Australian Rainfall & Runoff

Revision Projects

PROJECT 2

Spatial Patterns of Rainfall

Short Duration Areal Reduction Factors

STAGE 3 REPORT

P2/S3/019

SEPTEMBER 2015

Australian Government

ENGINEERS AUSTRALIA
Water Engineering

AUSTRALIAN RAINFALL AND RUNOFF
REVISION PROJECT 2: SPATIAL PATTERNS OF RAINFALL

SHORT DURATION AREAL REDUCTION FACTORS

STAGE 3 REPORT

SEPTEMBER, 2015

Project Project 2: Spatial Patterns of Rainfall	**ARR Report Number** P2/S3/019
Date 16 September 2015	**ISBN** 978-085825-9614
Contractor WMAwater Pty Ltd	**Contractor Reference Number** 28060-17
Authors Peter Stensmyr, Mark Babister	**Verified by**

ACKNOWLEDGEMENTS

This project was made possible by funding from the Federal Government through the Department of Climate Change. This report and the associated project are the result of a significant amount of in kind hours provided by Engineers Australia Members.

ENGINEERS
AUSTRALIA
Water Engineering

Contractor Details

WMA Water
Level 2, 160 Clarence Street
Sydney NSW 2000

Tel: (02) 9299 2855
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

wma water

FOREWORD

ARR Revision Process

Since its first publication in 1958, Australian Rainfall and Runoff (ARR) has remained one of the most influential and widely used guidelines published by Engineers Australia (EA). The current edition, published in 1987, retained the same level of national and international acclaim as its predecessors.

With nationwide applicability, balancing the varied climates of Australia, the information and the approaches presented in Australian Rainfall and Runoff are essential for policy decisions and projects involving:

- infrastructure such as roads, rail, airports, bridges, dams, stormwater and sewer systems;
- town planning;
- mining;
- developing flood management plans for urban and rural communities;
- flood warnings and flood emergency management;
- operation of regulated river systems; and
- prediction of extreme flood levels.

However, many of the practices recommended in the 1987 edition of ARR now are becoming outdated, and no longer represent the accepted views of professionals, both in terms of technique and approach to water management. This fact, coupled with greater understanding of climate and climatic influences makes the securing of current and complete rainfall and streamflow data and expansion of focus from flood events to the full spectrum of flows and rainfall events, crucial to maintaining an adequate knowledge of the processes that govern Australian rainfall and streamflow in the broadest sense, allowing better management, policy and planning decisions to be made.

One of the major responsibilities of the National Committee on Water Engineering of Engineers Australia is the periodic revision of ARR. A recent and significant development has been that the revision of ARR has been identified as a priority in the Council of Australian Governments endorsed National Adaptation Framework for Climate Change.

The update will be completed in three stages. Twenty one revision projects have been identified and will be undertaken with the aim of filling knowledge gaps. Of these 21 projects, ten projects commenced in Stage 1 and an additional 9 projects commenced in Stage 2. The remaining two projects will commence in Stage 3. The outcomes of the projects will assist the ARR Editorial Team with the compiling and writing of chapters in the revised ARR.

Steering and Technical Committees have been established to assist the ARR Editorial Team in guiding the projects to achieve desired outcomes. Funding for Stages 1 and 2 of the ARR revision projects has been provided by the Federal Department of Climate Change and Energy Efficiency. Funding for Stages 2 and 3 of Project 1 (Development of Intensity-Frequency-Duration information across Australia) has been provided by the Bureau of Meteorology.

Project 2: Spatial Patterns of Design Rainfall

Rainfall estimates from IFD relationships are applicable strictly only to a single point and not to a wider area such as a catchment. However, where the catchment area is small, the point IFD relationships is taken to be representative of the areal IFD relationship. For this purpose, a small catchment would be defined as being less than 4km^2. For larger areas, it is unrealistic to assume that the same intensity rainfall will occur over the entire area and reductions in the rainfall intensity are made. Unfortunately, at present there is limited information available regarding values for the areal reduction factor (ARF). Due to this, Canterford et al. (1987) recommended the use of areal reduction factors developed by the US National Weather Service (NOAA, 1980) for the Chicago region as being appropriate for all regions of Australia except for the inland regions where the recommendation is to use areal reduction factors developed for Arizona (NOAA, 1984). Hence the ARFs currently recommend for use in Australia were not defined from Australian data. Since that recommendation, Srikanthan (1995), Siriwardena and Weinmann (1996) and Catchlove and Ball (2003) have investigation ARFs using Australian data for different regions of the country. These studies have highlighted the inappropriateness of American ARFs for Australian conditions.

In addition to the need to estimate relationships between point and spatial rainfall there is a need to estimate rainfall variation over a catchment for historical storm events. This variation occurs as a result of catchment topography, storm movement, etc. A comparison of alternative approaches for estimation of the spatial variation of rainfall has been presented by Ball and Luk (1998) who showed that these alternative approaches have varying accuracy. A subsequent study by Umakhanthan and Ball (2005) highlighted the importance of rainfall models for simulation of flows from a catchment. At present, however, no guidance is presented in Australian Rainfall and Runoff to aid practioners in the spatial modelling of rainfall over a catchment for either historical or design events.

Mark Babister
Chair Technical Committee for
ARR Research Projects

Assoc Prof James Ball
ARR Editor

ARR REVISION PROJECTS

The 21 ARR revision projects are listed below:

ARR Project No.	Project Title	Starting Stage
1	Development of intensity-frequency-duration information across Australia	1
2	**Spatial patterns of rainfall**	**2**
3	Temporal pattern of rainfall	2
4	Continuous rainfall sequences at a point	1
5	Regional flood methods	1
6	Loss models for catchment simulation	2
7	Baseflow for catchment simulation	1
8	Use of continuous simulation for design flow determination	2
9	Urban drainage system hydraulics	1
10	Appropriate safety criteria for people	1
11	Blockage of hydraulic structures	1
12	Selection of an approach	2
13	Rational Method developments	1
14	Large to extreme floods in urban areas	3
15	Two-dimensional (2D) modelling in urban areas.	1
16	Storm patterns for use in design events	2
17	Channel loss models	2
18	Interaction of coastal processes and severe weather events	1
19	Selection of climate change boundary conditions	3
20	Risk assessment and design life	2
21	IT Delivery and Communication Strategies	2

ARR Technical Committee:

Chair: Mark Babister, WMAwater

Members: Associate Professor James Ball, Editor ARR, UTS

Professor George Kuczera, University of Newcastle

Professor Martin Lambert, University of Adelaide

Dr Rory Nathan, University of Melbourne

Dr Bill Weeks

Associate Professor Ashish Sharma, UNSW

Dr Bryson Bates, CSIRO

Steve Finlay, Engineers Australia

Related Appointments:

ARR Project Engineer: Monique Retallick, WMAwater

ARR Admin Support: Isabelle Testoni, WMAwater

TABLE OF CONTENTS

List of Figures

List of Tables

1. Introduction

The majority of studies on Areal Reduction Factors (ARF) conducted in Australia have been based on daily rainfall records (Srikanthan, 1995; Siriwardena & Weinmann, 1996) and are not directly applicable to rainfall durations less than 18 hours. As part of the update of Australian Rainfall and Runoff (ARR), SKM (2013) collated and reviewed the Areal Reduction Factor (ARF) methods recommended in Australia by the CRC-FORGE projects. The report collated both long and short duration equations. However, the short duration ARFs recommended by SKM (2013) are qualified as being interim, with further research recommended. Stensmyr & Babister (2013) undertook an initial exploratory study on short duration ARFs for the Greater Sydney region, which showed promising results consistent with those in SKM (2013), and recommended further investigation on other data rich areas.

This study builds on the methodology developed in Stensmyr & Babister (2013), and expands the study areas to also include Greater Brisbane and Greater Melbourne. This study also investigates the regional dependency of ARFs. The methodology developed by Stensmyr & Babister (2013) was updated to improve the quality of the analysis. In light of the changes to the methodology, Greater Sydney was reanalysed. This also ensures the results between regions are directly comparable.

2. Method

2.1. Overview

The aim of this study was to derive short duration ARF relationships for different regions of Australia. The methodology adopted for the study to derive the ARF consists of the following steps:

- Find all significant historical rainfall (point and areal),
- Spatially interpolate rainfall surfaces for the historical rainfall,
- Calculate point and average areal rainfall for theoretical circular catchments,
- Fit a Generalised Extreme Value (GEV) distribution to an Annual Maximum Series (AMS) of point and areal rainfall, and
- Calculate the ARF for a given site, catchment area, Annual Exceedance Probability (AEP) and duration by extracting point and areal rainfall quantiles for the gauge and theoretical catchment, and
- Aggregate the ARFs on a case basis (one ARF per area/AEP/duration combination) as the median ARF of a set of ARFs from catchments in the region

This is the methodology that was used in the previous study (Stensmyr & Babister, 2013) to derive ARFs for Greater Sydney. This study has adopted the same process, with some minor adjustments and improvements, to the regions of Greater Sydney, Brisbane and Melbourne. The following sections contain a short description of the process, with any changes to the methodology noted and described. For more detailed descriptions, refer to the previous study (Stensmyr & Babister, 2013).

2.2. Data

The pluviograph data used in this study was provided by the Bureau of Meteorology (BoM). Pluviograph data was available for stations operated by BoM as well as external data providers.

Figure 1 to Figure 3 below show the geographical distribution of pluviographs in the three regions. Figure 4 to Figure 6 below show the number of gauges available each year for the three regions.

Table 1 to Table 3 below show the distribution of gauge ownership for each region. Table 4 summarises the number of stations available in each region.

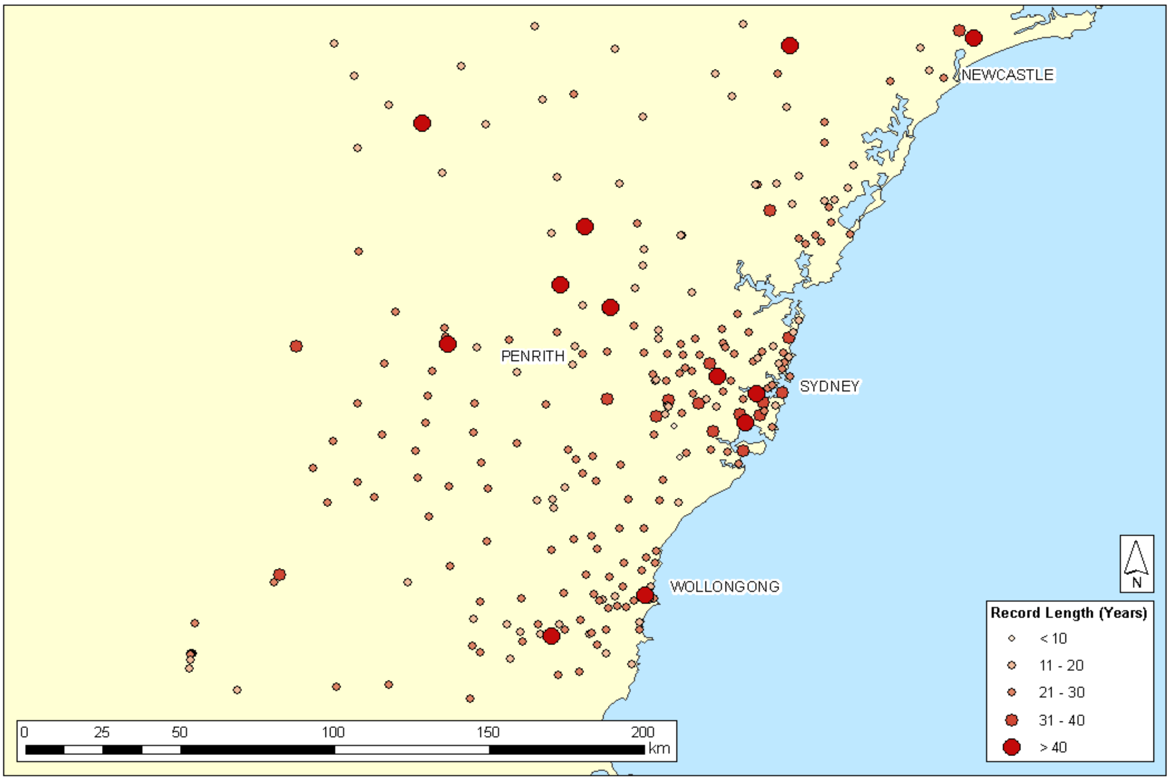


Figure 1: Distribution of Pluviographs (Sydney)

