffer of 0.25 degrees was used for the initial station selection, with some extra stations outside the buffer also being included, due to data availability. Table 1 below shows the number of stations used to interpolate the grids in each basin.

Table 1. Basin Details

Basin	Daily Read	Pluviograph	Total
Brisbane	326	37	363
Hawkesbury-Nepean	347	-	347

In total, six catchments were considered, three in each basin. Table 2 below provides details for each catchment.

Table 2. Catchment Details

Basin	Catchment	Area (km^2)
Hawkesbury-Nepean	Warragamba Dam	9000
	Nepean River	2200
	Catchment to Penrith	11800
Brisbane	Wivenhoe Dam	7000
	Brisbane River at Bremer Confluence	12600
	Bremer, Warrill and Purga Confluence	1800

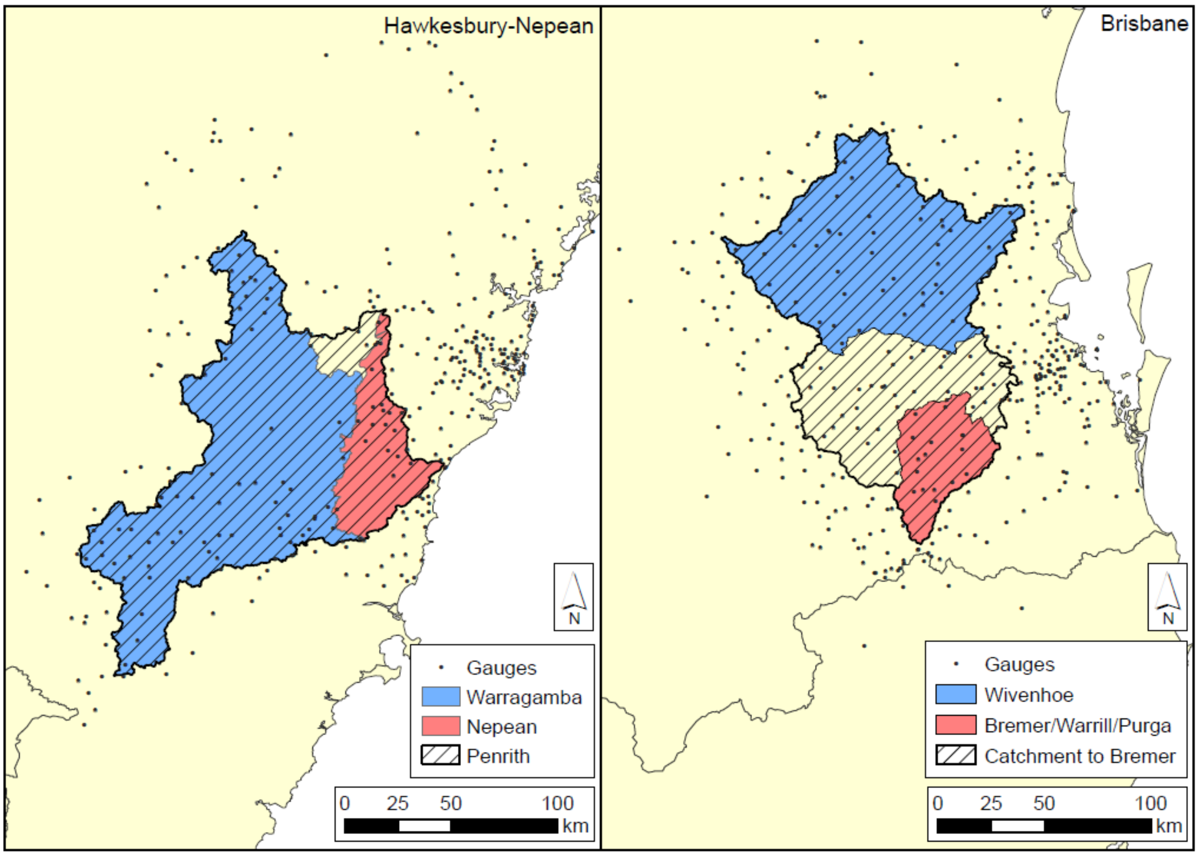

Figure 1 Available Gauges

The ARR 2013 IFDs used data from gauges operated by BoM as well as by external water agencies (Green, 2012). For the Hawkesbury-Nepean River basin, only daily data gauges were used. The Brisbane River analysis used BoM daily gauge data as well as pluviograph data operated by BoM and state agencies. Both regions have daily gauge networks available in the 1800s; the decision was made to start the analysis at 1871 for the Hawkesbury-Nepean River basin and at 1887 for the Brisbane River basin.