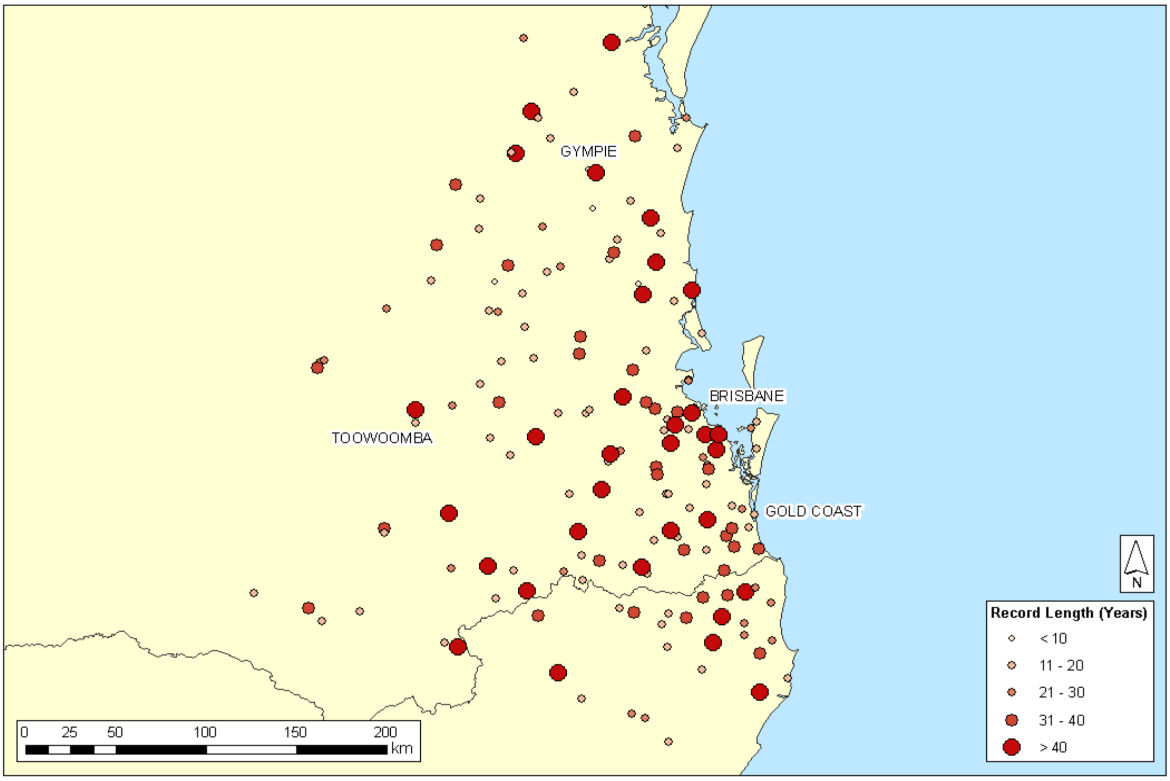


Figure 2: Distribution of Pluviographs (Brisbane)

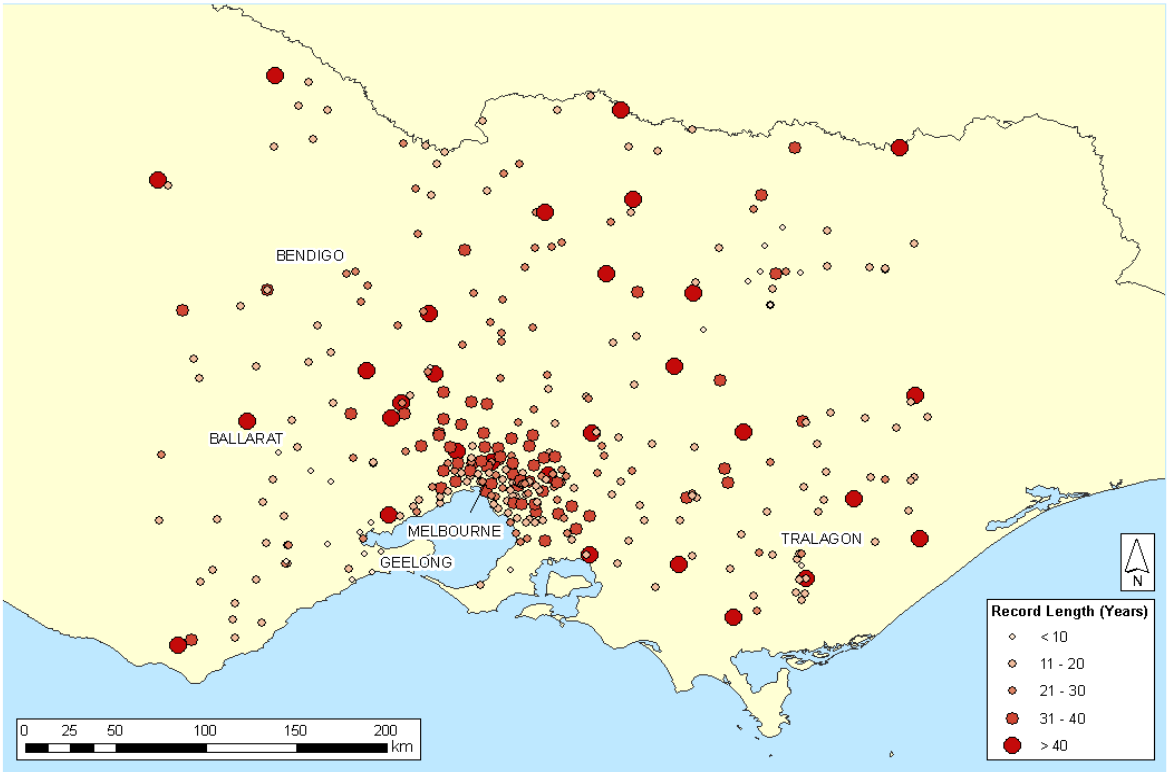


Figure 3: Distribution of Pluviographs (Melbourne)

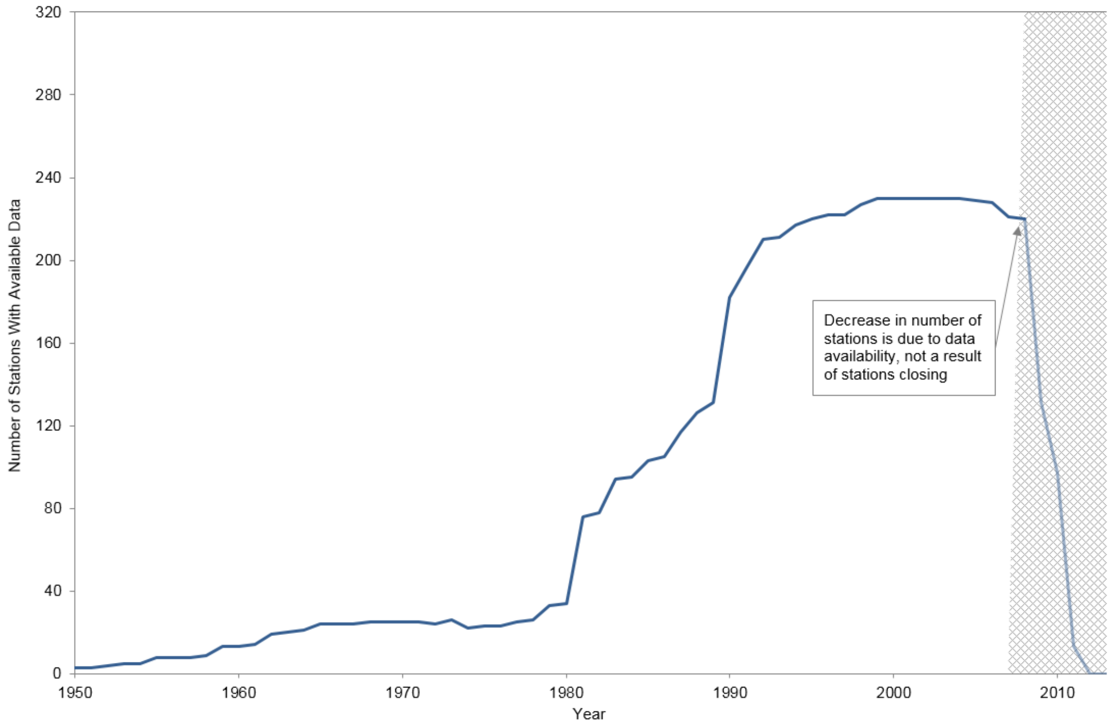


Figure 4: Data Availability over Time (Sydney)

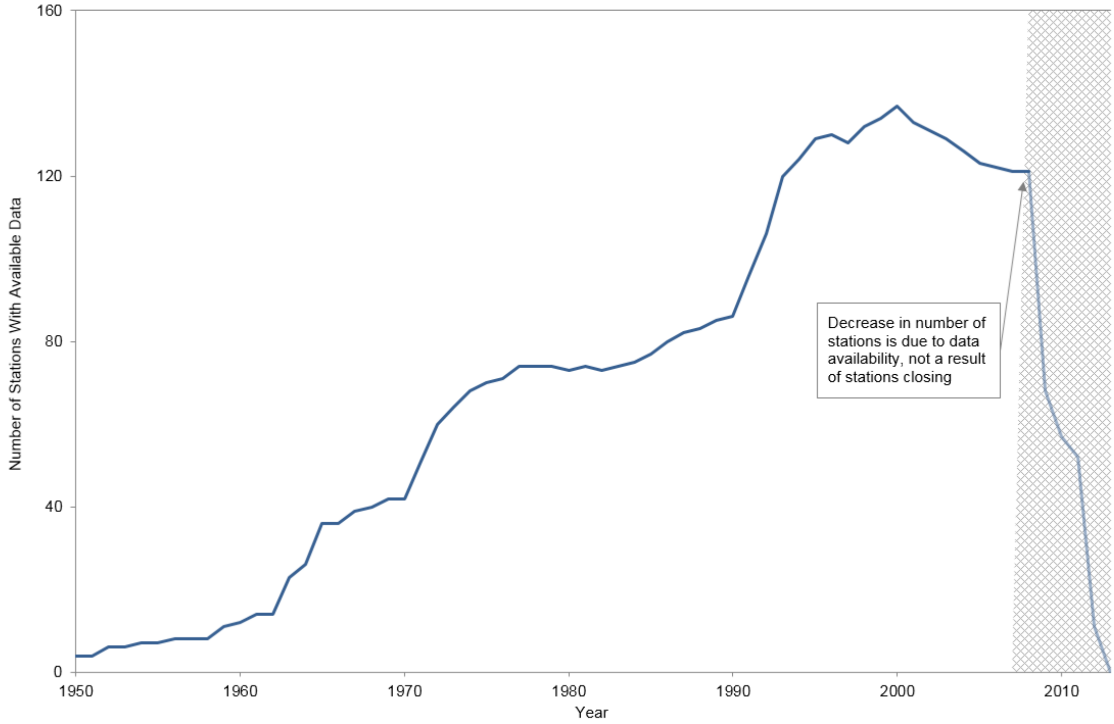


Figure 5: Data Availability over Time (Brisbane)

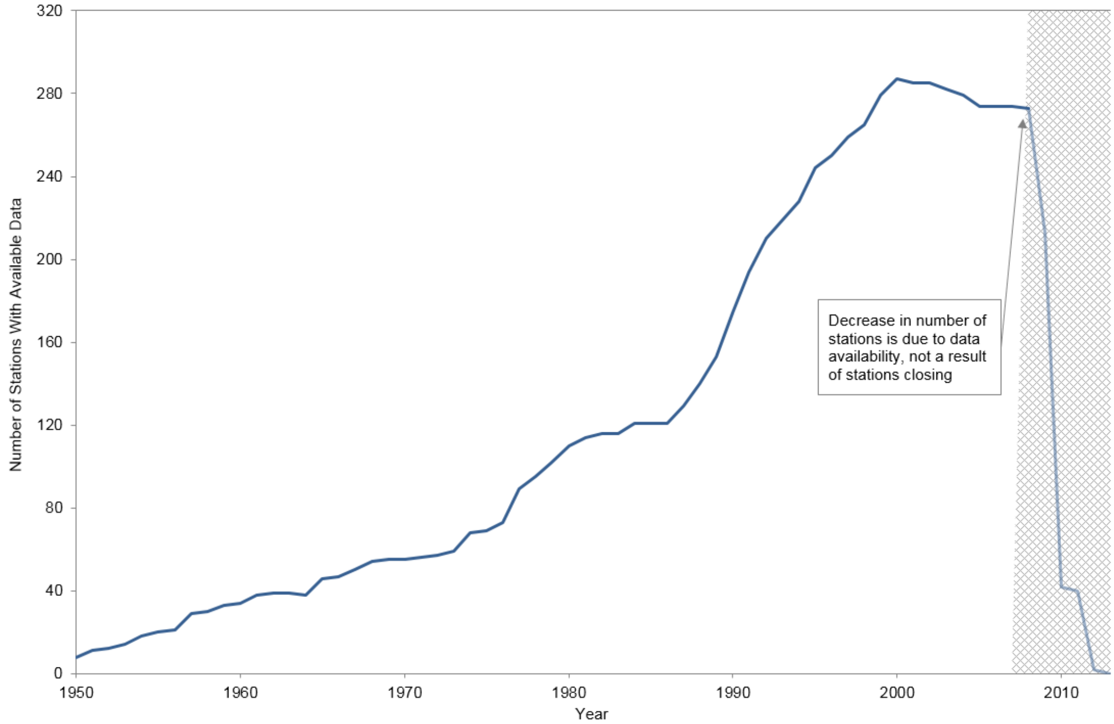


Figure 6: Data Availability over Time (Melbourne)