The included pluviographs were converted to equivalent 9 am to 9 am daily gauges. For days where the pluviograph data contained no error codes, all recorded rainfalls for the day were totalled. For days with error codes, the data was included if the error was a short period of missing or accumulated data, and otherwise excluded.

2.3. Grid Interpolation

Grids were interpolated for all dates where there were at least 10 stations operated, and the interpolated grid covered the whole catchment. For the Brisbane River basin, grids were interpolated for 1887-2011 and for the Hawkesbury-Nepean River basin, 1871-2011. Grids will be of lower quality when there are fewer stations in operation. For the initial period in the late 1800s, there were considerably less stations operating, which meant that these grids were of lower quality than later ones.

The Natural Neighbours algorithm was used as the interpolation method (Sibson, 1981). This algorithm builds on the traditional Thiessen Polygon based method for weighting rainfall, but provides a spatial pattern as well as weighted catchment rainfall. Previous work has indicated that Natural Neighbours provides good quality estimates while being fast and giving predictable results (Stensmyr & Babister, 2014). It has been suggested that a spline-based interpolation method is the most appropriate for rainfall (Umakhanthan, 2002; Luk & Ball, 1996). In this case, this was deemed impractical, as it would require a degree of quality control on each grid that was not possible given the size of the dataset. Another advantage of Natural Neighbours is that it preserves totals across durations; the sum of the polygon averages for five interpolated grids is equal to the sum of a single interpolated grid of the point data sums. This property makes it possible to only generate grids of the shortest possible duration, and then aggregate this data to longer durations at a later stage in the process. Since the grid interpolation step is the most computationally expensive part of the analysis, this can be a significant optimization.

2.4. Catchment Average Rainfall

For each basin, the catchment average rainfall is determined for each catchment, from the interpolated rainfall grid for that day. These values are then used to construct an Annual Maxima Series of rainfall for each catchment and duration. Since the data resolution is 24 hours, which is similar to the durations of interest, the Annual Maxima Series rainfall depths have to be converted from restricted to unrestricted rainfall. This is done by multiplying the rainfall by a duration-dependent factor. This conversion factor accounts converts between the annual maximum observed rainfall for a given duration and the actual annual maximum rainfall that occurred. It can be a significant adjustment when the duration of interest is close to the data resolution. The adopted conversion factors were based on work carried out as part of the ARR IFD revision project (Green, 2012). Other studies have shown similar conversion factors (Institute of Hydrology, 1999). Table 3 below shows the adopted values.

Table 3. Restricted to Unrestricted Rainfall Conversion Factors

Duration (days)	Factor
1	1.15
2	1.11
3	1.07
4	1.05
5	1.04
6	1.03
7	1.02
8	1.01
9	1.00
10	1.00

2.5. IFD Curves

A GEV distribution was fitted to each Annual Maxima Series, using L-Moments (Hosking & Wallis, 1990). From the fitted distribution, rainfall quantiles were extracted for the 1 in 2 and 1 in 1000 AEPs. However, it should be noted that quantiles rarer than the 1 in 100 AEP should be treated with caution, due to the length of the data (125 years for Brisbane, 137 for Hawkesbury-Nepean). The catchment rainfall quantiles were then compared to catchment averages extracted from the BoM 2013 IFD database with Areal Reduction Factors applied as per the Interim ARR ARFs (SKM, 2013).

3. RESULTS

Results for both basins are provided in Figure 2 and Figure 3 below. The figures show the derived catchment average design rainfall compared to the standard approach. Results are given for the 1, 3 and 5 day durations for the Brisbane River catchments, and for the 3 day duration for the Hawkesbury-Nepean catchments. The results for the 3 day duration are also summarised in Table 4 below, including percentage differences between the two methods.