Table 1: Distribution of Gauge Ownership (Sydney)

Owner	Number of Stations
Bureau of Meteorology	37
Department of Commerce	39
Department of Water and Energy	11
Sydney Catchment Authority	83
Sydney Water Corporation (Sydney Water)	80

Table 2: Distribution of Gauge Ownership (Brisbane)

Owner	Number of Stations
Bureau of Meteorology	99
Department of Commerce (NSW)	5
Department of Natural Resources and Water	56
Department of Water and Energy (NSW)	6

Table 3: Distribution of Gauge Ownership (Melbourne)

Owner	Number of Stations
Bureau of Meteorology	88
Barwon Region Water Corporation (Barwon Water)	7
Central Highlands Water	3
Department of Sustainability and Environment	111
Gippsland and Southern Rural Water Corporation (Southern Rural Water)	9
Melbourne Water Corporation (Melbourne Water)	123

Table 4: Total Number of Stations per Region

Region	Number
Sydney	250
Brisbane	166
Melbourne	341

2.3. Choosing Stations

The region extents were chosen based on the density of the pluviograph network, as the methodology requires a significant pluviograph density to produce meaningful results. As a consequence, the region for Melbourne is significantly larger than the other regions, extending to the top of Victoria. The Brisbane region extends further along the coast to include more gauges. There is a trade-off, in that increasing the size of the region to include additional gauges also means increased computational complexity and storage requirements. Since it is always possible to determine the final ARFs from a smaller region than the one selected, the choice of where to draw the region boundary generally erred on the side of larger regions. The Sydney region boundary is the same as in the previous study.

2.4. Finding Significant Events

Some improvements were made to the methodology with regards to identifying significant historic rainfall for gridding. In the previous study, the time of the 3 largest independent events at each pluviograph were identified for each duration. These times were then buffered three hours in each direction to create the list of timesteps to include in the grid interpolation process. This was done because it was not viable to grid all 5-minute timesteps between 1962 and 2011 for each duration. However, the Natural Neighbours grid interpolation algorithm preserves catchment averages when added together. That is, interpolating 5 timesteps separately and adding the grids together gives the same answer as interpolating a single grid for those same 5 timesteps with the point values summed together before interpolation. This means that it is not necessary to create separate grids for each duration; a more efficient approach is to only interpolate grids at the 5 minute duration and aggregate the data to longer durations later in the analysis. As the number of grids required has been significantly reduced, it is now viable to grid all timesteps where rainfall occurred anywhere in a region. The updated method ensures all recorded rainfall is captured for use in the analysis, with no approximations required.

By gridding 5 minute data, it is also possible to utilise more of the recorded data. Previously, if a gauge had a missing data point in a given 30 minute duration, it would have to be excluded from the 30 minute analysis. With the updated methodology, it is still possible to use the data recorded at the station for the remaining 25 minutes.

2.5. Grid Interpolation

For each 5 minute timestep, a rainfall grid was interpolated using all pluviograph data available at that timestep using the Natural Neighbours algorithm. A detailed explanation of the Natural Neighbours algorithm is described in the previous study. The study adopted a 0.025° grid cell size, which is consistent with the cell size used by the BoM when deriving IFD grids. The previous study used 2500 m as the grid size, however in the current study the GDA94 geographical projection was used instead of MGA56 to accommodate the study regions being in different MGA regions, a cell size of 0.025° was adopted. The distance of 0.025° varies across Australia, but is generally between 2200 m and 2800 m. In Sydney it is approximately 2300 m east-west and 2800 m north-south.

Due to the definition of the Natural Neighbours algorithm, the grid extent is equal to the convex hull of the points used to interpolate the grid. This means that the extent changes depending on which stations are in operation along the boundary. The quality of catchment average rainfall estimates can thus be unpredictable near the grid boundary. For example, if a station near the boundary has missing data for a period of time, a catchment near the boundary that was previously fully covered by the interpolated grids, might then instead have partial or no cover, which in turn influences the catchment rainfall estimate.

If a gauge has missing data or a bad quality data flag assigned by the BoM at a given timestep, it is excluded from the dataset used for the interpolation. This is done on a per-timestep basis. The pluviograph records were not further data quality processed (for example, converting sections marked as interpolated with a flagged average value). In addition, all recordings marked in the BoM data quality checking with the -666 flag were excluded, including the ones marked ‘ACCEPT’. This was done due to concerns with some of the accepted data not making sense spatially. A single bad data point can have a significant effect on the final results, so it was deemed appropriate to err on the side of caution in these cases.

2.6. Calculating Areal Rainfall

The areal rainfall for a given catchment at a given timestep is calculated in the same way as the earlier study. However, an expanded discussion of the polygon overlay algorithm is provided below, along with a section on the effects of the grid cell size.

The end output after this step is a single file with 5 minute catchment average rainfall series for each circular catchment between 1962 and 2011. In the previous study, each duration had a separate time series with rainfall depths, however due to the updates in methodology (pushing the aggregation step to later in the analysis), this is no longer necessary.

2.6.1. Polygon Overlay Algorithm

The catchment average rainfall is the average value of all grid cell centres within the theoretical catchment polygon. Cells that partially overlap the polygon, but have a centroid outside the polygon, are not included. This is a consequence of raster and vector data being fundamentally different. To sample from a polygon overlay, it is necessary to either rasterise the polygon, or polygonise the raster. All standard zonal statistics algorithms rasterise the polygon to determine the overlap, as it is computationally a more efficient operation. Polygonising the raster effectively means creating square polygons around each grid cell, which results in a large quantity of polygons even for comparatively small grids. It is not hard to realise that this approach would be much more computationally expensive than creating a small raster with cells where the cell centroid is inside the polygon. As this project involves a large number of overlays (hundreds of catchments on millions of grids), the computationally simpler and standard method was adopted.

2.6.2. Grid Size Considerations

As the polygon area gets smaller, the grid cell becomes more significant. The smallest catchment area considered for ARF calculations in this study was 10 km^2. At 10 km^2 the catchment average estimates are of significantly lower quality than for larger areas. A single grid cell has an approximate area of 6.25 km^2, which means that the catchment average rainfall is generally based on a single cell. A smaller grid size is not viable at this stage, due to space and computation time constraints. While a smaller grid would address this issue it was rejected due to space and computational time constraints.

2.7. Calculating Areal Reduction Factors

To determine the ARF for a single catchment with a given area, duration and AEP, design rainfall quantiles for the catchment and point rainfall are required. The ARF can then be determined through this equation:

$$ARF = \frac{I_{Area}}{I_{Point}}$$

Where I_{Area} is the derived catchment rainfall quantile and I_{Point} is the derived point rainfall quantile. The process for generating these quantiles is described in the following sections. The ARFs can then be aggregated to a single value for each combination of area, duration and AEP. The process for this is described in section 2.7.3.

2.7.1. Design Rainfall

The process for creating the point-based catchment IFDs has been further developed from that adopted in the previous study. The pluviograph Annual Maximum Series (AMS) was filtered in a slightly different way to the previous study. The following filters were applied:

- Years with zero as the maximum rainfall were excluded,
- Years at either end of the record with less than 10 months of data were excluded, and
- Years outside the period selected for gridding (1962-2011) were excluded.

Stations with short records were not specifically excluded, as this was shown to have no noticeable effect on the results (see Stensmyr and Babister, 2013). The majority of stations have records longer than 10 years.

After these filters were applied, a GEV distribution was fitted to a set of durations for each pluviograph. Previously, the point IFD for a circular catchment was based only on the GEV quantiles from the corresponding pluviograph. This meant that the IFD was the same for all catchment areas. In the current study point design rainfall is derived in the following way:

- Derive design rainfall quantiles for all pluviographs and durations,
- Interpolate grids at the quantiles of interest (50%, 20%, 10%, 5%, 2% and 1% AEP), using the Natural Neighbours algorithm (as used for the areal estimates), and
- Take the catchment average value as the design rainfall for the circular catchment.

This is akin to overlaying a catchment on a grid of the BoM IFD data and taking the average value, but with a custom IFD grid that is more appropriate in the context of the project. The new method allows for IFDs that vary with catchment size, and more accurately captures the spatial variability of design rainfall.

It is generally desirable to restrict the pluviograph set by a minimum record length depending on the rarity of the AEP quantile, so that design rainfall estimates for rarer AEPs only include pluviographs with sufficiently long records. For example, restricting the dataset used to derive the 1% AEP rainfall grid to stations with more than 30 years of data. This approach is theoretically appealing, but has practical issues. Consistency between AEPs is lost if the same pluviograph set is not used, and problems such as higher design rainfall for the 5% AEP than for the 2% AEP can (and did) occur for some catchments. This type of approach was trialled, but was discarded in favour of a simpler approach using all stations for all AEPs.

Another option would be to simply use the BoM IFD grids as the base for the point design rainfall estimates. For general design rainfall purposes, the BoM data is more appropriate than deriving custom IFD grids. The approach of regionalising the scale and shape parameters are superior to purely using at-site data. Also applying a spline algorithm with care will give better results than using Natural Neighbours. However, for comparing catchment to point rainfall using the current methodology, it is more appropriate to develop point IFD estimates using a manner that is similar to the one used to derive catchment estimates. The derived 50% AEP / 1 hour duration grid for Sydney, Brisbane and Melbourne, is depicts in Figure 7 to Figure 9. Table 5 summarises the design rainfall variability by region.

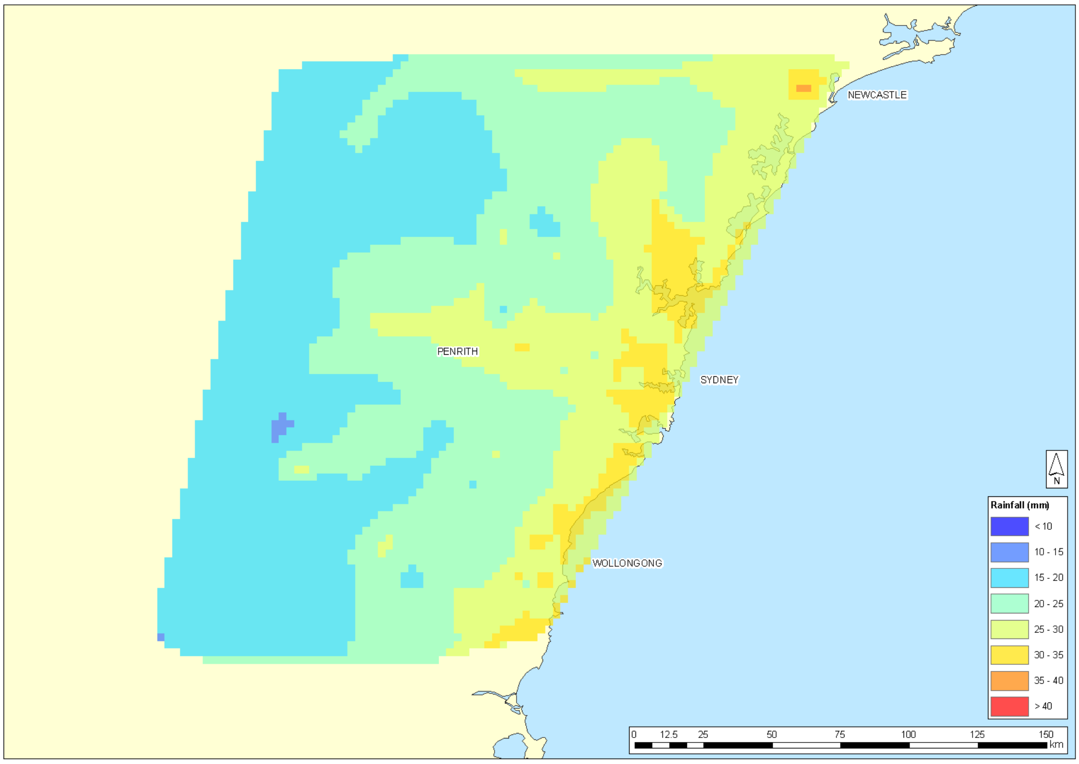


Figure 7: Design Rainfall Grid 50% AEP / 1 Hour (Sydney)