The catchment average derived IFD produced very similar estimates to the catchment average BoM 2013 IFD with areal reduction factors applied. The catchment average IFD tends to be higher than the 2013 IFD for shorter durations (1-2 days) and lower for longer durations (5-7 days). A possible cause is that the restricted to unrestricted conversion factor may be too high for shorter durations. The factor is designed for point data, not spatially averaged data, and so it may overestimate the fraction of the total rainfall that is missed when using a fixed window. Accurately estimating the conversion factor is most important for the 1 day duration, which might be why the discrepancy between the two methods tends to be largest there.

For the Nepean River catchment the match is poor at rarer AEPs. It seems likely that both smaller catchments and larger rainfall gradients tend to produce worse estimates. These factors both mean that it is more important to get the rainfall surface correct, to obtain high quality catchment average estimates. For a larger catchment with smaller gradient, it is easier to get the correct answer.

The analysis was undertaken from the year 1887 as it was the first year with more than ten gauges in operation across the area of interest. However, ten gauges are not considered adequate to represent a rainfall surface across such a large area. In the late 1800s several of the largest floods on record occurred on the Brisbane River. Therefore, it was decided to include these events in the analysis. A number of these gauges are located outside the catchment boundary; as a result, these rainfall surfaces are of significantly lower quality than those from later years. This will have some influence on the quality of the IFD estimates.

Table 4. Design Rainfall Depth Comparison (72 hour duration)

Catchment	AEP	BoM 2013 IFD (mm)	Catchment IFD (mm)	Difference
Warragamba	10%	161	164	2%
	1%	257	253	-2%
Nepean	10%	263	249	-5%
	1%	452	408	-10%
Penrith	10%	176	179	2%
	1%	282	282	0%
Wivenhoe	10%	208	211	1%
	1%	360	386	7%
Bremer/Warrill/Purga	10%	205	197	-4%
	1%	353	340	-4%
Catchment to Bremer	10%	197	195	-1%
	1%	338	326	-4%

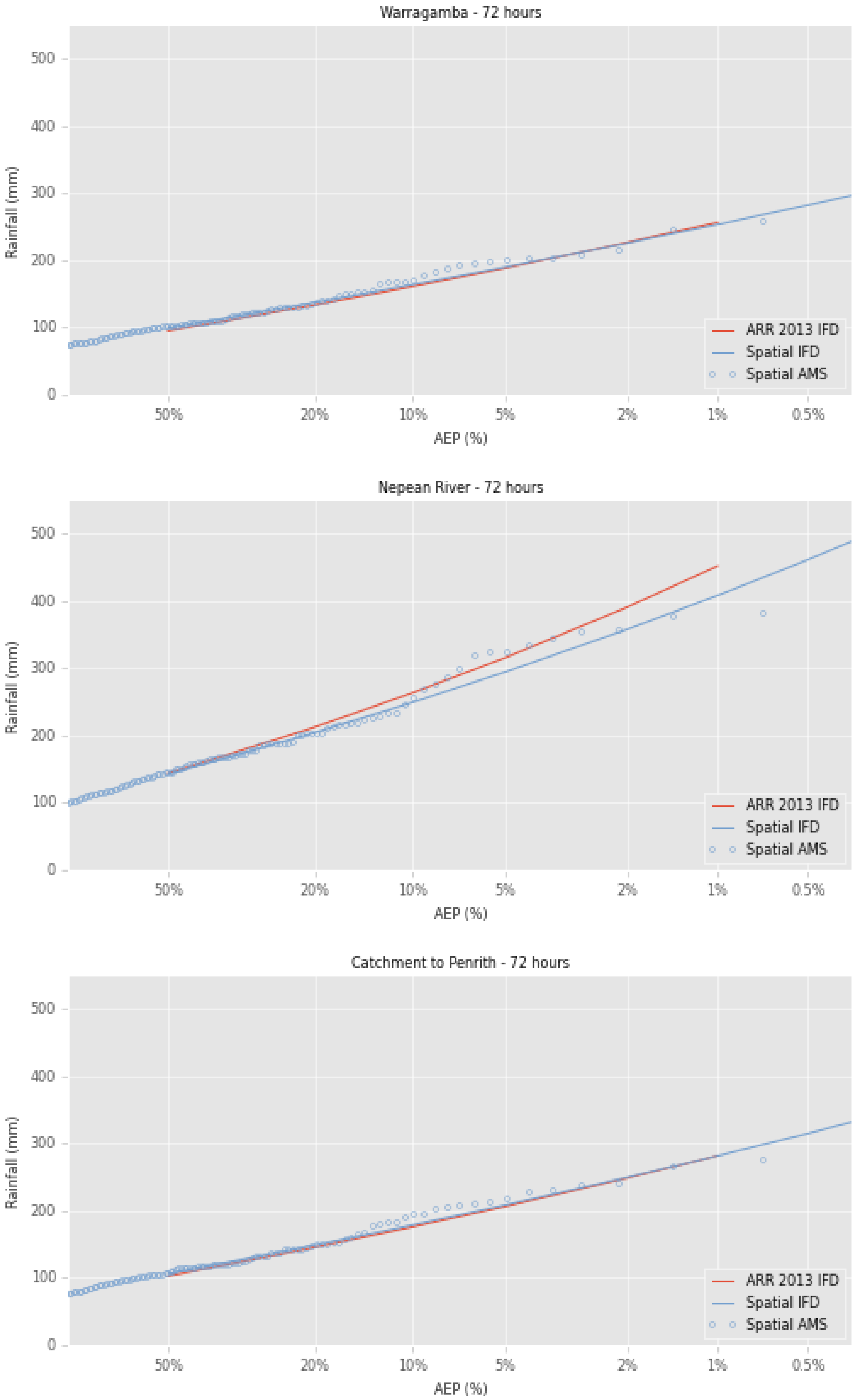

Figure 2 Hawkesbury-Nepean Catchments IFD Comparison.