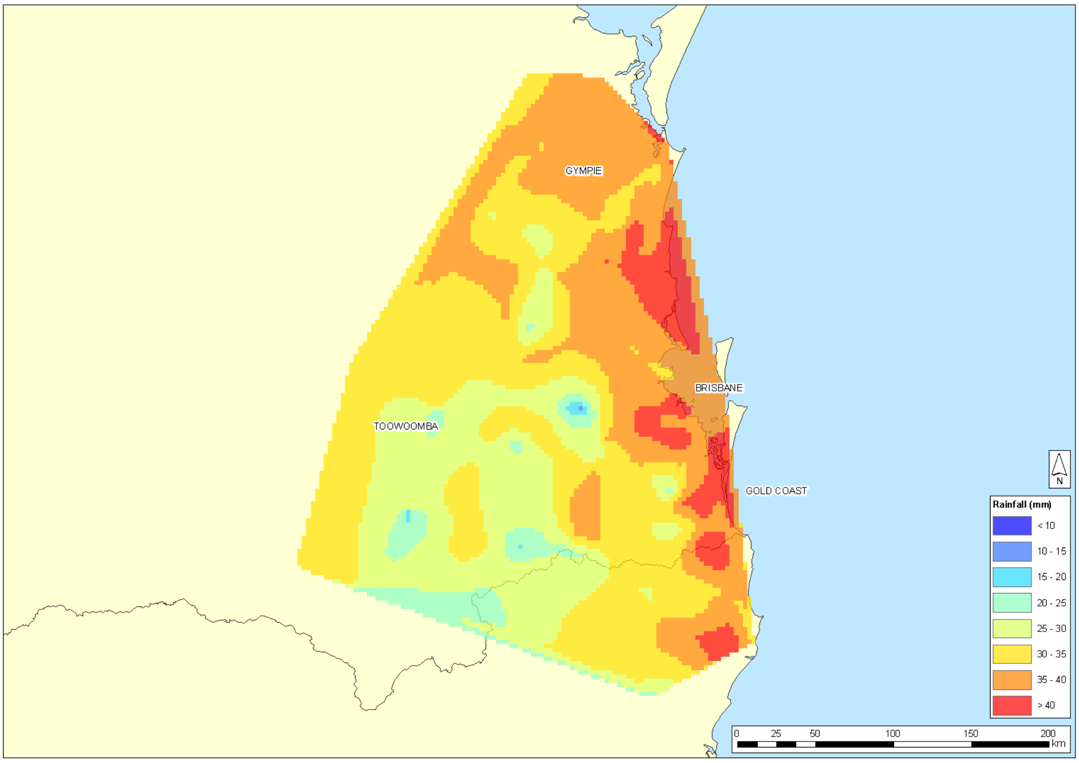


Figure 8: Design Rainfall Grid 50% AEP / 1 Hour (Brisbane)

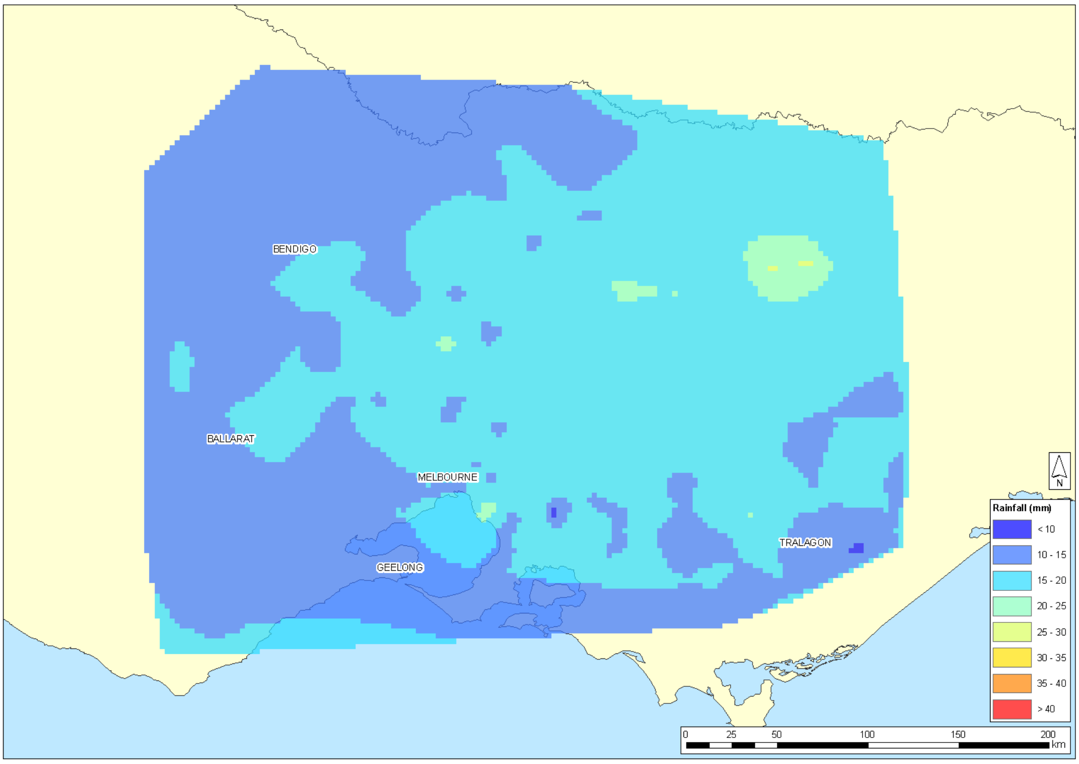


Figure 9: Design Rainfall Grid 50% AEP / 1 Hour (Melbourne)

Table 5: Design Rainfall Depth Variability by Region (50% AEP / 1 Hour) (mm)

	Sydney	Brisbane	Melbourne
Minimum	13.9	14.7	9.3
Maximum	37.3	45.4	25.5
10th Percentile	17.6	26.7	12.9
90th Percentile	29.0	39.3	18.2

The IFDs for the three regions are quite different, both in magnitude and spatial variability. Melbourne exhibits the most uniform IFDs, while both Sydney and Brisbane show significant gradients going from coastal to inland areas. All regions exhibited a similar variability in terms of the ratio between the minimum and maximum grid value. Sydney exhibits the most variability (90^{th} percentile value is 65% larger than 10^{th} percentile, versus 47% and 41% larger for Brisbane and Melbourne, respectively). While Melbourne is similar to Brisbane in this regard, the gradient is much more uniform.

2.7.2. Catchment Rainfall

Catchment rainfall quantiles for a given catchment and duration are generated by creating an AMS from the 5 minute time series data produced by the process described in section 2.6. This AMS is then filtered to only include years when the corresponding pluviograph AMS has a value.

This filtering step is done after the pluviograph AMS has been filtered according to the steps in section 2.7.1. This is done to ensure comparable datasets between point and areal rainfall.

The Generalised Extreme Value (GEV) distribution is then fitted to the catchment series using an L-moments approach. From this, design catchment rainfall quantiles can be extracted at selected AEPs.

An argument can be made for using the whole generated dataset between 1962 and 2011, to make use of all of the data to the largest extent possible. This approach was trialled, but led to skewed results for many catchments, where large annual maxima would be recorded for the catchment before at-site pluviograph data became available. This resulted in the catchment design rainfall being higher than the point design rainfall; hence, an ARF larger than 1. While an ARF above 1 is not technically impossible per se, in this case it is due to differences in sampling. In light of this, the decision to only use years available in both datasets was made.

2.7.3. Aggregating Areal Reduction Factors

Using the outputs from sections 2.7.1 and 2.7.2, ARFs were calculated for each individual circular catchment and case (combination of AEP, duration and area). For each case, the set of ARFs were aggregated to a single value, using the following process:

1. Filtering the set of catchments to exclude those near the study area boundary,
2. Using random selection, creating a non-overlapping set of catchments,
3. Determine the median ARF from the selected non-overlapping catchments,
4. Repeat steps 2 and 3 a total of 250 times, and
5. Determine the median of the 250 median ARFs. This value is the ARF for the given case.

The set of catchments were filtered to remove catchments on the boundary of the region, to minimise any boundary effects that could occur. This was done by eliminating catchments that overlap less than 70% with the convex hull of all pluviographs, which is the same filter as in the previous study.

From the filtered set, non-overlapping sets of catchments were created stochastically for each case. This was done by:

- randomly selecting a catchment from the set in random order,
- checking if it overlapped with an already chosen catchment,
- adding it to the non-overlapping set if it did not overlap, and otherwise discarding it.

This was repeated until each catchment had been selected. However, filtering to non-overlapping catchments means that the sample size becomes significantly smaller, especially for larger areas. This increases the variability of the aggregated ARF and can result in inconsistent behaviour across cases. To counteract this and minimise the impact of the random number generator, the process of generating an ARF from a non-overlapping set was repeated 250 times for each case. The median of these 250 median ARFs is then calculated as the ARF for the given case.

The final result of this is a set of ARF values for each region, one per case (combination of duration, catchment area and AEP). In this study, the ARFs are visualised in different ways, but it is also possible to generalise the results to an equation. This should be done as part of future work.

3. Results

In the following sections, figures depicting how the ARF varies with duration, area and AEP (section 3.1) are provided. Comparisons between ARFs developed by this study and other studies are also made. Box plots that express the variability of the ARF for a number of individual cases are provided in section 3.2. The spatial relationship of the ARF and a comparison with using non-overlapping catchments are provided in sections 3.3 and Appendix A respectively.

3.1. General ARF Trends and Comparisons

Figure 10 to Figure 12 below show the ARF by area and duration for Sydney, Brisbane and Melbourne for the 50% AEP. The results for all regions exhibit the expected basic properties of ARFs:

- For longer durations there is less reduction in rainfall from the point rainfall,
- As the area increases there is more reduction in rainfall from the point rainfall, and
- As the area decreases the ARF approaches 1 (therefore the area rainfall approaches the point rainfall).

The period of gridded rainfall is 50 years, but the majority of the pluviographs have significantly shorter record lengths (for example, the average record length for the Sydney dataset is 24 years). Therefore the results for rarer AEPs have a much lower confidence than the frequent AEP results. However, ARF relationships are still required for rarer AEPs, therefore the decision was made to include these results in the report.

Figure 13 to Figure 15 depict the ARF by area and duration for Sydney, Melbourne and Brisbane for the 2% AEP. The results are consistent with to the results at 50% AEP, but with more variability (for example the 1 hour curve for Brisbane). To allow for an easier comparison of the results between regions, the curves for the 50% and 2% AEP for all regions have been plotted on the same graph, for the 1 and 12 hour durations (Figure 16 and Figure 17). The interim short duration results currently recommended by ARR Project 2 (SKM, 2013) for NSW GSAM region are also plotted for comparison.

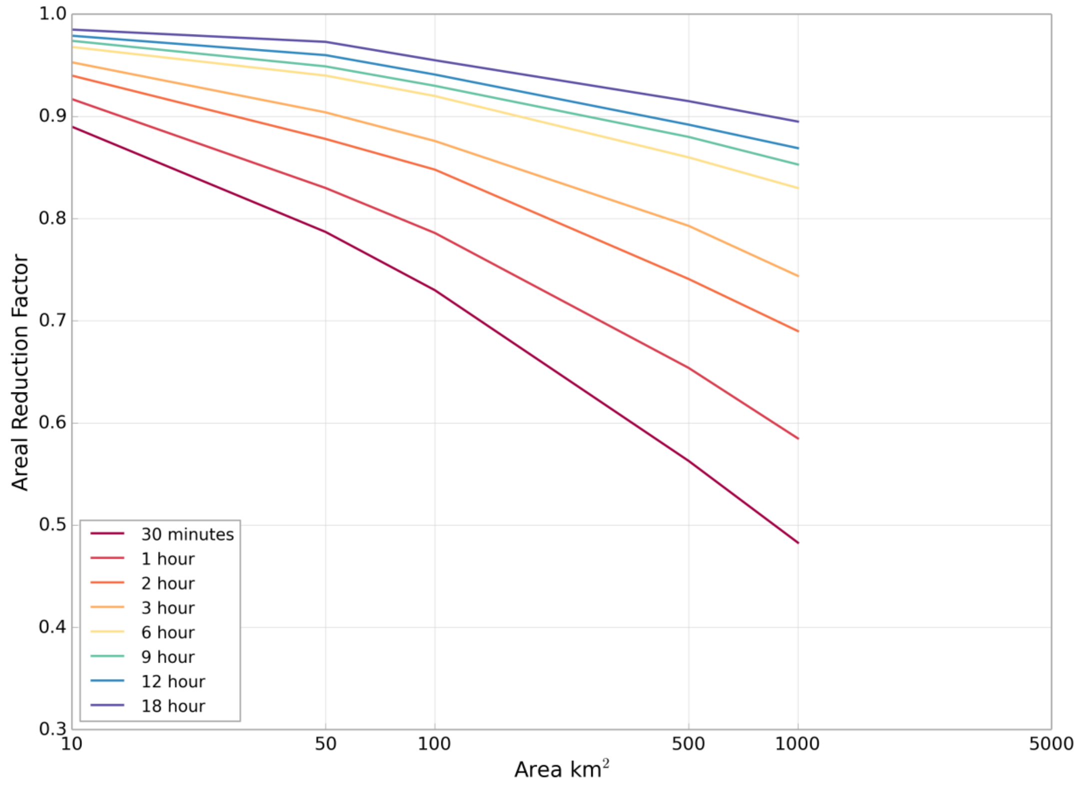


Figure 10: Areal Reduction Factor by Area and Duration – 50% AEP (Sydney)

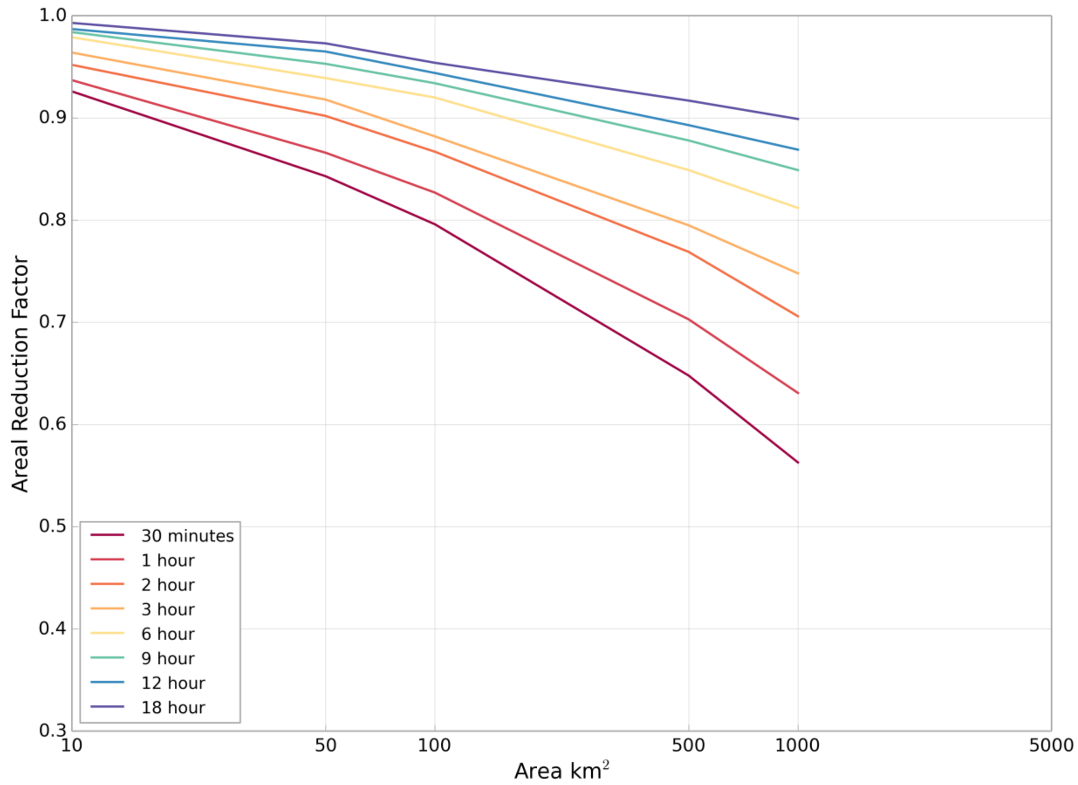


Figure 11: Areal Reduction Factor by Area and Duration – 50% AEP (Brisbane)

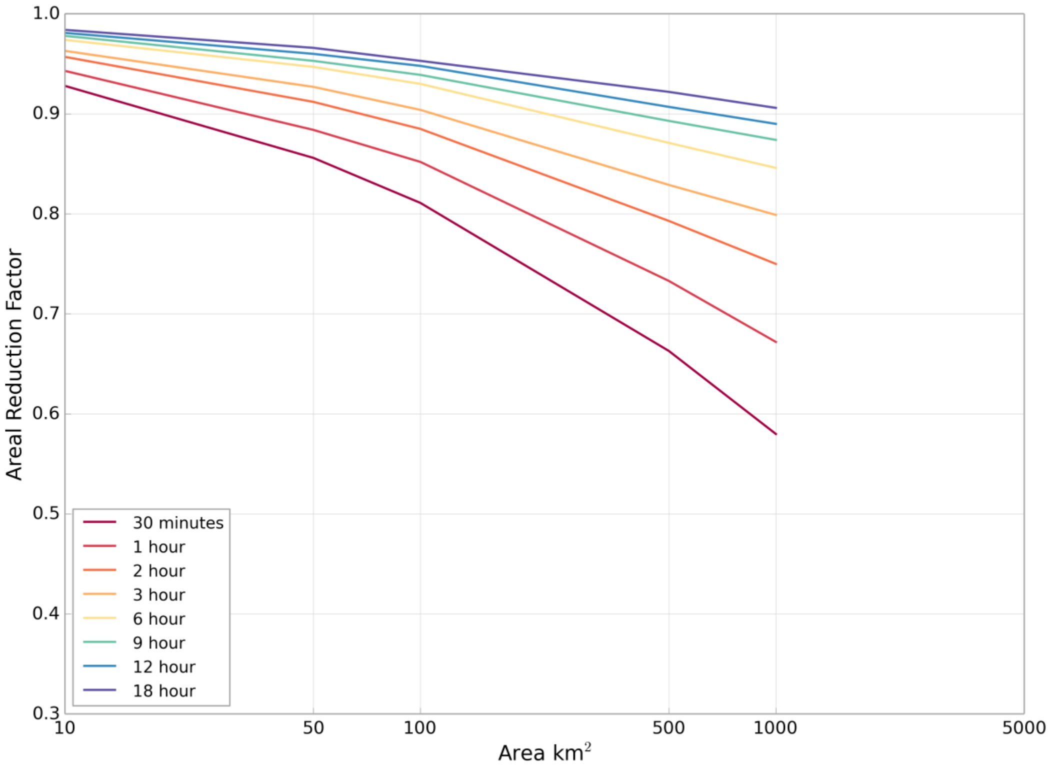


Figure 12: Areal Reduction Factor by Area and Duration – 50% AEP (Melbourne)

The ARF curves are similar across the regions, and are comparable with the interim equation (which is a simple interpolation between the adopted long duration ARF equations derived in (SKM, 2013) and the UK Flood Studies Report (Natural Environmental Research Council, 1975)). For the 12 hour duration, all three regions exhibit similar behaviour, with minimal differences, though they all lie above the interim line. For the 1 hour duration, the results exhibit more variability. In particular, the Sydney results stand out as being significantly lower than the results for Melbourne and Brisbane. If the differences are caused by storm mechanisms and rainfall intensity, then a gradual trend would be expected between Melbourne, Sydney and Brisbane. However, Sydney is lower than the other two regions. While there are several possible explanations, the greater IFD gradient in Sydney is the most probable cause. The Sydney region is also the smallest geographically with more coastal stations.

For the 12 hour duration, the results for all three regions are above the interim equations. A consequence of this is that, were these results to be adopted for short duration ARFs, there would be inconsistencies when moving from the short to the long duration method. In many cases, the 18 hour short duration ARF is higher (less reduction in rainfall) than the 24 hour ARF derived in the long duration ARF project. For some cases, even the 12 hour short duration ARF is above the 24 hour long duration ARF. This is a result of the differences in the methodologies. The cause of the discrepancy is unknown at this stage. If the results of this study were to be adopted, some smoothing would need to be applied.

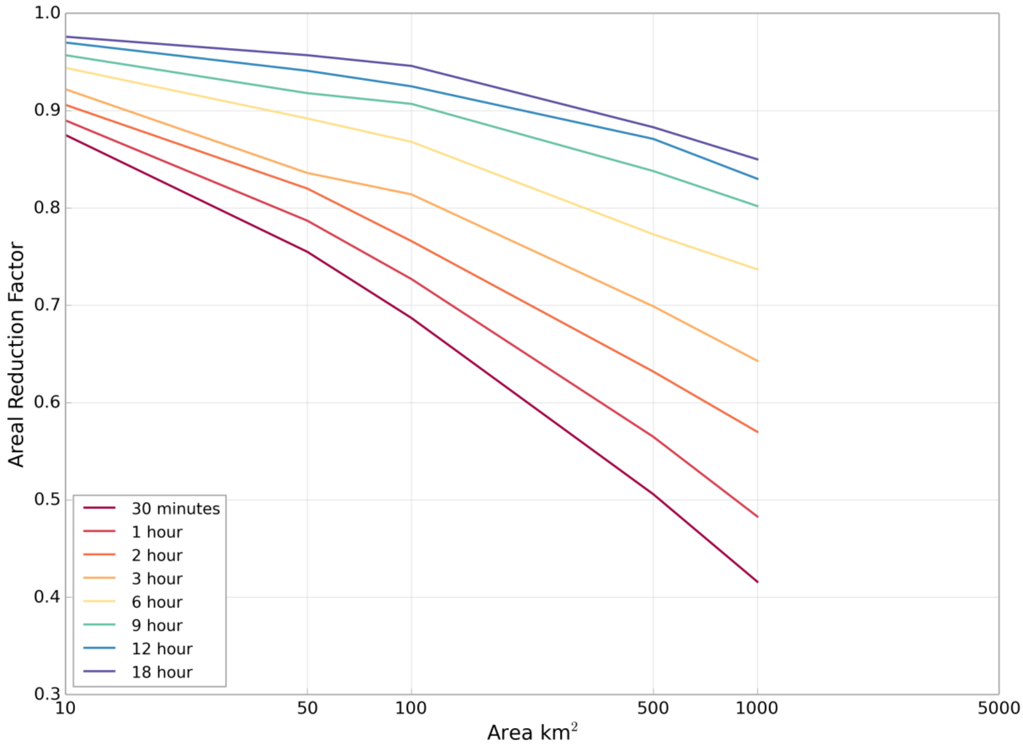


Figure 13: Areal Reduction Factor by Area and Duration – 2% AEP (Sydney)

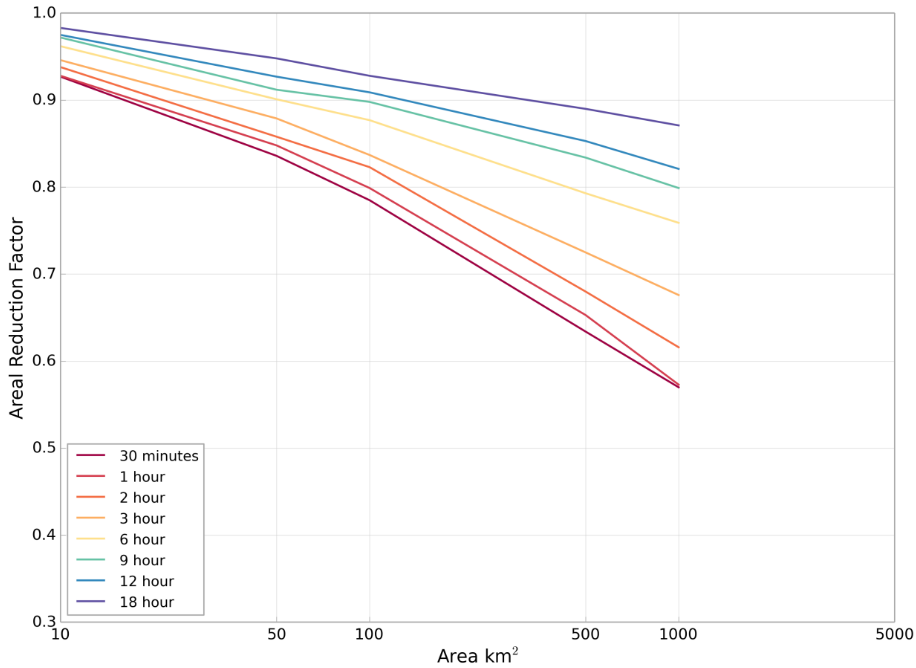


Figure 14: Areal Reduction Factor by Area and Duration – 2% AEP (Brisbane)

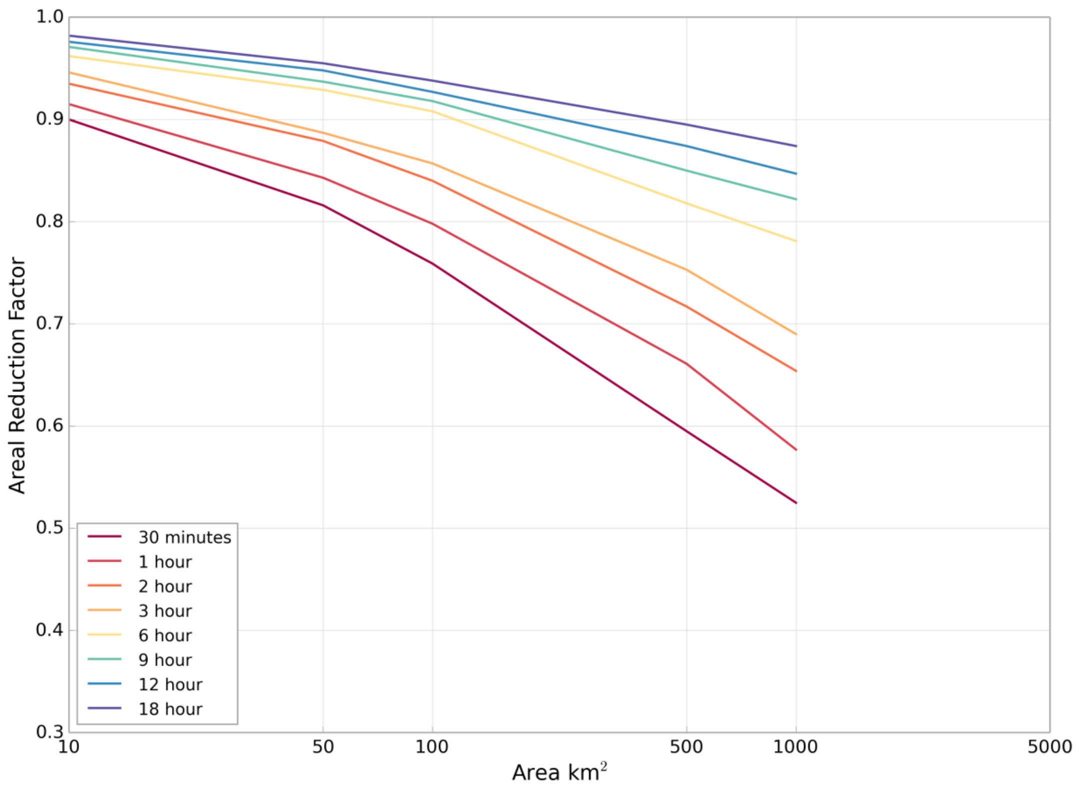


Figure 15: Areal Reduction Factor by Area and Duration – 2% AEP (Melbourne)

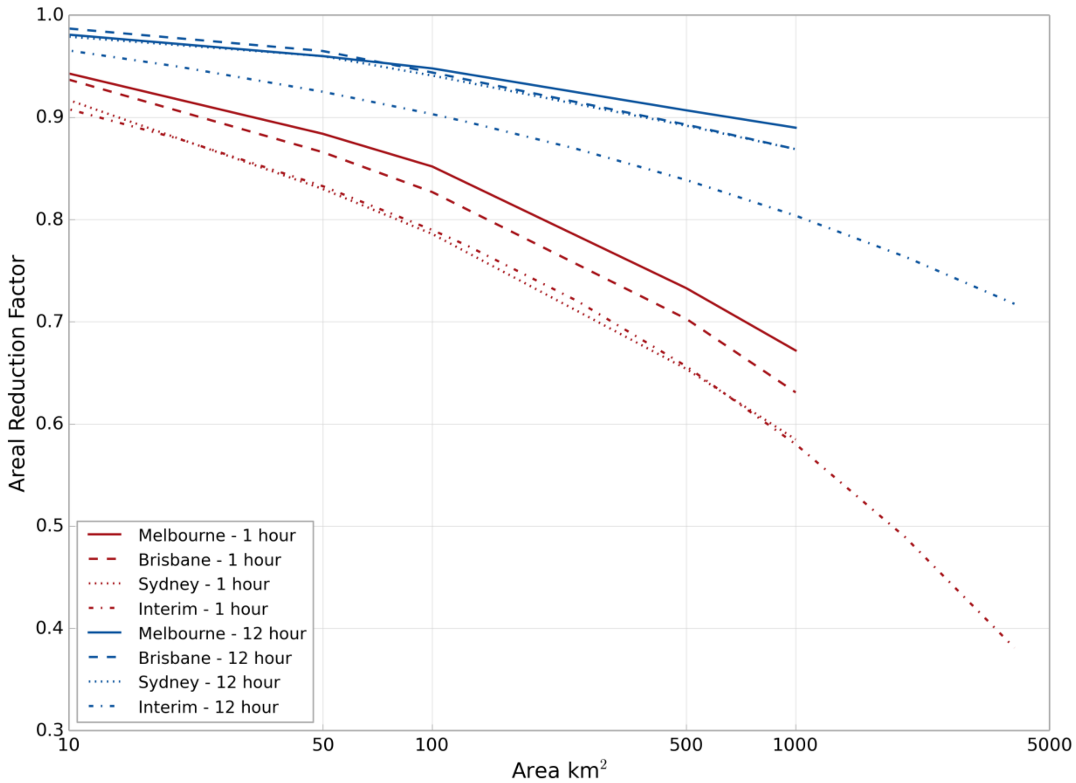


Figure 16: Regional Areal Reduction Factor Comparison – 50% AEP

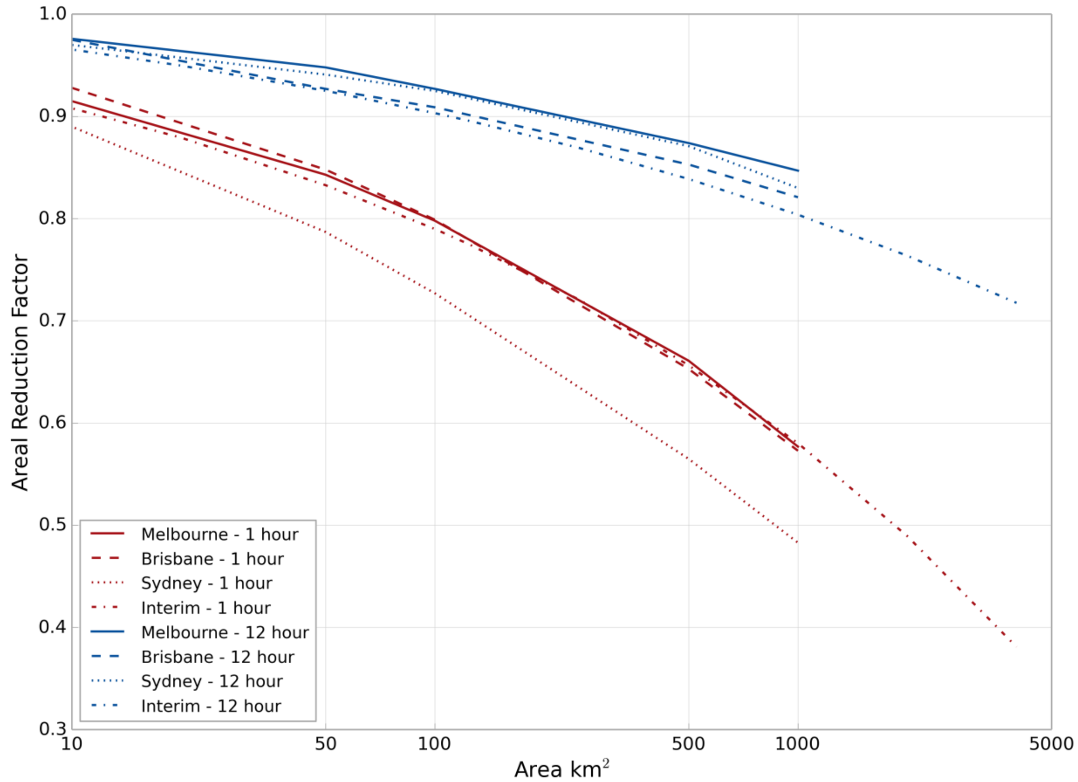


Figure 17: Regional Areal Reduction Factor Comparison – 2% AEP

3.2. Box Plots

To illustrate the variability in ARFs between catchments for a given case, box plots for select durations and catchment areas are depicted on Figure 18 to Figure 20. The figures show the results for all catchments, not an aggregation of overlapping sets.

Figure 18: Areal Reduction Factor Box Plots (Sydney)

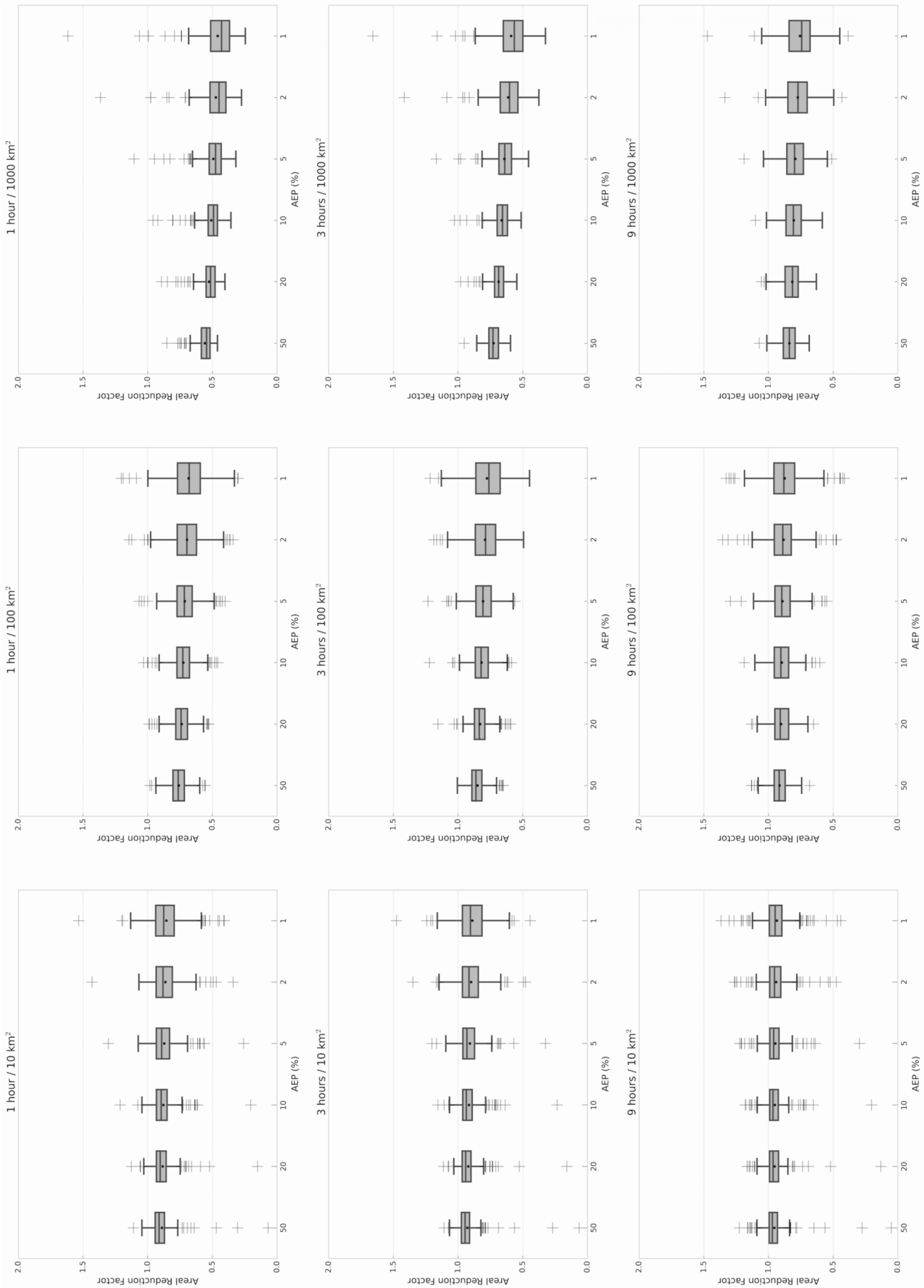


Figure 19: Areal Reduction Factor Box Plots (Brisbane)

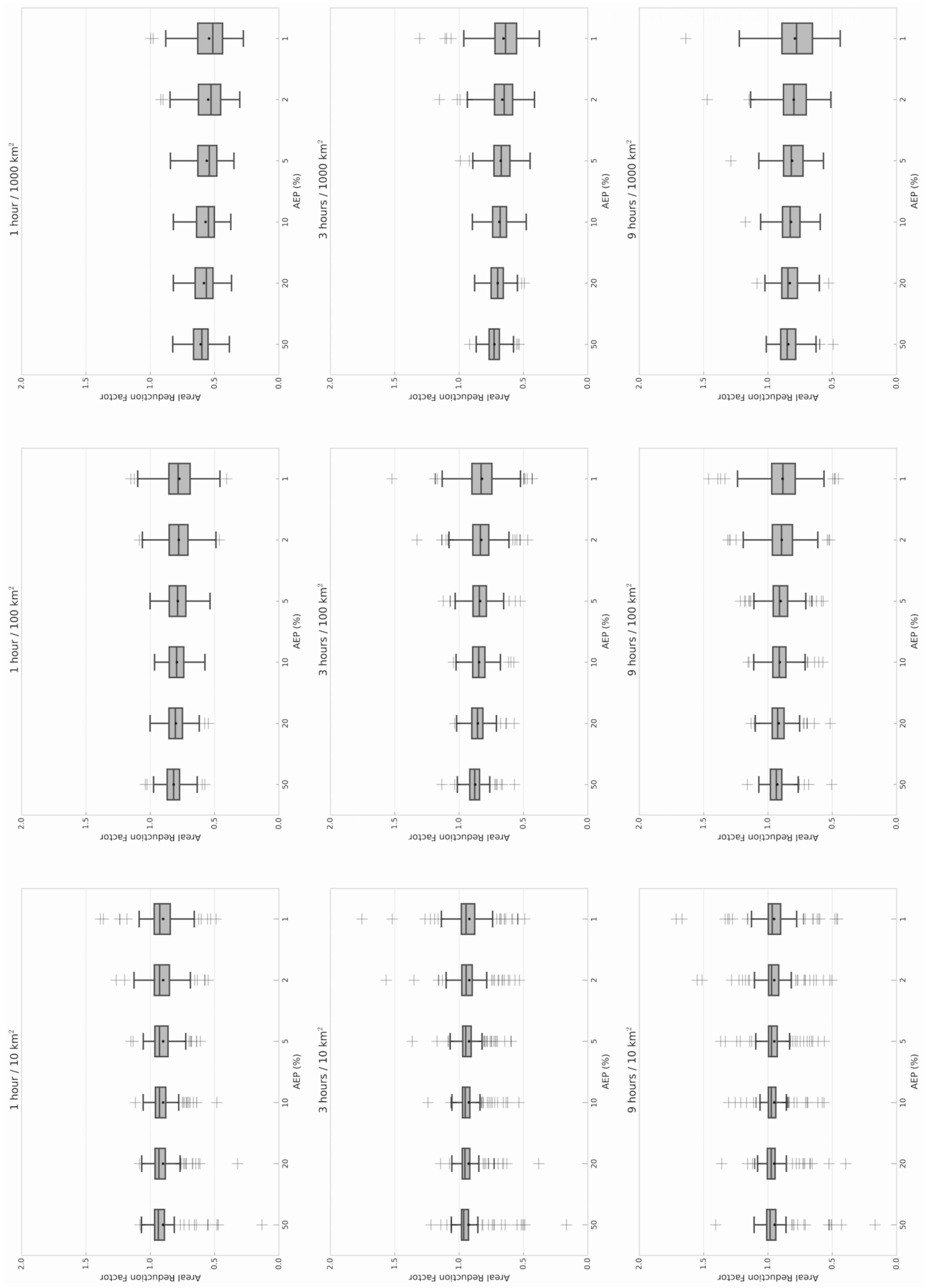
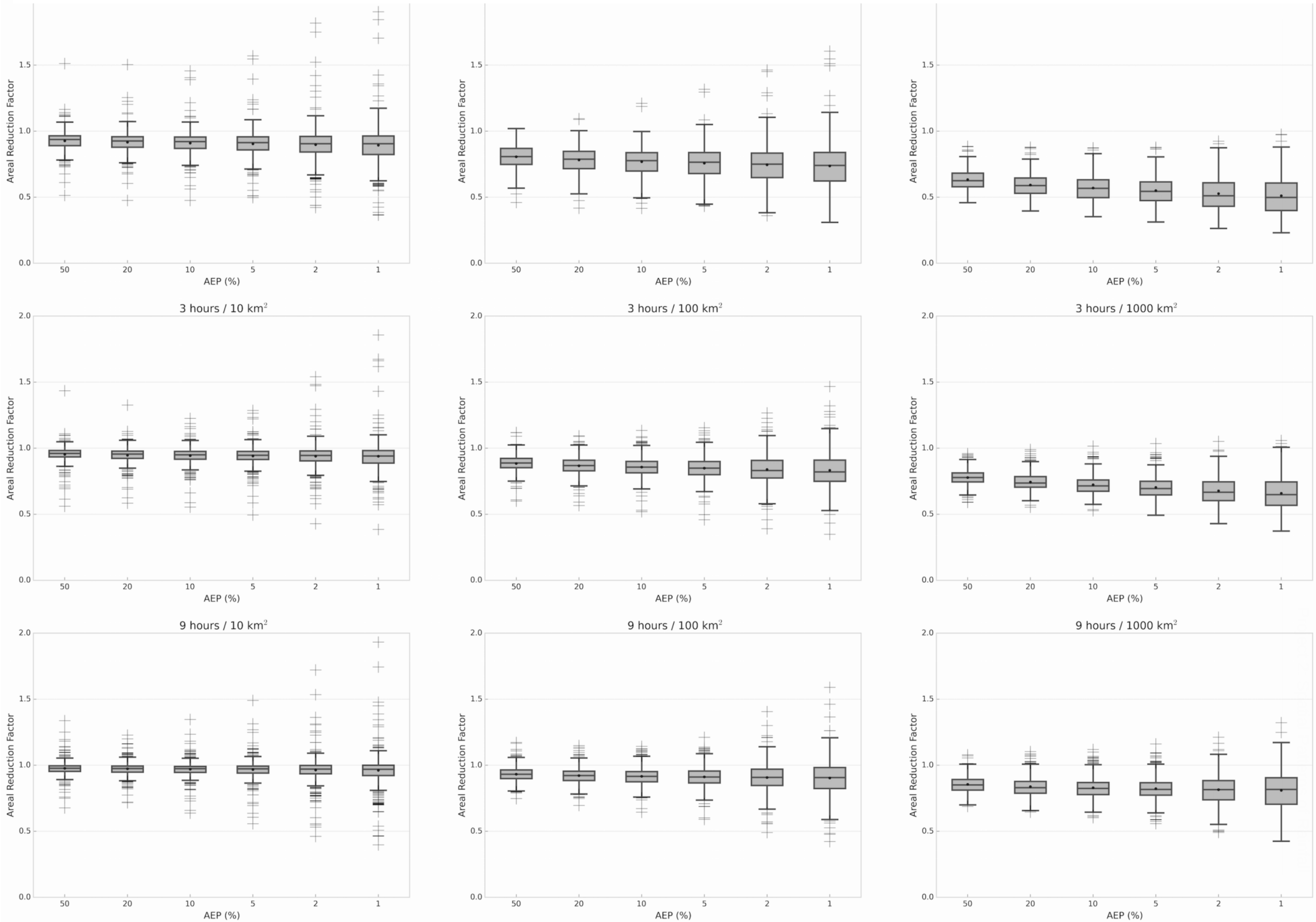


Figure 20: Areal Reduction Factor Box Plots (Melbourne)



The box plots exhibit similar characteristics for all regions. Generally, there are more outliers for smaller areas, particularly for the 10 km^2 case. This is likely a consequence of the grid cell size, as described in section 2.6. The plots also show that the AEP trend is weak or non-existent with the longer duration cases showing a possible slight trend. A significant number of catchments have a ARF above 1. While this is not impossible, for the majority of catchments it's more likely to be due to issues with the data or short duration of record, rather than being a real value. ARFs tend to be larger than 1 in areas with a significant orographic effect, due to the strong design rainfall gradient.

To assess the effects of the changes in methodology and data compared to the previous study, a comparison plot for the 50% AEP for the Sydney region is shown in Figure 21. The results of the current study display a clearer trend towards an ARF of 1 with decreasing area. This is a result of the methodology improvements and increased quality control of the pluviograph data.

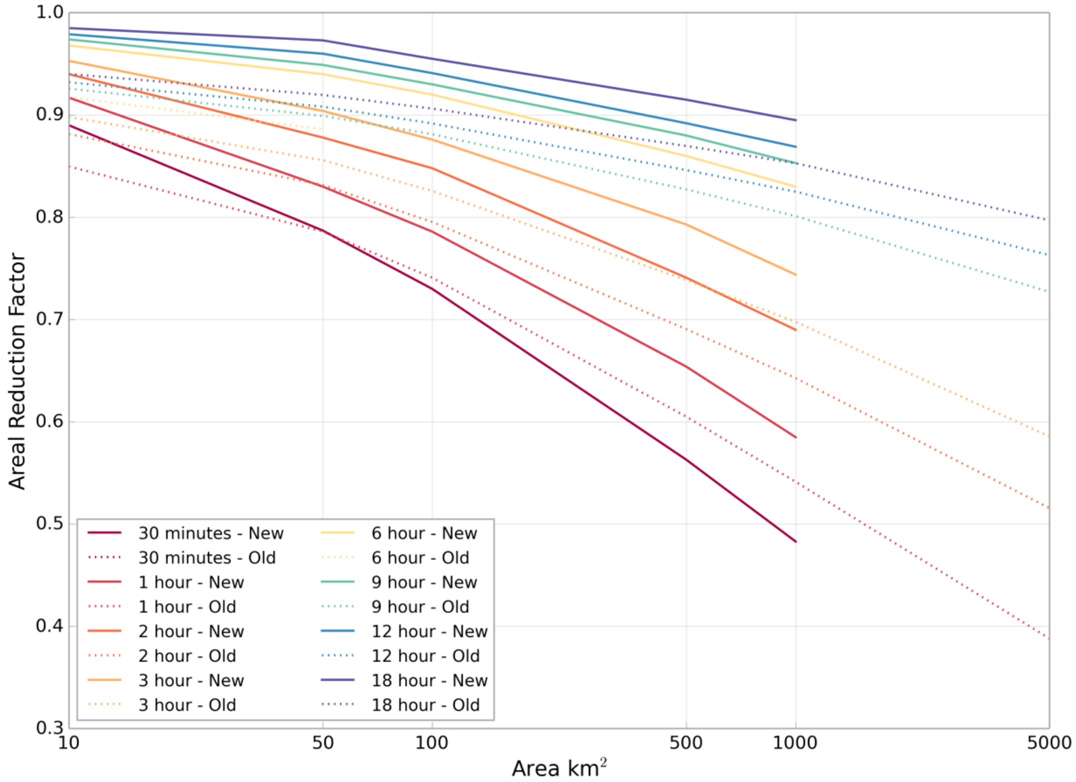


Figure 21: Comparison with Previous Study – 50% AEP (Sydney)

3.3. Spatial Variability

The individual catchment ARFs were gridded for the 50% AEP / 100 km^2 area / 1 hour case for the Sydney region. Lower values (more reduction in rainfall) occurs along the coast and inland from Sydney Harbour towards Penrith. Some stations showed distinctly different results from surrounding stations. The spatial ARF relationship resembles the derived IFD curve (see Figure 7). However, IFD magnitude is not the sole driver, as if this were the case there would be lower ARFs for Brisbane than for Sydney across the board, which is not the case. A combination of IFD gradient, IFD magnitude and clustering of stations is the likely cause for the differences. It is also possible that the difference is caused by meteorological differences.

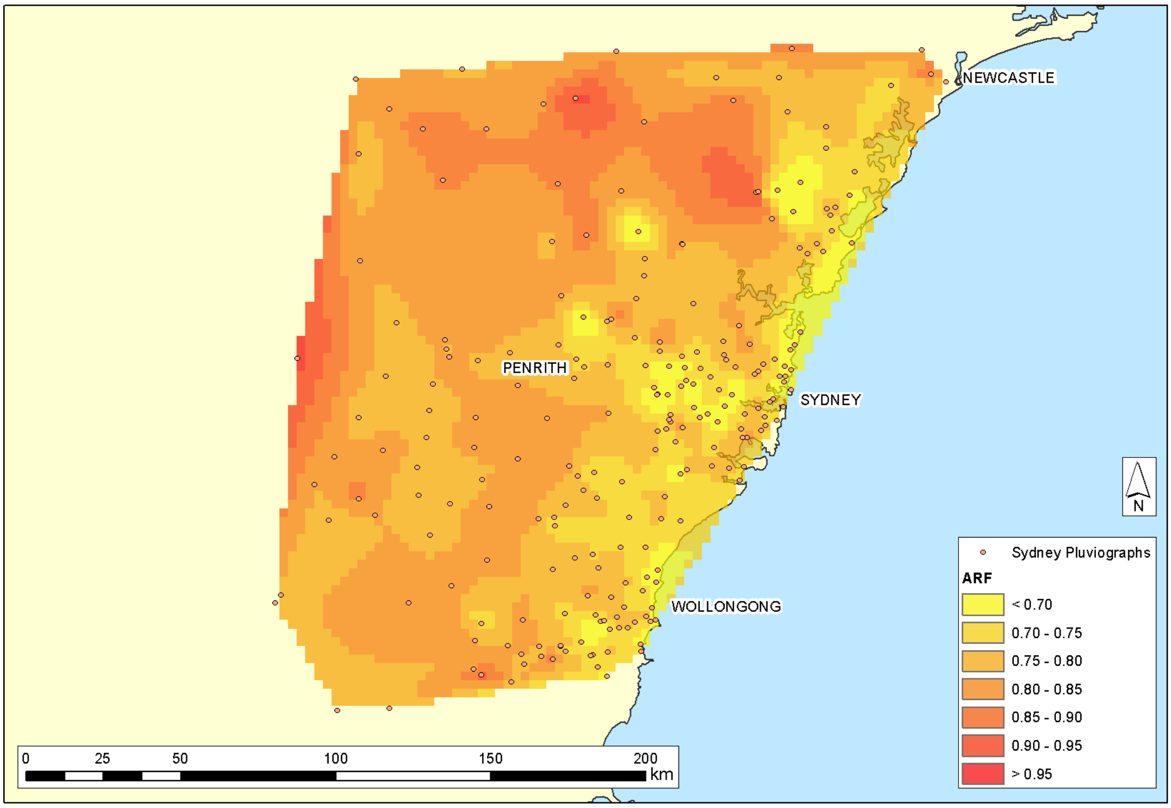


Figure 22: Spatial Variability of ARF – 50% AEP / 100 km^2 / 1 hour (Sydney)

4. Conclusions

All three regions exhibit similar characteristics with regards to dependency on duration, AEP and area. At the 12 hour duration, the adopted ARFs for each region are very similar, while for the 1 hour duration, the Sydney ARF is lower than those for Melbourne and Brisbane. This is likely due to a combination of spatial station distribution, IFD magnitude and IFD gradient. It is also possible that the difference is caused by meteorological differences.

The results generally yield ARFs similar to the interim equations derived in (SKM, 2013), which are based on the long duration ARFs and the 1 hour ARF derived as part of the UK Flood Studies Report (Natural Environmental Research Council, 1975). However, the ARFs derived for the 12 and 18 hour durations in this study generally lie above the 24 hour ARFs derived in the long duration study. This issue will require some smoothing between the two methods if the short duration ARFs were to be adopted for design purposes.

A pragmatic approach would for the whole country would be to ignore the Sydney results and use a simple average of the Brisbane and Melbourne results for the whole country.

4.1. Further Work

The methodology adopted for this study is very similar to the traditional modified Bell's method, but with Natural Neighbours instead of Thiessen polygons as the basis for catchment rainfall. The method used in this study is not limited to circular catchments, nor locations with a gauge located at the centroid. The method could be used for real catchments including those defined by the BoM Geofabric. A grid cell sampling approach would provide better estimate of the spatial variability of ARFs.

It would also be worthwhile to compare and validate the natural neighbours rainfall surface fits of this study of this study against the processed radar image data set generated by BoM as part of the ARR climate change revision project.

The spatial-temporal rainfall surfaces developed as part of this study could be used as a design input for flood estimation and could be normalised so they could be transferred to different catchments.

5. References

Natural Environmental Research Council. (1975). *Flood Studies Report, Vol. 2.* Institute of Hydrology, Wallingford, UK.

Siriwardena, L., & Weinmann, E. (1996). *Derivation of Areal Reduction Factors for Design Rainfalls in Victoria.* Cooperative Research Centre for Catchment Hydrology.

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.

Srikanthan, R. (1995). *A Review of the Methods for Estimating Areal Reduction Factors for Design Rainfalls.* Cooperative Research Centre for Catchment Hydrology.

Stensmyr, P., & Babister, M. (2013). *Short Duration Areal Reduction Factors.* Institution of Engineers, Australia.

APPENDIX A – Non-overlapping Catchments

Figure 23 compares the all catchments case (base case) to a single non-overlapping catchments (option A) case by area and duration for the 50% AEP for Sydney. Figure 24 shows the same comparison for the 2% AEP. Figure 25 shows a comparison between Sydney, Melbourne and Brisbane for the 50% AEP, non-overlapping catchments case.

Figure 23 and Figure 24 show that the median ARFs generally increase when enforcing non-overlapping catchments. However, due to the decrease in sample size, the variability is also significantly higher. Some erroneous results are also introduced, where the ARF goes up with larger area (for example the 2% AEP 3 hour case when moving from 500 to 1000 km^2). The problem also gets worse with rarer AEP. Using this approach does remove some of the bias towards coastal regions, but introduces new problems with sample size. For this reason, it was decided to adopt the case of using all catchments (aside from boundary cases as discussed in section 2.7.3). Figure 25 shows, using non-overlapping catchments does not remove the differences between the regions, which means that this effect is not caused simply by coastal station clustering.

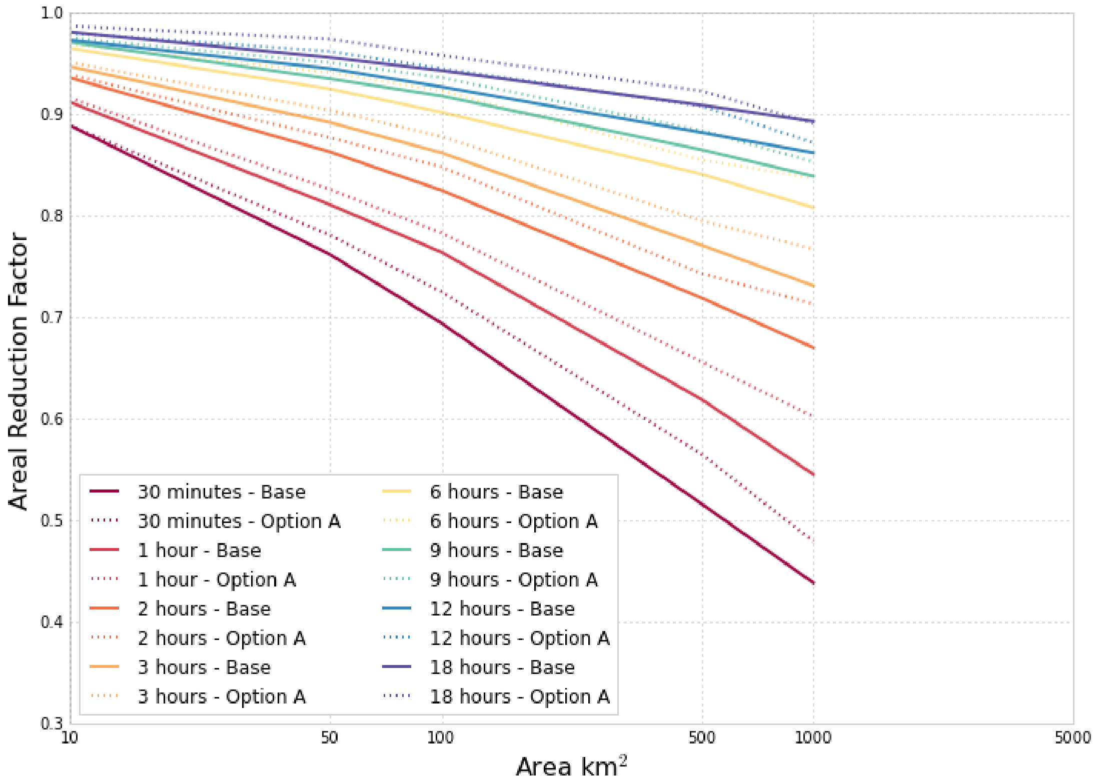


Figure 23: ARF by Area and Duration – 50% AEP (Sydney, Non-Overlapping Catchments)

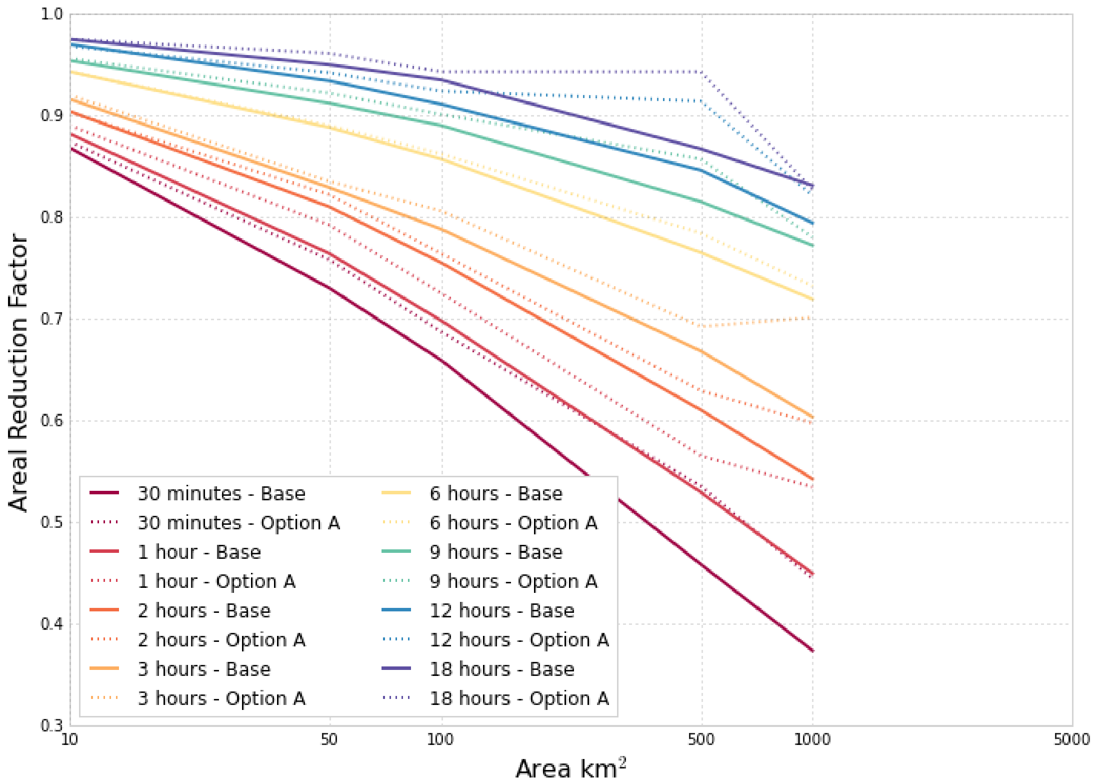


Figure 24: ARF by Area and Duration – 2% AEP (Sydney, Non-Overlapping Catchments)

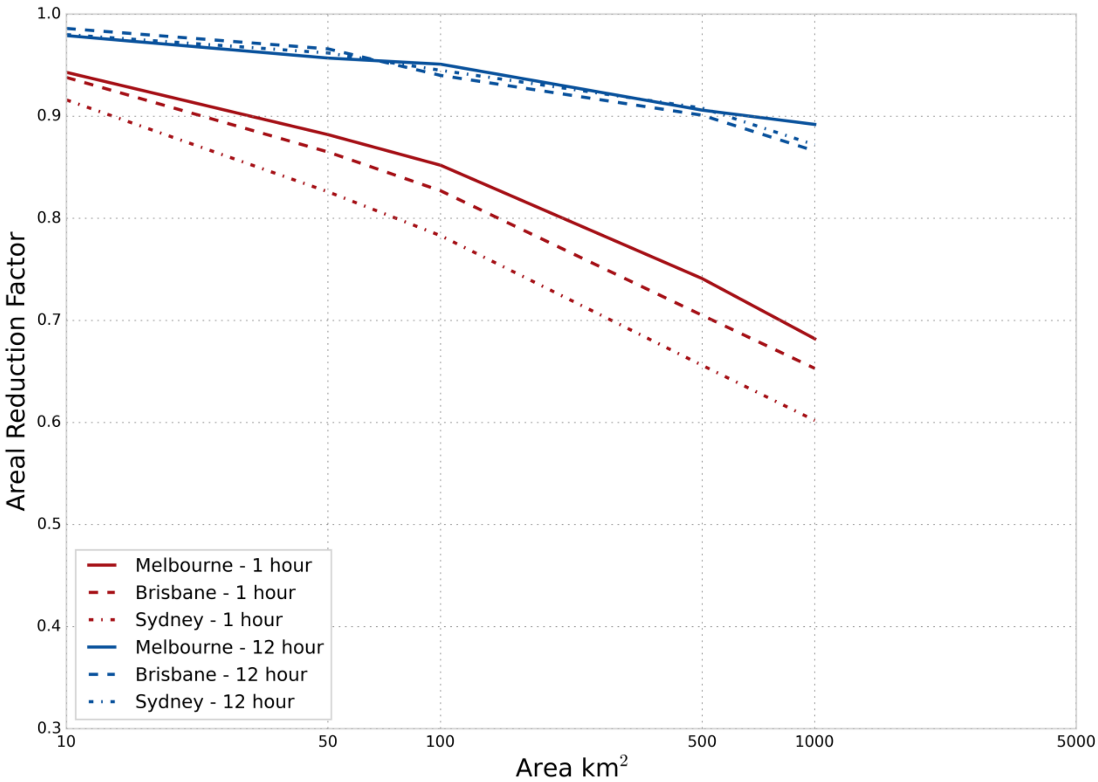


Figure 25: Regional ARF Comparison – 50% AEP (Non-Overlapping Catchments)