Note: ARR 2013 IFD = BOM 2013 IFD x ARF

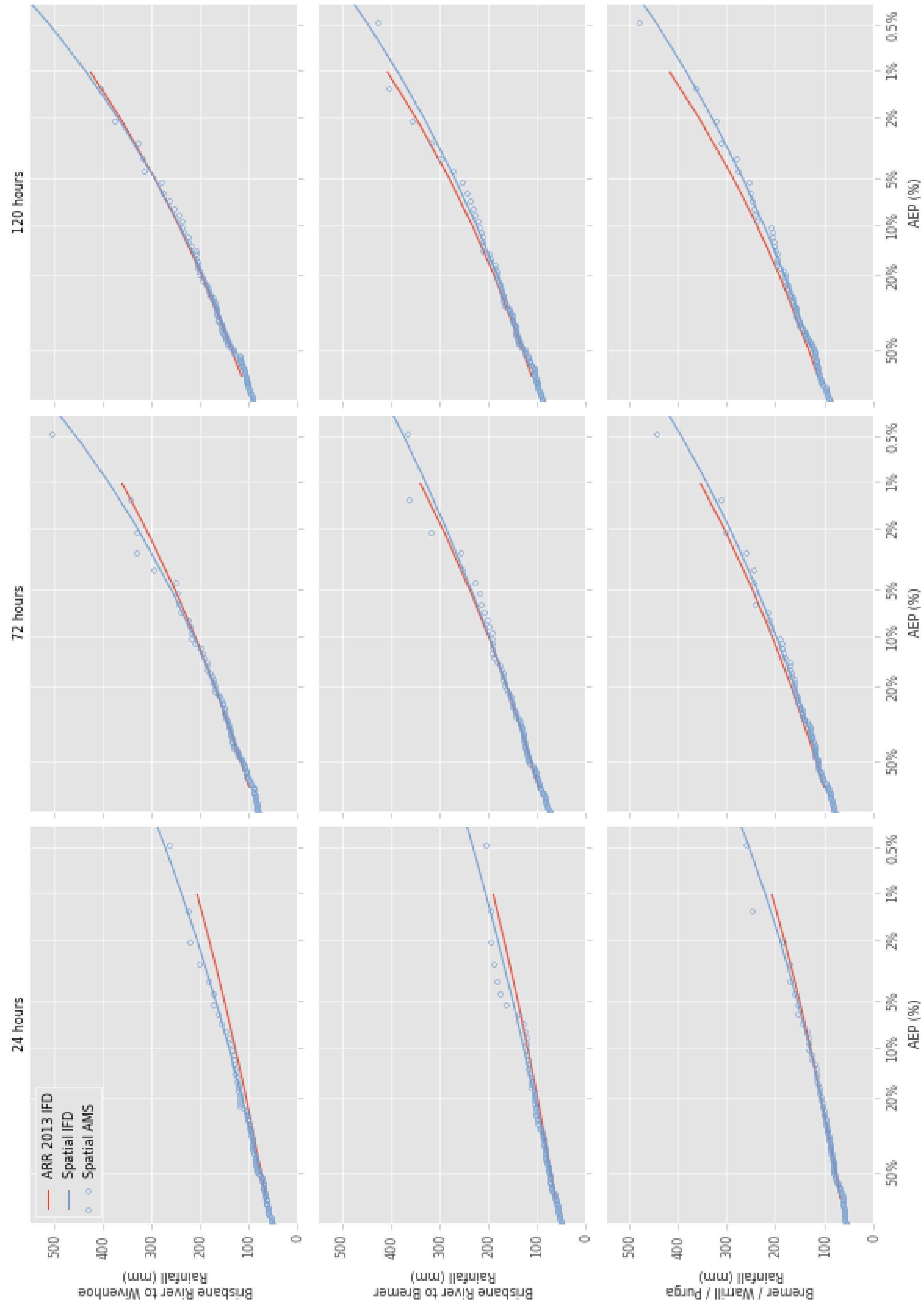

Figure 3 Brisbane River Catchments IFD Comparisons

Note: ARR 2013 IFD = BOM 2013 IFD x ARF

4. CONCLUSIONS

The calculated catchment average IFDs are in the majority cases similar to the BoM 2013 IFDs with appropriate areal reduction factors. Generally, the catchment average IFD estimates are higher than the BoM 2013 estimates for shorter durations and lower for longer durations. The factor used to convert from restricted to unrestricted rainfall is derived for point data and may not be directly translatable to spatial data for 1 to 2 day durations. The results are very similar when considering how different the methods are, and can be interpreted as a very strong endorsement of the traditional design approach with 2013 IFDs and ARFs.

Further research into determining the causes behind the differences between the methods for smaller catchments is recommended. It is likely to be a combination of gauge density and rainfall gradient, but the relationship is unknown. A possible improvement to the method is to use regional statistical parameters (GEV shape and scale) derived by BoM with the spatially derived mean.

5. ACKNOWLEDGEMENTS

The initial components of this work was carried out for Sydney Catchment Authority and the Brisbane River Catchment flood study. ARR for providing access to the BoM database to allow a more pure comparison.

6. REFERENCES

Green, J., Xuereb, K., Johnson, F., Moore, G., The, C. (2012*), The Revised Intensity-Frequency-Duration (IFD) Design Rainfall Estimates for Australia – An Overview*, 34th Hydrology and Water Resources Symposium, Sydney, Australia, pp. 808-815

Hosking, J.R.M. and Wallis, J.R. (1990), *Regional frequency analysis using L-moments,* (RC 15658), IBM Research Division, Yorktown Heights, New York

Institute of Hydrology (1999*). Flood Estimation Handbook*, Institute of Hydrology, Wallingford, United Kingdom

Luk, K.C. and Ball, J.E. (1996), *Application of GIS modelling of the spatial distribution of rainfall*, Research Report No. 191, Water Research Laboratory, University of New South Wales, Manly Vale, Australia

Sibson, R. (1981*), A Brief Description of Natural Neighbor Interpolation*, in “Interpolating Multivariate Data”, John Wiley & Sons, New York, pp. 21-36.

SKM (2013), *Australian Rainfall and Runoff Revision Project 2: Spatial patterns of Rainfall: Collation and Review of Areal Reduction Factors from Applications of the CRC-FORGE Method in Australia*, Institution of Engineers Australia

Stensmyr, P. and Babister, M. (2014), *Short Duration Areal Reduction Factors for Greater Sydney,* 35th Hydrology and Water Symposium, Perth, Australia, pp. 581-588

Umakhanthan (2002), K., *Estimation of the Spatio-Temporal Heterogeneity of Rainfall and its Importance towards Robust Catchment Simulation, within a Hydroinformatic Environment*, Doctoral Dissertation, School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia