Floodplain Risk Management Guide

Incorporating 2016 Australian
Rainfall and Runoff in studies

Cover photo: Snowy River in flood (R Gibbs/OEH)

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Abbreviations

AEP	annual exceedance probability
AIDR	Australian Institute of Disaster Resilience
ARI	average recurrence interval
ARF	areal reduction factor
ARR	Australian Rainfall and Runoff
AVM	Average Variability Method
BoM	Australian Bureau of Meteorology
CRC-FORGE	Cooperative Research Centre – FOcussed Rainfall Growth Estimation
DRM	direct rainfall method
EY	exceedances per year
I&D	investigation and design
ICOLLs	intermittently closed and open lakes and lagoons
IFD	Intensity–Frequency–Duration
FFA	flood frequency analysis
FMP	Floodplain Management Program
FRM	floodplain risk management
FRMS	floodplain risk management study
FRMS&P	floodplain risk management study and plan
OEH	NSW Office of Environment and Heritage
PMF	probable maximum flood
PMP	probable maximum precipitation
PRM	Probabilistic Rational Method
RCP	Representative Concentration Pathway
RFFE	Regional Flood Frequency Estimation

1. Introduction

Studies to understand and manage flood risk funded under the Floodplain Management Program in New South Wales generally follow guidance provided in the Floodplain Development Manual (FDM) (DIPNR 2005) and associated technical guides. They are also informed by national best practice as outlined in the Australian Institute of Disaster Resilience Handbook 7 series of documents (AIDR Handbook 7 series) and the national guide for flood estimation, Australian Rainfall and Runoff (ARR).

In July 2016, a significant update of techniques and base information in ARR was released (ARR2016; Ball et al. 2016), to replace earlier versions (ARR1987). The NSW Office of Environment and Heritage (OEH) has developed this guide to assist councils to transition to ARR2016 when developing and implementing floodplain risk management (FRM) plans under the process outlined in the FDM.

This guide does not remove the need for flood risk managers to fulfil their professional responsibilities to consider ARR2016 in depth. This includes ensuring that studies use data and techniques that are relevant to the context of the study, are fit for purpose for the location and ensure that results are reasonable in consideration of flood history.

New South Wales has developed a range of specific advice and techniques that take precedence over ARR2016; these are outlined in Section 3.7. This is consistent with Book 1 Chapter 1 of ARR2016, which states: '…where circumstances warrant, designers have a duty to use other procedures and design information more appropriate for their design flood problem.'

The FDM and AIDR Handbook 7 (AIDR 2017b) identify the need to consider a range of end users involved in managing flood risk. This is reflected in ARR2016 which is less focused on peak flood levels than ARR1987. It supports a broader understanding of flood behaviour and the factors (such as peak flood levels, variation in timing of floods to reach critical levels and flood volumes) that influence community risk, which vary in importance with location.

Transition to ARR2016 involves a learning curve. Depending on the stage in a study and in the FRM process, it may fully incorporate ARR2016 or only include a sensitivity analysis to ARR2016 (see Table 1 in Section 2). The scale of this assessment influences how results should be used to ensure decisions align with the principles of the FDM (see Section 2).

The guide provides the following advice to support transition to ARR2016 in studies funded under the Floodplain Management Program:

Section 2   provides specific advice on when to consider ARR2016 in studies and how to consider the outcomes of assessments of ARR2016 in decisions

Section 3   outlines the changes to ARR and where NSW guidance and approaches have precedence in studies under the NSW FMP

Section 4   provides guidance on applying ARR2016; it discusses model selection, runoff routing application, simple, ensemble, and Monte Carlo approaches

Section 5   provides advice on reporting and data handover related to ARR2016

Appendix A   provides advice on the limitations of using the ARR Data Hub and provides an example of the ARR Data Hub output

Appendix B   provides advice on Regional Flood Frequency Estimates (RFFE)

Appendix C   details additional considerations when using direct rainfall methods (DRMs)

Appendix D   provides an example of at-site Intensity–Frequency–Duration (IFD) analysis

Appendix E   provides some additional points for checklists considering ARR2016

Appendix F   provides NSW mapping of comparisons between the 1987 and 2016 versions of some statistical rainfall values and climate change zones.

In addition, two case studies (urban catchment (WMAwater 2017b) and rural catchment (WMAwater 2017a)) are available to provide guidance on how to test and report on sensitivity to changes relating to ARR2016 and updated design inputs, such as the 2016 IFDs. These highlight the decision-making processes involved, the scale of reporting and the level of discussion expected in reporting on adopting the ARR2016 approach. They should not be used beyond this purpose, nor results used for decision-making.

2. Transition process and how to consider ARR2016 assessments in decision-making

Studies developed consistent with previous versions of ARR through the FRM process outlined in the FDM remain the best available information to manage flood risk in a location until more detailed investigations that fully consider ARR2016 are completed and considered, as discussed in Section 2.2.

Studies under the NSW FMP need to consider ARR2016 as the current industry guidance on flow estimation; how they do this depends on the type of project and its progress. Table 1 provides a quick reference guide that takes into consideration where a project is up to in the process, the type of project being undertaken and its scope.

Advice on scoping of projects is incorporated into OEH's Flood Brief Development Tool, available through OEH Flood Specialists.

The way ARR2016 is addressed in studies under the NSW FMP is likely to vary over the next few years, as is the scope of software to address ARR2016, and the knowledge and the skill of the industry in using these techniques.

In many studies currently underway, ARR2016 methodologies and relevant updated IFDs will be examined to test the sensitivity to this change. The use of sensitivity assessments in decision-making is discussed in Section 2.1.

New studies will generally be using ARR2016 techniques (including updated flood frequency analysis (FFA) approaches) with the relevant updated IFDs. The use in decision-making of the results from these analyses is discussed in Section 2.2.

2.1 Using ARR2016 sensitivity analysis results

Where only a sensitivity analysis is undertaken, results should only be used to understand the sensitivity to change and the potential impact it may have on decisions to inform:

- The relative priority and scope of the next stage of the FRM process. For example, if the sensitivity assessment results completed as part of a flood study show significant sensitivity to ARR2016 changes, the scope of the subsequent FRM study and plan (FRMS&P) should include a review of the flood study fully considering ARR2016.

- The relative priority and scope for review of an FRMS&P. For example, where an ARR2016 sensitivity analysis completed in an FRMS&P shows a significant sensitivity to change, the review of the plan to consider ARR2016 should be prioritised over plans in areas where sensitivity to change is limited. The scope of the FRMS&P review should include a review of the flood study to fully consider ARR2016.

- The scope of investigations and designs of floodplain management actions. Some management actions that are very sensitive to changes in flow and storm pattern may be sensitive to ARR2016 changes. Where this is the case and the project is in the investigation or preliminary design phase, consideration should be given to examining how this may influence design.

The methodology and information used for examining ARR2016 methods and the associated results should be fully documented. The case studies accompanying this guideline provide an outline of the recommended scope of reporting on ARR2016 transition.

2.2   Using results from studies completed with ARR2016

Studies applying ARR2016 need to consider NSW specifics as outlined in Section 3.7, as well as relevant state, local and regional data sets, and relevant data from the ARR Data Hub. Wherever possible these studies should be calibrated and validated to historic flood events, with calibrated and validated losses from previous reports being considered.

During the transition period for ARR2016, the results of such studies should be used in a precautionary manner when considering changes in management practices and standards.

Where results of studies indicate a reduction in peak flood levels or flood behaviour primarily due to ARR2016 transition, the council whose area is covered by the study may make a precautionary decision not to change practice or standards (such as minimum floor levels) until they complete further investigations. These further investigations should examine the implications of changes in practices or standards on the full range of flood risk to the community and document any associated decisions in an FRM plan.

Where results of studies indicate an increase in peak flood levels or flood behaviour, the relevant council may also take a precautionary approach. This may involve implementing the recommendations for changes in practices or standards while further investigations are completed. These further investigations should examine the implications of changes in practices or standards on the full range of flood risk to the community and document any associated decisions in an FRM plan.

The approaches outlined above are considered consistent with the FDM.

Table 1   Quick reference guideline on transitioning to ARR2016 – floodplain risk management process stage versus how to consider ARR2016

Stage of FRM process	Hydrological modelling approach used	ARR2016 practical to include?	Intend to go to next FRM process stage soon?	How to consider ARR2016	Result of sensitivity analysis (where applicable)
New studies	–	Yes, include in the brief	N/A	Fully consider ARR2016 and this guide, relevant data, NSW specifics and calibrated and validated data where possible. Test sensitivity to ARR1987 by comparing 1% AEP results with previous studies using ARR1987. Document basis for change.	N/A
Flood study or review underway prior to 2018–19	Runoff routing	Yes – if yet to do design flood estimates and consult community	No	Use ARR2016 and consider this guide, relevant data and test and report on sensitivity to ARR1987 methods.	–
			Yes	Continue with ARR1987. Consider ARR2016 and this guide in future FRMS.	–
		No – too late, generally if past the above point	No	Could consider addendum to study to test sensitivity to change.	If change is significant, reconsider timeline for next phase of the process. Clearly document reasons for change.
			Yes	Continue with ARR1987. Consider ARR2016 and this guide in future FRMS.	–
	FFA – unsupported methods	Yes – if a significant flood has occurred since FFA undertaken		Update FFA to use latest techniques.	–
	FFA – new methods	N/A			–

Stage of FRM process	Hydrological modelling approach used	ARR2016 practical to include?	Intend to go to next FRM process stage soon?	How to consider ARR2016	Result of sensitivity analysis (where applicable)
FRM study and plan underway prior to 2018–19	–	Yes – yet to assess options, set planning controls & consult community	N/A	UseARR2016 and consider this guide and compare results to previous flood study.	–
		No – too late if past the above point		Consider addendum that tests potential for sensitivity of flood behaviour to change and whether this influences management options and development controls.	If change is significant, include a recommendation to update FRMS&P and consider in I&D of relevant mitigation actions.
Investigation & design of mitigation works that change flood behaviour	–	Yes – early in investigation & preliminary design phase	N/A	Consider ARR2016 and this guide and compare results to previous study, document reasoning and confirm design is adequate.	N/A
		No – investigation & preliminary design nearing completion		Consider addendum that tests potential for sensitivity of flood behaviour to change and whether this will significantly influence the performance of mitigation work.	If change is significant, document reasoning. Where feasible, consider assessing in more detail and updating design.
Construction of mitigation work which is sensitive to flow or storm pattern	–	No	N/A	Consider testing sensitivity of flood behaviour to change as part of post-mitigation works behaviour assessment.	Consider in future FRM advice.

3. Overview of ARR2016 considering NSW practice

ARR2016 is the current national guideline on design flood estimation for Australia. It incorporates advances in input data, modelling techniques and associated technology. It provides advice on the use of different techniques and approaches to allow for the varying nature of catchments, floodplains and other factors that influence flood behaviour across Australia. It promotes improved modelling techniques, best practice and utilises more historic rainfall data than previous versions.

The update of ARR was developed around a wider evidence base than previous versions and in the context of great advances in access to technology and data. This allows for sophisticated approaches to the development and delivery of flood information. It also considers the needs of a broader range of end users of information. Therefore, it is less focused on peak flood levels and instead supports a broader understanding of flood behaviour and the factors that influence community flood risk and its management.

The update was also accompanied by changes in statistical rainfall information by the Bureau of Meteorology (BoM). Updated rainfall estimates were provided for up to 1 in 2000 annual exceedance probability (AEP) events. Probable maximum precipitation (PMP) estimates and procedures have not changed.

ARR2016 is not prescriptive. It recommends that practitioners use the most appropriate and up-to-date techniques and information for the circumstances being examined. As such, there are a range of NSW practices outlined in Section 3.7 that take precedence over ARR2016 advice or techniques in projects funded under the NSW Floodplain Management Program. In addition, in the majority of cases, information sources will exist that are more specific and relevant to the location than the information in the ARR Data Hub. Where this is the case these sources should be used in preference to data from the ARR Data Hub.

3.1 ARR2016 – main elements

ARR2016 consists of three main elements:

- the guideline
- spatial data sets
- enabling software for:
  - Regional Flood Frequency Estimation (RFFE), recommended only as a check in studies under the FMP and discussed in Appendix B
  - coastal/catchment coincident flooding, **not recommended for use in New South Wales**
  - blockage assessment, recommended for sensitivity testing and flood extent enveloping.

There is also a series of revision project reports upon which the main ARR2016 report is based that provide further information. Table 2 provides a summary of where the key elements of ARR2016 can be found.

3.2 ARR2016 – the guideline document

ARR2016 is available electronically so it can be updated dynamically to incorporate advances in data and technology. No hardcopy version has been produced. The guideline document consists of nine books. The books are divided into the core elements of design

flood estimation as described in Table 3, which also includes links to related tools and sections. ARR2016 is licensed under <u>Creative Commons Attribution 4.0 International</u>, therefore it can be reproduced with attribution.

Table 2   Where to access ARR2016

ARR element		Access at
ARR Guideline		http://arr.ga.gov.au/arr-guideline
ARR data inputs	IFD	http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016
	All other data	http://data.arr-software.org/
ARR enabling software	Regional Flood Frequency Estimation (RFFE)	http://rffe.arr-software.org/
	Interaction of coastal and riverine flooding **Use NSW Government advice as outlined in Section 3.7.2** rather than the ARR enabling software, which does not address entrance condition variability	http://p18.arr-software.org/
	Blockage assessment	http://www.arr-software.org/pdfs/BLOCKAGE_ASSESSMENT_FORM.pdf
ARR revision project reports		http://www.arr-software.org/project_reports.html

3.3 Key changes to ARR

Key changes with the update of ARR are discussed in the following sections:

- terminology (Section 3.4)
- ARR2016 design inputs, needs, accessibility and source management (Section 3.5 and Appendix A)
- flood frequency analysis (FFA) (Section 3.6.1)
- hydrologic and hydraulic modelling approaches including the use of multiple techniques to verify estimates (Section 3.6 and Section 4)
- approaches dealing with climate change and uncertainty (Sections 3.5.7 and 3.7.4).

3.4 Terminology

ARR2016 recommends terminology that is not misleading to the public and stakeholders. Therefore, the use of terms such as 'average recurrence interval' (ARI) and 'return period' are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals, e.g. 100 years. On the contrary, rare events may occur in clusters, such as the events at Kempsey in 1949 and 1950, and twice in 1893 in Brisbane, each of which were events with less than 1.25% chance of occurring in a year.

ARR2016 recommends the use of annual exceedance probability (AEP), which is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or as a 1 in X probability. Floodplain management typically uses the percentage terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year. ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. Table 4 shows how they are different.

Table 3   ARR16 Guideline books and related tools

Book	Overview	Related tools	Link to tool
1 Scope and Philosophy	Provides a general introduction to ARR and the basic philosophy and terminology. Discusses why ARR needed revision, provides the basic philosophy for the application of the guidelines, introduces terminology, discusses fundamental issues and basic approaches to flood estimation, data related aspects including management and uncertainty, risk-based design and dealing with climate change.	Climate change tool for projections replicated on ARR Data Hub	https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/ http://data.arr-software.org/
2 Rainfall Estimation	Discusses the importance of design rainfall for flood estimation, differences between historical and design rainfalls, and issues associated with development of rainfall models for design flood estimation in ARR. It provides the basis for the recommended IFD relationships, design spatial patterns of rainfall, pre-burst and burst rainfall and design temporal patterns.	IFDs via BoM website	http://www.bom.gov.au/water/designRainfalls/index.shtml
		Data for ARF regions, pre-burst & temporal patterns via ARR Data Hub	http://data.arr-software.org/
		Rainfall generator for continuous simulation	http://www.hydrology.unsw.edu.au/download/software/multisite-rainfall-simulator
3 Peak Flow Estimation	Advice on methods to estimate peak flow only. Flood frequency analysis (illustrated by examples) and RFFE techniques and describes RFFE tool application.	Flike program support by TUFLOW	http://flike.tuflow.com/
		RFFE accessed on website	http://rffe.arr-software.org/
4 Catchment Simulation for Design Flood Estimation	Advice on general concepts, theory and issues for different methods of catchment modelling for design flood estimation. It discusses catchment simulation and hydrologic processes and how these are represented in modelling systems. It also discusses types of catchment modelling systems, the need for integrating hydrologic and hydraulic components of the system, and treatment of joint probability issues and model output uncertainty.	None	
5 Flood Hydrograph Estimation	Theory on different hydrologic model types and baseflow and losses and provides design data for these inputs to design flood estimation and flood hydrograph estimation.	Data for losses and baseflow can be accessed via ARR Data Hub	http://data.arr-software.org/

Book	Overview	Related tools	Link to tool
6 Flood Hydraulics	Basic hydraulic aspects, blockage of structures, and interaction of catchment flooding and coastal inundation. The material presented in this book is not a replacement for the many textbooks in this area nor will it cover all the information necessary for the application of hydraulic principles in design flood estimation. Information is presented on hydraulic modelling of river reaches, floodplains and structures for design flood estimation, the application of software for numerical modelling of flood hydrographs, blockage of hydraulic structures and interaction of coastal and catchment flooding, as well as guidance on designing for the safety of people and vehicles, and it includes a discussion of the importance of demographics in assessing safety.	Use NSW advice (Section 3.7.2) instead of ARR interaction for coastal & catchment flooding tool.	http://p18.arr-software.org/
		An ARR form is available to assist in structure blockage assessment. It can be used to assess sensitivity of structures to blockage and produce enveloped flood extents.	http://www.arr-software.org/pdfs/BLOCKAGE_ASSESSMENT_FORM.pdf
7 Application of Catchment Modelling Systems	Discusses major issues in the practical application of catchment modelling systems to different flood estimation, problems including establishing systems, calibration and validation of parameters and dealing with uncertainty in model outputs.	None	
8 Estimation of Very Rare to Extreme Floods	Provides information and guidance for special design applications where these floods and their hydrographs need to be estimated for sizing spillways for large dams, design of major structures in the floodplain and FRM in situations where very large flood damages or significant risk to life is expected. Methods generally used to estimate these floods are described in Book 8, Chapter 2 with Book 8, Chapter 7 discussing special considerations, and additional data needs described in Book 8.	None	See BoM website
9 Runoff in Urban Areas	Provides a basic philosophy for urban catchments, discusses stormwater volume and conveyance, urban drainage approaches, impacts of urbanisation on the natural hydrologic cycle and design flood estimation, and use of on-site to large-scale storage facilities. It also discusses the limitations of the rational method and the changes in approach needed when considering volume-based problems rather than peak flow-based problems.	None	

For more frequent events than 50% AEP, AEP is not meaningful and can be misleading particularly in areas with strong seasonality. Therefore, the term exceedances per year (EY) is recommended (see Figures 1 & 2). Statistically, a 0.5 EY event (an event that would, on average, occur every two years) is not the same as a 50% AEP event. A 2 EY event (an event likely to occur twice a year) is equivalent to a design event with a six-month ARI where there is no seasonality.

The probable maximum flood (PMF) is the largest flood that could possibly occur on a catchment. It is related to the PMP, which has an approximate probability. Due to the conservative values applied to other factors influencing flooding, a PMP does not translate to a PMF of the same AEP. Therefore, an AEP is not assigned to the PMF. Note that the BoM uses a different terminology for the frequency descriptor of design rainfalls (Table 4).

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
	0.69	50	2	1.44
Frequent	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
	0.005	0.5	200	200
Very Rare	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
	0.0002	0.02	5000	5000
Extreme				
			PMP/ PMPDF	

Figure 1   ARR2016 preferred terminology (source: Figure 1.2.1 Book 1 Chapter 2 ARR2016)
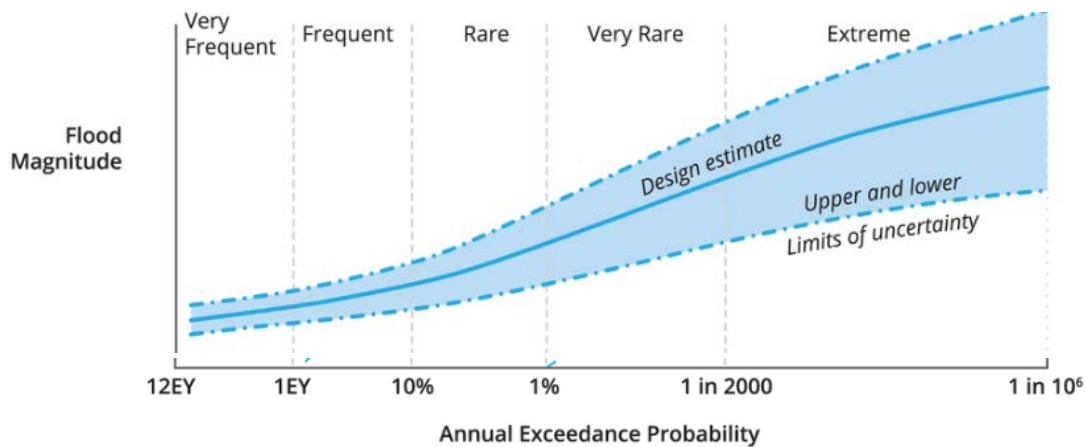
Figure 2   Illustration of use of terminology and interconnection with relative frequency (source: Figure 1.3.2 Book 1 Chapter 3 ARR2016)

Table 4   Comparison of BoM and ARR terminology

BoM terminology	ARR terminology
Very Frequent	Very Frequent
Frequent	Frequent
Infrequent	Rare
Rare	Very Rare
Extreme	Extreme

3.5   ARR2016 updated design inputs

Data for flood investigations comes from many sources that consider the local conditions. These may include previous studies which may incorporate calibrated and validated parameters for catchment losses and other factors.

One source of data to consider in local modelling is the data available with ARR2016 through the ARR Data Hub (use of the ARR Data Hub is discussed in Appendix A) and the BoM with links provided in Table 2. This section discusses the key inputs that are being or have been revised as part of the ARR revision projects. These include the revised IFD data, updated estimates using Cooperative Research Centre – FOcussed Rainfall Growth Estimation (CRC-FORGE) (for 1 in 200, 1 in 500, 1 in 1000 and 1 in 2000 AEP estimates), work on extending beyond CRC-FORGE to the PMF (Nathan et al. 2014), areal reduction factors, temporal patterns, losses, pre-burst and baseflow.

In ARR1987 most parameters either covered very large areas or were displayed on maps and required interpolation between contours. This led to issues with reproducing earlier results. This problem was compounded in the transition between map zones. Software suppliers and practitioners often embedded the input data into software for use in studies.

However, ARR2016 delivers all spatially-based information electronically via the internet. This removes problems with reproducibility and standardisation of approaches in the transition zones. Practitioners are required to gather updated information at the beginning of studies rather than using inputs embedded in software. This helps to ensure that the most up-to-date data is being used in studies. Note: The date and version number of each parameter set is a reporting requirement for studies, to facilitate review and reproducibility.

Table 5 provides a summary and comparison of design inputs for ARR2016 and ARR1987.

3.5.1 Design rainfall data

The updated IFDs were based around rainfall gauge data collected by the BoM and other agencies and incorporated a significantly larger number of continuous rainfall gauges than in ARR1987 (Green et al. 2012). The IFDs were the first of a number of design inputs to be released with data initially released in July 2013. As indicated in Table 6, ARR2016 is based upon a significantly improved coverage and length of pluviograph and daily-read rainfall data. All data used in the process was quality controlled. Table 6 presents a comparison of the data used to derive the 1987 and 2016 IFDs.

Updated rainfall estimates were provided in 2016 for the 2% and 1% AEP (50 and 100-year ARI) events as well as the very frequent IFDs (12, 6, 4, 3, 2, 1, 0.5 and 0.2 EY) and rare rainfalls (1 in 100, 1 in 200, 1 in 500, 1 in 1000 and 1 in 2000 AEP). PMP estimates and procedures have not changed.

Table 5   Changes to design inputs between ARR1987 and ARR2016

Design input	ARR1987 input	Standard practice prior to ARR2016	ARR2016	
			Reference book/section	Input and delivery method
IFD	Hard copy maps (mm/hr)	BoM website. Grid resolution 0.025 degrees	Book 2 Chapter 2 Design Rainfall	Revised 2016 IFDs updated by BoM and other agency gauges Available online Grid resolution 0.025 degrees Depths (mm) http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016
Areal reduction factors (ARFs)	Figure 2.7 from US data	CRC-FORGE work (except NSW)[1]	Book 2 Chapter 4: Areal Reduction Factors	New equations derived using Australian data Provided on ARR Data Hub
Spatial pattern	Centroid	Spatially distributed IFD including areal reduction factors	Book 2 Chapter 6	Spatially distributed IFD Provided on ARR Data Hub
Temporal patterns	Average Variability Method (AVM)	AVM, filtered for embedded burst	Book 2 Chapter 5: Temporal Patterns	Ensemble of 10 real storms Available on ARR Data Hub
Losses	State-based advice, sometimes based on data	Calibrated in the hydrologic model	Book 5 Chapter 3: Losses	Calibrated losses. Uncalibrated rural models use loss information (including NSW specific information[3]) available from the ARR Data Hub Urban losses use procedure in Book 5
Pre-burst	Allegedly incorporated into advice	Mixed[2]	Book 2 Chapter 5	National and NSW estimates[3] provided on ARR Data Hub
Baseflow	Methods but no ungauged catchment advice	–	Book 5 Chapter 4	National estimates provided on ARR Data Hub

Notes:

[1] In New South Wales a range of ARF values were used; it was often ignored, extrapolated out from the 1% AEP ARF, or the 1% AEP ARF was used for rarer events.

[2] Most areas in Australia ignored pre-burst. In New South Wales this was sometimes incorporated into the initial loss estimates from calibration.

[3] New South Wales approaches to losses and pre-burst are outlined in Section 3.7.1 of this guideline.

The 2016 IFDs, in general, provide an improvement over the 1987 IFD information; however, a broadscale assessment has shown that in coastal areas of New South Wales where relatively short duration storm events (less than six hours) may be critical, the broadscale methods used in the derivation of the 2016 IFDs and the grid density at which this information is provided (2.5 x 2.5 km grid) may not always be able to suitably capture local variations that may be important in relatively small catchments.

This means that in NSW coastal catchments where critical storm duration is likely to be less than six hours the BoM 2016 IFD information should be checked for consistency with at-site data derived from the stations in the area, where this information is available. This enables a decision to be made on whether to use the 2016 IFDs or locally derived IFD data in the specific circumstances. Advice on how this at-site analysis can be undertaken is available in Appendix D. Issues related to local coastal areas with orographic enhancement in New South Wales are discussed in Section 3.7.3.

Table 6   Comparison of data used in the ARR1987 and ARR2016 IFDs

Data	ARR1987 IFDs	ARR2016 IFDs
Number of rainfall stations	Daily-read: 7500 Continuous: 600	Daily-read: 8074 Continuous: 2280
Period of record	Up to ~1983	Up to December 2012
Length of gauge records used in analyses	Daily-read: >30 years Continuous: >6 years	Daily-read: >30 years Continuous: >8 years
Source of data	Bureau of Meteorology (primarily)	Organisations collecting rainfall data across Australia (including local and state government water agencies, hydropower generators and urban water utilities)
Quality controlling	Manual	Automated and manual

3.5.2 Spatial aspects of rainfall and areal reduction factors

Areal reduction factors (ARFs) are used to transform point IFD estimates to spatial rainfall estimates.

ARR1987 used ARFs derived from an American study that did not extend to rare events or long durations. Since 1987 ARFs have been estimated for longer durations as part of the CRC-FORGE project, with zones based on state boundaries. CRC-FORGE estimates were available for New South Wales in 2010 with the state split into two zones. Work by Jordan et al. (2013) as part of the ARR update has developed an approximation between the long and short (18 hr/24 hr to 1 hr) duration ARFs using Bell's (1976) method.

Since then, a trial of short duration ARFs in New South Wales was undertaken (Babister et al. 2014). This work was extended using short duration IFDs based on high-density pluviograph data from appropriate locations to produce short duration ARFs for use in Australia. This research was finalised and incorporated into ARR2016, with recommended ARF equations provided in Book 2 Chapter 4 Section 4.3.1.

3.5.3 Temporal patterns

Temporal patterns were revised as part of ARR2016, where over 100,000 storms were analysed.

A number of issues with the ARR1987 Average Variability Method (AVM) have been documented (Retallick et al. 2009). The pre-2016 ARR approach uses a peak burst only rather than a complete storm. ARR2016 recommends combining pre-burst rainfall with the traditional burst approach to reduce the difference between design storms and real storms.

The use of a single temporal pattern is not suitable for most projects as it does not allow for the natural variability of storms. A range of FRM actions (for example detention basins) and decisions are sensitive to the variability of storm patterns. Considering this variability can provide a better understanding of the impact of storm pattern sensitivity on the effectiveness of FRM actions.

ARR2016 recommends the use of an ensemble of at least 10 temporal patterns. As discussed in Section 3.6.5, the full ensemble will typically only be used in hydrological modelling with a single event (or a small number of events) selected for hydraulic modelling.

3.5.4 Losses

Wherever possible consideration should be given to the use of loss estimates that are calibrated and validated for areas relevant to the catchment in question. In all cases, the balance between losses and pre-burst (discussed in Section 3.5.5) should be examined to ensure they are reflective of flood history and observations in the lead-up to events.

ARR1987 losses advice was based on state, not hydrological boundaries. The advice for losses in some states was based on limited or no data.

ARR2016 analysed 35 stream records, using the approach outlined in Hill et al. (2015), which increased the reliability of loss estimates. The initial approach to develop predictor equations was problematic until the BoM released data from the Australian Water Resources Assessment Landscape (AWRA-L) model, a distributed water balance model that outputs information about soil moisture as a national gridded dataset.

Industry raised concerns that using the nationally derived information for loss and pre-burst parameters from the ARR Datahub in New South Wales was resulting in a significant bias toward underestimation of flows in studies.

This led to OEH commissioning a review of initial and continuing loss parameters and pre-burst developed through the update of ARR 2016 and recommended the approach outlined in Section 3.7.1 for New South Wales.

ARR2016 advice is based upon the outcomes of Revision Project 6 and recommends continuation of the use of the initial loss/continuing loss (IL/CL) loss model. ARR Book 5 Chapter 3 provides recommended median loss values for rural catchments and a process for estimating losses for urban catchments. While ARR1987 only considered initial losses for burst rainfall, ARR2016 considers pre-burst rainfall in the derivation and application of initial losses. Further information on how initial losses are derived is contained in Section 4.2.1.

3.5.5 Pre-burst

To convert storm initial loss to burst initial loss, pre-burst rainfalls were derived as part of the Australian Rainfall and Runoff revision projects. Pre-burst rainfalls were pooled from numerous representative events to create a pre-burst distribution. This pooling was carried out using the regionalisation strategy from the ARR Project 3 Stage 1 report (WMAwater 2015) to determine the closest 40 pre-burst events in this regional space at a multitude of target sites covering the entirety of Australia. The 10th, 25th, 50th, 75th and 90th percentiles were taken from the pre-burst distributions of the pooled rainfall events and gridded using a natural neighbours algorithm to define pre-burst rainfalls for all of Australia. In most areas pre-burst is not significant.

The derived pre-burst estimates allow for more detailed design event modelling using rainfall-based methods that better accounts for spatial trends and probabilities of pre-burst rainfalls.

The same review that examined losses (discussed in Section 3.5.4) also reviewed the use of median initial losses and pre-burst. The recommended approach for use in New South Wales is outlined in Section 3.7.1.

3.5.6 Baseflow

Project 7 of ARR2016 developed a method for calculating and adding baseflow contribution to design flood estimates (Revision Project 7). This involved the analysis of 236 catchments across Australia and the development of equations and application methods to produce design estimates for baseflow parameters. The project produced the baseflow volume (Figures 3 and 4). The ARR Data Hub provides baseflow factors presented in these figures. Note that the factors the ARR Data Hub produces are to a catchment outlet.

3.5.7 Climate change

ARR1987 provided no guidance on how to factor climate change into design rainfall estimates. The scope of the advice on changes in climate in ARR2016 has been limited to projected changes in rainfall intensity (or equivalent depth) because there is little available information on projected changes in rainfall frequency, duration and temporal patterns, antecedent wetness and baseflow. In its current interim form, the guidance recommends a 5% increase in design rainfall intensity per °C of projected warming. The magnitude of this scaling factor is based on multiple lines of evidence.
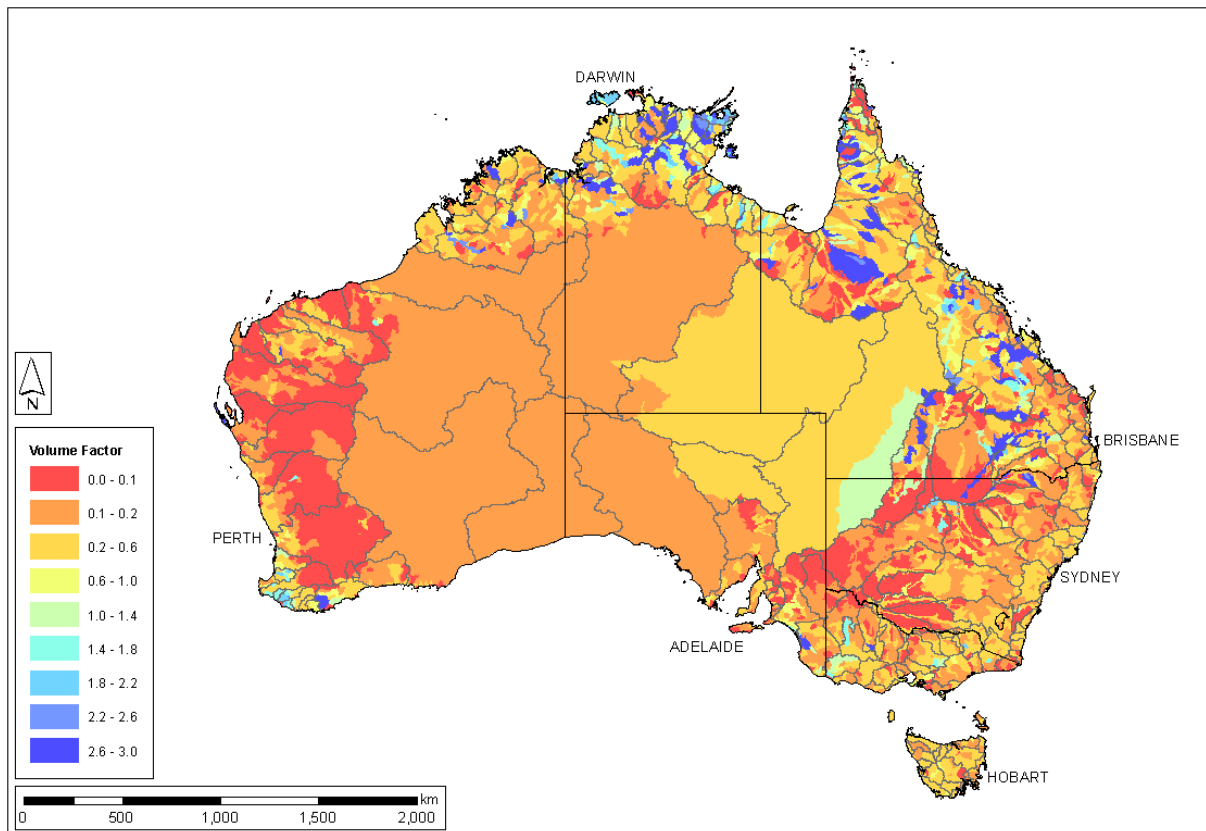
Figure 3 Map of baseflow volume factor for a 10% AEP
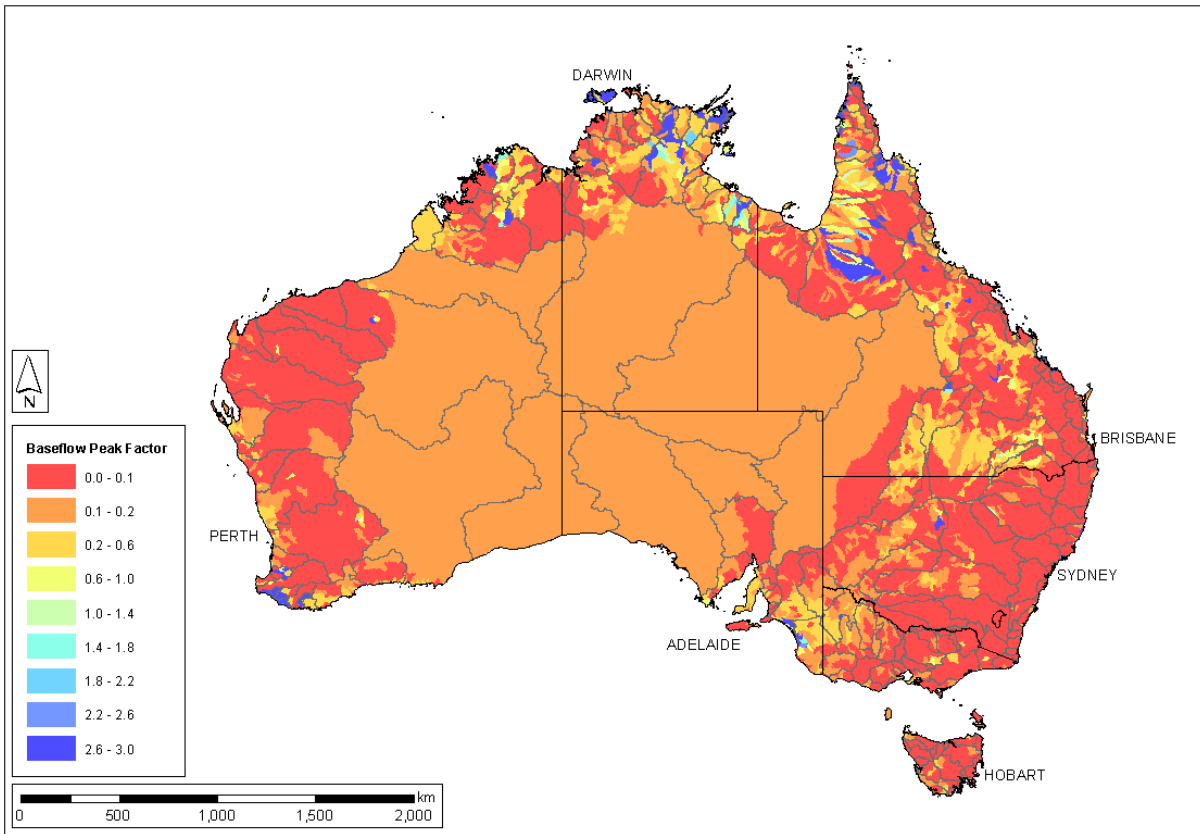
Figure 4   Map of baseflow peak factor for a 10% AEP

The ARR Data Hub provides the interim climate change factors as both temperature increases and percent rainfall increases based on the Climate Futures Tool. ARR2016 recommends the use of Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 values. These values are available as a percentage that the rainfall should be factored by from the ARR Data Hub. Appendix F Map 7 shows the climate change regions that apply to New South Wales. Figure 5 shows a screenshot of the information provided on the ARR Data Hub which incorporates the CSIRO work in relation to the impacts of temperature of different climate scenarios. Table 7 shows the climate change values for different NSW regions from the CSIRO work.

NSW guidance in Section 3.7.4 should be followed in studies under the FMP. The changes in the intensity and volume of flood-producing rainfall events derived from the ARR Data Hub should be discussed and included in reporting on climate change impacts.

Data

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	RCP 8.5
2030	0.892 (4.5%)	0.775 (3.9%)	0.979 (4.9%)
2040	1.121 (5.6%)	1.002 (5.0%)	1.351 (6.8%)
2050	1.334 (6.7%)	1.28 (6.4%)	1.765 (8.8%)
2060	1.522 (7.6%)	1.527 (7.6%)	2.23 (11.2%)
2070	1.659 (8.3%)	1.745 (8.7%)	2.741 (13.7%)
2080	1.78 (8.9%)	1.999 (10.0%)	3.249 (16.2%)
2090	1.825 (9.1%)	2.271 (11.4%)	3.727 (18.6%)

Layer Info

Time Accessed	26 July 2017 04:14PM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

Figure 5   ARR Data Hub – screenshot of climate change information

Table 7   Climate change values for regions in New South Wales (source: CSIRO)

Year	% change in rainfalls (based on 5% change in intensities for every 1°C change in mean temperature)									
	Central Slopes		East Coast South		Murray Basin		Rangelands		Southern Slopes	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
2030	4.9	5.3	4.5	4.9	4.3	4.9	5.1	5.5	3.6	4.1
2040	6.1	7.4	5.6	6.8	5.4	6.7	6.3	7.7	4.6	5.6
2050	7.4	9.8	6.7	8.8	6.5	8.7	7.6	10.0	5.6	7.2
2060	8.4	12.3	7.6	11.2	7.4	11.1	8.6	12.7	6.4	9.3
2070	9.2	15.2	8.3	13.7	8.1	13.8	9.5	15.7	7.0	11.7
2080	9.9	18.1	8.9	16.2	8.7	16.3	10.1	18.6	7.4	13.9
2090	10.2	20.8	9.1	18.6	9.0	18.7	10.3	21.4	7.6	16.1

3.5.8 Broadscale comparison of ARR2016 and ARR1987 inputs

Maps of New South Wales showing the difference between ARR2016 and ARR1987 IFDs are provided in Appendix F. These maps can assist in indicating the scale of likely relative change in parameters on a catchment or local government area basis. Maps include differences between the 2016 IFD and 1987 IFD for 1% AEP for durations of 1, 6, 12, 24, 48 and 72 hours (Maps 1 to 6).

Examining this information identifies that:

- significant increases in the 1% AEP 1-hour duration IFD occur on the coast from Gosford to Wingham, in a patch near Armidale and in south-western New South Wales
- significant decreases in the 1% AEP 1-hour duration IFD occur in Sydney and on the south coast
- significant decreases occur in the Hunter, Manning, Hastings, Macleay and Bellinger catchments for the 1 day 1% AEP IFD. Significant decreases occur near Cooma (sub-daily durations) and Lismore (durations longer than 24 hours) in the 1% AEP.

3.6   ARR2016 updated methods

A number of the methodologies used to derive flow estimates and associated issues were revised as part of the ARR2016 revision as shown in Table 8 and discussed in the remainder of this section. The order of discussion does not relate to their order of appropriateness or relevance. Selection of techniques is discussed in Section 4.1.

3.6.1 Flood frequency analysis updated

Flood frequency analysis (FFA) involves estimating peak flows from historical flood levels and using probability models to extrapolate the probability of different magnitude events occurring. FFA is generally not applicable to peak flood level data as the rate at which flows increase relative to flood levels is dependent on the channel geometry at the gauge and not suitable for extrapolation.

Peak flow estimates are used to generate either an annual maxima series or a peak-over-threshold series (see ARR2016 Book 3 Chapter 2 for a detailed description). The peak flow series is generally then analysed by software (such as TUFLOW Flike) to produce a relationship between peak flow and AEP.

FFA with a decent record length of quality data is the most reliable method of estimating design flows. All other methods are based on FFA or calibrated to it. ARR2016 Book 3 Chapter 2 Section 8 includes a number of worked examples of FFA.

Table 8   Changes to methodologies between ARR1987 and ARR2016

Method	ARR1987	ARR2016
At-site flood frequency analysis • gauged • ungauged	Probabilistic Rational Method in some states	Bayesian of L moments Regional Flood Frequency Estimation
Hydrograph estimation methods	Simple design event	Ensemble and Monte Carlo
Direct rainfall	Not considered	ARR Project 15
Blockage	Not considered	Blockage Guidelines
Interaction of coastal and river flooding	Not considered	ARR Project 18 [1]
Joint probability	Not considered	ARR Book 4 Chapter 4
Safety design criteria	Not considered	People, vehicle and building hazard curves [2]
Climate change impacts on flood-producing rainfall events	No specific advice	Interim Advice ARR Project1, ARR Book 1 Chapter 6 [3]

Notes:

[1] Use NSW Government advice as per Section 3.7.2

[2] Use Australian Institute for Disaster Resilience (AIDR) FRM Guideline 7.3 Flood Hazard (AIDR 2017a) unless otherwise specified in briefs

[3] See Section 3.7.4

ARR2016 has focused on reducing and exposing uncertainty in peak flood estimation resulting in a substantial change from the at-site FFA methods from the 1987 edition. Significant changes from ARR1987 include:

- reduced prescription about the choice of flood probability model and fitting methods
- the ARR1987 recommendation of using Log Pearson 3 (LP3) distribution fitted using method of moments is no longer supported
- a range of distributions can be investigated for a site. Generalised Extreme Value (GEV) and Log Pearson 3 (LP3) are main distributions recommended
- LH-moments and Bayesian fitting methods are recommended. Bayesian fitting methods included to make better use of available flood information and allows for censoring of low flow data using the Multiple Grubbs and Becks approach
- inclusion of estimates of uncertainty
- software is integral to the approach – TUFLOW Flike software is required to implement Bayesian methods.

The adoption of a Bayesian approach for fitting a distribution allows for explicit modelling of uncertainty, and the integration of additional information with the at-site flow records. Additional information could include historic (pre-gauge) flood information or information from a regional FFA. The Bayesian approach can also incorporate methods to censor low flow data to provide a better fit to the high flow data of interest.

There are limitations to FFA that should be considered, including:

- rare events are typically extrapolated from a limited set of data with significant margins for error
- peak flow estimates can be sensitive to the accuracy of the rating curve used to convert the flood levels to peak flows
- the rating curve may not be relevant for historic data due to catchment changes, changes to stream morphology or gauge relocation.

3.6.2 Hydrological modelling replaces urban rational method

The rational method for urban areas is based on data from 1958. Work on ARR2016 found very few quality urban streamflow gauges in a national search and therefore this method was not able to be updated in ARR2016.

The urban rational method is only recommended for very small areas (i.e.1–2 urban lots). The urban rational method, therefore, should not be applied on studies undertaken under the Floodplain Management Program.

As an alternative, hydrologic and hydraulic modelling should be used. Models reproduce catchment flows well at a small scale (i.e. 1–5 km^2) and are a better basis for extrapolation. They also better represent characteristics that change with scale, such as gutters and pipes.

3.6.3 Runoff routing modelling is recommended rather than unit hydrographs

The runoff routing approach is recommended in ARR2016. The general term 'runoff routing' refers to flood hydrograph modelling approaches where a simplified conceptual representation is used to convert rainfall and catchment inputs to a flood hydrograph at the catchment outlet (using a routing model). The increase in computing power in the 30 years since the release of ARR1987 means that runoff routing models are now routinely used.

ARR2016 does not recommend using the unit hydrograph approach for practical applications based on recognised limitations and the availability of more flexible runoff routing approaches. The only situation where the unit hydrograph is recommended to be applied is where the assumptions that limit this method (linearity of catchment response and spatial uniformity of rainfall excess) can be satisfied. However, this is rarely the case. The unit hydrograph approach is also unsuitable for determining flood behaviour for changed catchment conditions, as it is based on a range of observed hydrographs for the catchment condition at the time. These limitations are not present in runoff routing approaches.

ARR2016 describes a range of approaches to calculate design flood hydrographs including time-area, unit hydrograph, runoff routing, and direct rainfall on grid approaches.

3.6.4 Regional Flood Frequency Estimation replaces Probabilistic Rational Method

ARR2016 supports the use of the Regional Flood Frequency Estimation (RFFE) method.

It <u>does not</u> support the use of the Rural Probabilistic Rational Method (PRM) to determine flows from ungauged catchments.

RFFE involves regionalising gauged stream flow data to determine flood quantiles at an ungauged location. It is the first regional flood method that applies for the whole of Australia. Over 900 gauges across the country including 176 in New South Wales in the humid coastal region (which covers the whole NSW coast) were used in its development. The method uses complex regression equations which pool data from nearby stations. Background on the method development can be found in ARR Book 3 Chapter 3. There is also a summary of useful publications at http://rffe.arr-software.org/publications.html.

The RFFE method (discussed in Appendix B) can be used to:

- Estimate design flows for ungauged rural catchments.
- Verify flow estimates. It can be used for checking estimates of flows for rural catchments. It can also be used with caution to check estimates for non-urbanised conditions in urban catchments.
- As prior information to inform at-site flood frequency.

Comparisons between the PRM and RFFE are provided in Gilmore et al. (2014). Rahman et al. (2011 and 2012) discuss perceived shortcomings of the PRM.

3.6.5 Ensemble modelling approaches replace single design events

To estimate flood behaviour, ARR1987 proposed using a single design event that used the AVM for the temporal pattern.

ARR2016 recommends four approaches, as shown in Figure 6. Table 9 provides a summary of when to use each of these approaches, which are described in more detail in Section 4.3.
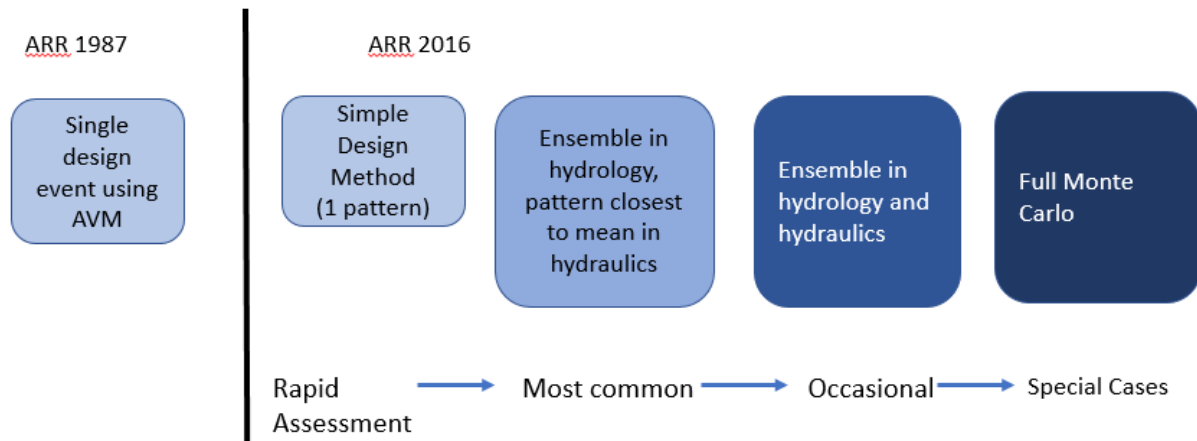

Figure 6   Methods for design flood estimation

Table 9   Summary of methods for design flood estimation and typical uses

Method	Use	Example
Simple design method	Rapid assessment	N/A
Ensemble in hydrology, mean in hydraulics	Most common	Large rivers such as Hunter River, Manning River (refer to ARR2016 Case Study – Rural (WMAwater 2017a)) Most flood studies
Ensemble in hydrology and hydraulics	Occasional	May be used when the hydraulic model runs quickly (refer to ARR2016 Case Study – Urban (WMAwater 2017b)) Direct rainfall approaches An ensemble in hydraulics may also be considered in volume driven systems where significantly different storm patterns derive similar peak flows to the mean and when assessing management measures such as basins, that are sensitive to storm patterns
Full Monte Carlo	Special cases	Very large systems with large populations at risk, dam studies; for example, Hawkesbury–Nepean River or Brisbane River

3.6.6 Direct rainfall

For modelling for the direct rainfall method (DRM), an ensemble approach involves running the 10 temporal patterns in the hydraulic model, which can be time-consuming.

Issues associated with DRM that need to be addressed in studies using ARR2016 are discussed below and in Appendix C.

For studies under the NSW FDP practitioners wishing to use DRM need to:

- ensure that DRM is fit for purpose for the catchment and floodplain being considered
- outline the alternative hydrological method that is intended to be used. Note that runoff routing modelling is required

- outline how calibrated and validated runoff routing model results will be used in developing DRM
- ensure that DRM is appropriate to enable full assessment of potential management options
- ensure that relevant volume checks are undertaken.

Written justification and agreement for the use of DRM is required by the relevant council and OEH Flood Specialists before DRM is used in any study.

The aspects identified above and in Appendix C need to be addressed in full in reporting.

3.6.7 Blockage

Blockage of hydraulic structures was not considered in the previous version of ARR.

The ARR2016 Blockage Guidelines outline a methodology for assessing the likely blockage (referred to as guideline blockage) of each structure (Weeks and Rigby 2015 and ARR Book 6 Chapter 6). This is supported by a blockage assessment form. This approach should be applied where location-specific advice has not been developed.

It is recommended that studies completed under the NSW FMP use this information as part of the blockage assessment, where the sensitivity of flood behaviour to a range of blockage scenarios (from 'all clear' to double the blockage identified in the guideline) is assessed. Where flood behaviour is sensitive to structure blockage, an envelope approach that amalgamates the results of different scenarios should be used when presenting model results.

3.6.8 Coincident coastal and catchment inundation

The approach in ARR2016, outlined in Zheng et al. (2014), examines the interaction of flood levels in the waterways and coastal water level conditions in isolation of entrance condition, to produce a method that statistically analyses the interaction of coastal and river flooding for ARR. The method has been implemented in ARR enabling software, however, this approach does not deal directly with entrance variability and therefore **should <u>not</u> be used in studies under the NSW FMP without agreement** as outlined above. NSW advice is to be used instead of the ARR methodology for studies under the NSW FMP (see Section 3.7.2).

3.6.9 Joint probability

It is becoming more common to use joint probability approaches when factors other than rainfall have a significant effect on flooding. Typically, the industry has used the average value for other factors such as losses and pre-event dam levels. The most common application of a joint probability approach for studies under the NSW FMP will be at the junction of two major rivers where the headwaters are in very different areas, so they respond differently. Background on joint probability analysis and typical applications to flood estimation problems, including the confluence of two rivers and the estimation of flood levels downstream, are available in ARR Book 4 Chapter 4.

3.6.10 Flood hazard

Australian Institute for Disaster Resilience (AIDR) Guideline 7-3 Flood Hazard (https://knowledge.aidr.org.au/resources/guideline-7-3-flood-hazard) should be utilised for flood hazard. The work in ARR Revision Project 10 updated the work done in the 1970s on hazards to people and vehicles. AIDR Guideline 7-3 extended this work and combined it to create one set of hazard curves that cover buildings, vehicles and people. This work was included in ARR Book 6 Chapter 7.

3.7 NSW approaches used with or instead of ARR2016

There is a range of specific advice, techniques, information and requirements that are considered more appropriate to the NSW context than national approaches in ARR2016. Their use is consistent with FDM 2007, AIDR Handbook 7 and ARR2016.

Studies undertaken with funding from the NSW FMP should use these where appropriate and specified unless agreed to in writing by the relevant council and OEH Flood Specialists after considering the justification provided. These practices relate to:

- estimating initial and continual losses, pre-burst and burst losses in NSW Catchments (Section 3.7.1)
- the coincidence of coastal inundation and catchment flooding (Section 3.7.2)
- IFDs in local coastal areas of orographic enhancement (Section 3.7.3)
- consideration of climate change impacts (See Section 3.7.4)
- defining the PMF for flood risk management purposes (3.7.5)
- review and update of rating curves at river gauge locations (Section 3.7.6)
- what to look for in reviewing studies and models for ARR transition (Section 3.7.7)
- reporting and data handover requirements relating to the ARR2016 transition (Section 5). These are in addition to the general project reporting requirements outlined in project specifications developed from the OEH brief development tool.

3.7.1 Initial and continuing losses, pre-burst and burst losses in NSW

Industry practitioners in New South Wales have raised concerns that the nationally derived information for loss and pre-burst parameters from the ARR Data Hub in New South Wales was resulting in a significant bias toward underestimation of flows in studies.

This led OEH to commission a review of initial and continuing loss parameters and pre-burst developed through the update of ARR2016. The subsequent study (WMAwater 2019):

- Showed that when using the data available from the ARR Data Hub there is a considerable underestimation bias in the design event method in New South Wales due in part to the nationally derived estimated loss and pre-burst parameters available from the ARR Data Hub.
- Demonstrated that the use of median pre-burst in the formula (*Burst loss (IL$_B$) = median storm loss (IL$_S$) – median pre-burst* as shown in Figure 7) is unrepresentative of using the full pre-burst distribution for a number of durations in New South Wales and therefore should not be used; this is particularly a problem when you have a high 90% pre-burst and when the ratio of 90% to median pre-burst is high.
- Recommended the use of NSW probability neutral pre-burst information rather than the median values; this information is available through the ARR Data Hub.
- Derived NSW FFA-reconciled losses at gauges in a range of catchments across New South Wales; advice on where this is available and the information itself is accessible on the ARR Data Hub.
- Derived a NSW adjustment factor of 0.4 to be applied to continuing losses derived from the national approach used in ARR and available through the ARR Data Hub.
- Indicated that the ARR Data Hub initial loss values are typically high for NSW; therefore, it recommended that for catchment areas of 100 km^2 or less additional scrutiny should be applied to the balance between initial losses and probability neutral pre-burst to ensure they are reflective of flood history and observations in the lead-up to events. High storm initial loss values are not a problem if they result in reasonable burst initial loss, but caution should be exercised where high burst initial losses are removing a large amount of rainfall excess and represent a large portion of the storm.
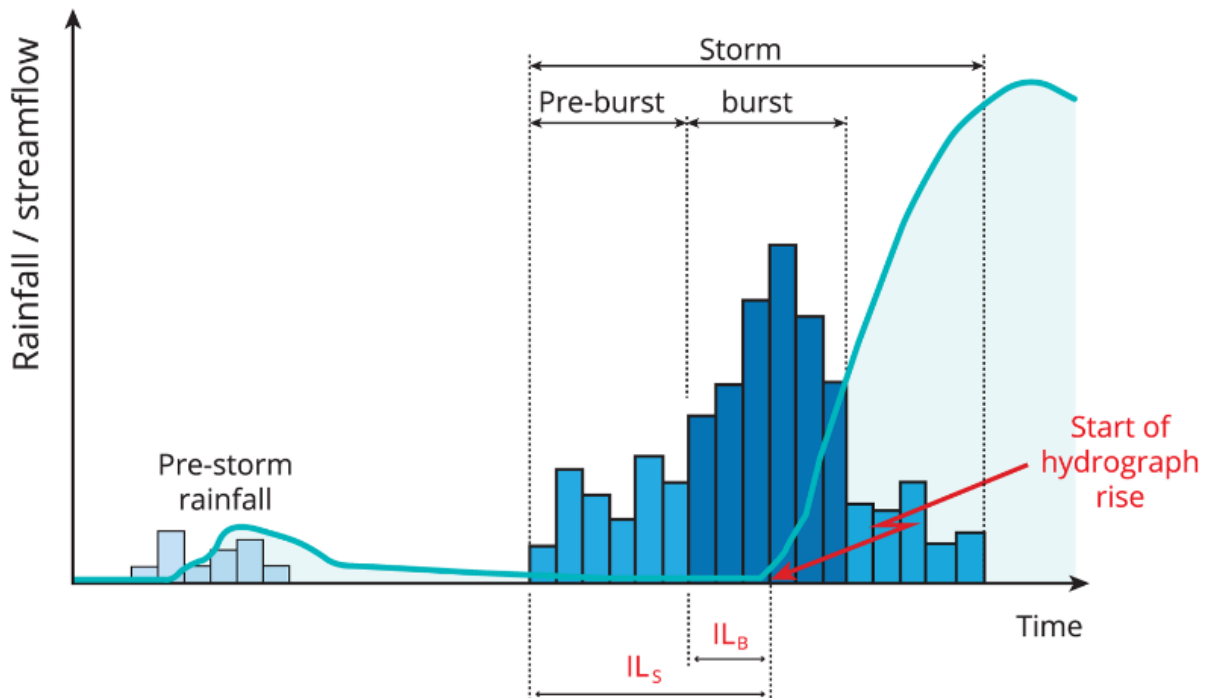
Figure 7   Burst loss versus storm loss (source: ARR Figure 5.3.5)

Considering this new information, practitioners undertaking flood investigations in New South Wales should use a hierarchical approach to loss and pre-burst estimation. This hierarchy goes from 1 (most preferred) to 5 (least preferred) as indicated in Table 10 and described below.

1. Use the average of calibration losses from the actual study on the catchment if available.

2. Use the average calibration losses from other studies in the catchment, if available and appropriate for the study.

3. Use the average calibration losses from other studies in similar adjacent catchments, if available and appropriate for the study.

4. Use the NSW FFA-reconciled losses available through the ARR Data Hub. These losses may be used within the catchment in which they were derived (available through the ARR Data Hub) or similar adjacent catchments with appropriate scrutiny. This is used with the unmodified ARR Data Hub initial losses which requires the application of additional scrutiny to the balance between initial loss and pre-burst to ensure it is reflective of flood history and observations for the catchment being investigated in the lead-up to events. This is particularly important in catchments of 100 km^2 or less.

5. Use default ARR data hub continuing losses for a location with a multiplication factor of 0.4. This is used with the unmodified ARR Data Hub initial losses which requires the application of additional scrutiny to the balance between initial loss and pre-burst to ensure it is reflective of flood history and observations for the catchment being investigated in the lead-up to events. This is particularly important in catchments of 100km^2 or less.

Where good local initial loss data is not available (Cases 4 and 5) the probability neutral burst initial loss values determined in the WMAWater 2019 study and available through the ARR datahub should be used in all instances unless a detailed Monte Carlo assessment of pre-burst and losses has been carried out.

For storm initial losses obtained by methods other than through the ARR data hub, burst initial losses should be adjusted using the below equation.

Equation 1

$$IL_{burst\,for\,design} = IL_{storm\,calibrated\,or\,transformed} \times \left(\frac{IL_{burst\,from\,ARR\,datahub}}{IL_{storm\,from\,ARR\,datahub}} \right)$$

Table 10   Hierarchy of approaches from most (1) to least (5) preferred

Approach	Storm initial loss	Pre-burst (transformational)	IL burst	Continuing loss
1	Average Calibration	Not required or back calculated using IL$_{storm}$ - IL$_{burst}$	Calculated from Equation 1 above	Average Calibration
2	Average Calibration	Not required or back calculated using IL$_{storm}$ - IL$_{burst}$	Calculated from Equation 1 above	Average Calibration
3	Average Calibration	Not required or back calculated using IL$_{storm}$ - IL$_{burst}$	Calculated from Equation 1 above	Average Calibration
4	NSW FFA reconciled initial loss (see ARR Data Hub)	Not required or back calculated using IL$_{storm}$ - IL$_{burst}$	Probability Neutral Burst Loss available through ARR Data Hub	NSW FFA reconciled continuing losses where available (see ARR Data Hub)
5	ARR Data Hub initial loss	Not required or back calculated using IL$_{storm}$ - IL$_{burst}$	Probability Neutral Burst Loss available through ARR Data Hub	ARR Data Hub continuing losses multiplied x 0.4

3.7.2 Coastal inundation/catchment flooding guidance

Flooding in the downstream areas of many coastal catchments results from runoff from catchments interacting with elevated sea levels, both generated by the same weather event. This interaction influences conditions at the waterway's entrance or in the waterway itself.

Historically, assumptions have been made about either the independence of these events, or the degree of interdependence, based on the timing of rainfall or flood peaks and peak ocean and/or estuarine conditions; for example, peak runoff and peak ocean or estuary levels coinciding.

Assuming that the weather events that generate elevated ocean or estuary conditions and significant catchment runoff are independent can underestimate flood levels in coastal areas. Conversely, an assumption that the flood peak coincides with the peak elevated ocean or estuarine conditions can overestimate flood levels in coastal areas.

Many coastal waterways in New South Wales have untrained or partially trained entrances with entrance conditions varying substantially over time and in some cases closing completely, as is the case of intermittently open and closed lakes and lagoons (ICOLLS). These entrance conditions can be a dominant factor in flood levels in the lower portion of coastal waterways; ignoring these entrance conditions can underestimate flood levels in lower coastal waterways.

To specifically address this issue, OEH produced the *Flood Risk Management Guideline: Modelling the Interaction of Coincidence of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (OEH 2015). The guideline and associated documents are available at: Floodplain Risk Management Guidelines.

The guideline outlines a procedure for examining this interaction in coastal waterways in New South Wales. This approach considers the entrance conditions and should be used in preference to the approach outlined in ARR2016, which does not explicitly consider the variability of entrance conditions.

The NSW OEH Flood Brief Development Tool provides the ability to refer to this guidance in project specifications.

3.7.3 IFDs in local coastal areas of orographic enhancement

The development by the BoM of national IFD information as part of the ARR2016 update is generally a significant improvement on that in ARR1987. It is based on longer records across a denser network of rain gauges with significantly more pluviographs and involved more advanced estimation techniques (Section 3.5.1).

This approach involved deriving a statistically significant number of gauge years of information at each relevant location. Deriving sufficient information at a location involved pooling data from stations based upon proximity, i.e. from the closest gauges.

This approach has the advantage of being able to incorporate large flood-producing rainfall events that affected nearby gauges but can result in the pooling of data from areas with dissimilar rainfall characteristics.

This is particularly an issue in some smaller catchments in coastal areas of New South Wales where the driving forces for flood-producing rain, such as orographic enhancement, can vary. The method of pooling data from nearby gauges can result in gauges in the coastal plains, the orographic enhanced area of the coastal escarpment, being pooled together with those in the rain shadow of the coastal escarpment. This has the potential to overestimate IFDs on the flatter coastal plains and in the rain shadow (western side) of the escarpment while underestimating rainfalls in the orographic enhanced areas of the coastal (eastern) escarpment.

In studies where this variation may be important, consideration should be given to assessing at-site data (some guidance on techniques is given in Appendix D) and comparing this to the 2016 IFD data. If 2016 IFDs vary significantly from the at-site IFDs then consideration should be given to using the at-site IFDs rather than the 2016 IFDs. This is likely to occur primarily in some smaller coastal catchments with a critical storm duration of six hours or less, in areas where the terrain and the driving forces for flood-producing rainfall events vary significantly.

The NSW Government Flood Brief Development Tool provides the ability to select a clause in the project specification to facilitate at-site IFD assessment and comparison with 2016 IFDs in coastal areas. This should only be selected in coastal catchments with critical storm durations of six hours or less.

The use of locally derived IFDs is not new in New South Wales. Coffs Harbour used locally derived IFDs rather than the 1987 IFDs to account for the rapid variation in the terrain which resulted in unique flood-producing rainfall driving mechanisms, such as orographic enhancement, that significantly influenced IFD estimates. Similar conditions existed in the vicinity of the Illawarra escarpment; however, no locally derived IFDs were used in response to the 1987 IFDs. Given that these issues occurred in the 1987 IFDs, OEH commissioned WMAwater Pty Ltd to examine this issue. The findings of this work are available in WMAwater (2018b).

3.7.4 Consideration of climate change impacts on flood events

The FRM process provides knowledge of flood behaviour so that it can be considered in decision-making.

The tools used for understanding existing flood behaviour can be adapted to consider flood behaviour with both changing sea level as well as changing flood-producing rainfall events.

The sensitivity of flood behaviour and consequences for the community of changes in sea level rise and changes in flood-producing rainfall events should be documented in studies.

Sea levels

The NSW Government recommends local councils consider developing sea level rise projections based upon broadly recognised scientific opinion. In relation to changing flood behaviour with sea level rise, council projections can be used to derive an understanding of flood behaviour with the changed conditions in waterways, as outlined in the NSW Government flood risk management guideline on the interaction of catchment flooding and coastal inundation (OEH 2015). This changed behaviour should be considered in decision-making where appropriate.

Flood-producing rainfall events

Climate change is also expected to impact upon flood-producing rainfall events.

Section 3.5.7 provides ARR2016 advice on how the scale of this change may be estimated. Table 7 provides an understanding of the projected rainfall changes based upon the recommended interim approach in ARR for 5% change in the intensity and volume of flood-producing rainfall events for every 1°C change in mean temperature for the recommended scenarios of RCP4.5 and RCP8.5. The results provided in Table 7 indicate that for 2090 percentage changes in rainfall across NSW regions, based on ARR interim advice, are between 7.6 and 10.3% for RCP4.5 and 16.1 and 21.4% for RCP8.5. The ARR Data Hub will provide advice relative to the actual location, as discussed in Appendix A.

This information can be compared to changes in flood-producing rainfall events developed using other data sources, such as AdaptNSW. This includes the NSW and ACT Regional Climate Change Modelling (NARCliM) Project, which provides a range of climate scenarios for 2030 and 2070.

Studies under the NSW FMP are to take a practical approach to consideration of the impacts of changes in flood-producing rainfall events on flood behaviour. Studies under the NSW FMP generally consider a range of floods, including several above the 1% AEP flood (generally used to derive flood planning levels and areas) to understand the changing scale of impacts (including damages) of flooding on the community. This may include the 0.5% (1 in 200 year) AEP and 0.2% (1 in 500 year) AEP flood events along with the PMF.

The 0.5% and 0.2% AEP flood events are in the order of 15% and 30% more rainfall than the 1% AEP flood event respectively, although the actual difference varies with location within New South Wales and can be determined in individual studies. Rather than simulating additional scenarios specifically to consider climate change, the scale of climate change impacts can generally be practically assessed using the 0.5% and 0.2% AEP floods as proxies for the 1% AEP flood, subject to long-term changes in flood-producing rainfall events related to climate change.

The percentage change in rainfall intensity for these events relative to the 1% AEP flood event can be compared to the estimated climate change projections from methods discussed above and in Section 3.5.7.

Reporting can discuss the sensitivity to change and can inform decisions on the need to further consider adaptation strategies for this change.

3.7.5 Defining the PMF for Flood Risk Management Purposes in NSW

The probable maximum flood (PMF) as defined in the Floodplain Development Manual provides the upper limit of flooding to inform flood risk management for communities. Estimation of the PMF provides a basis for understanding the extent of the floodplain and the upper scale of the flood problem faced by communities. It is of particularly important to consider the PMF in emergency management.

The estimation of the PMF involves both flow estimation and routing of flows through a hydraulic model established for the project. PMF flow estimation has generally been undertaken using techniques 1 or 2 outlined below. These techniques have been found to be cost effective and fit for purpose for studies conducted under the FRM process in New South Wales.

Book 8 of ARR2016 (Nathan & Weinmann 2016) now provides a third technique, outlined below, relevant to flood risk management. This can be used but requires greater effort and is more time consuming and costly.

Therefore, the use of technique 1 is preferred with the use of either options 2 or 3 for a specific project requiring clear justification based on evidence of the need for and reasonableness of the approach. Their use is to be clearly justified to OEH technical flood specialists and the relevant council staff and agreement provided in writing before proceeding.

1. Use of probable maximum precipitation (PMP) and the associated temporal pattern and spatial characteristics derived using the appropriate generalised PMP method from the Bureau of Meteorology (BoM 2006, http://www.bom.gov.au/water/designRainfalls/pmp/). The PMF flow derived from this method has the same probability as the PMP. The Generalised Short Duration Method (GSDM) is applicable for all small catchments in NSW. For large catchments the Revised Generalised Tropical Storm Methods (GTSMR) is used north of the Hunter River catchment while the Generalised Southeast Australian Method (GSAM) is used south of the Hunter River catchment. The Hunter River catchment is considered the transition zone and the long duration methods that produce the highest flows are used. In all cases this advice is used with low initial and continuing losses (typical an initial loss of zero mm and a continuing loss of 1 mm/hr) and storages in dams in the catchment full to be reflective the worst flood producing catchment conditions.

2. By agreement with OEH flood specialists and the relevant council, the use of an equivalent extreme event to represent the PMF. The derivation of flows for such an event should be adequately justified and may involve the use of a multiplier for either the rainfall or runoff for a design event, such as the 1% AEP event, or a key historic event, such as the flood of record at a location. Typically used where use of PMPs and associated hydrologic modelling is not practical.

3. By agreement with OEH flood specialists and the relevant council, the derivation of a PMP flood (ARR2016) can be used as a PMF estimate for flood risk management purposes. ARR2016 outlines that the estimation of the PMP flood uses the median of an assessment of the PMP across a range of different temporal patterns (to be made available through the ARR datahub) and that the flow derived has the same probability as the PMP estimate. As with option 1, this advice is used with low initial and continuing losses (typically an initial loss of zero mm and a continuing loss of 1 mm/hr) and storages in dams in the catchment full to be reflective the worst flood producing catchment conditions.

It should be noted that ARR 2016 also provides for the estimation of a PMF for dam safety purposes. This is not the same as the PMF for flood risk management and is not considered relevant for that purpose. This dam safety PMF is more conservative (the 90 percentile estimate using technique 3) than the PMF used for flood risk management purposes for

communities. This conservatism allows for the additional risks to downstream communities associated with structural failure of the dam during a flood. As such, it may also be necessary to calculate this dam safety PMF for design of flood retention or retarding basins or dams where required by relevant state or national guidance. Note: the dam safety PMF is significantly rarer than the PMP rainfall estimate on which it is based.

3.7.6 Review and update of rating curves at river gauge locations

Where hydraulic modelling for a study includes relevant river gauge locations it should incorporate a review and update of the rating curve for the gauge within the project scope.

Where an update to the rating curve is required, it should be reviewed as follows:

- Review the current rating relationship.
- Confirm accuracy of cross-section at gauge (or source new survey if necessary).
- Ensure cross-section extends sufficiently for extreme floods.
- Investigate any changes to the cross-section over the gauge record, which may render the current rating unsuitable for historic readings (such as relocation of gauge or geomorphic changes).
- Develop a suitably calibrated hydraulic model within the vicinity of the gauge. Model boundaries should be located far enough from areas of interest to not influence model results. Run a range of flows through the model and extract height (H) and flow (Q) at the gauge.
- Plot Q-H relationship with historic gaugings.
- Documentation and reporting of the above as per Section 5.3.

The information outlined in Section 5.4 should be handed over as part of general requirements and provided to the gauge owner for their consideration.

This information will assist in improving the RFFE tool, which provides estimates for ungauged rural catchments by pooling information from at-site FFA from surrounding water level gauges. While this uses a sophisticated procedure, it is only as accurate as the input information.

3.7.7 What to look for in reviewing studies and models for ARR2016 transition

Appendix E provides a list of issues to consider in reviewing studies addressing ARR2016 transition. This does not negate the need to do broader assessments of reports, modelling and outcomes to ensure that these are fit for purpose.

4. Application of ARR2016 in NSW FMP studies

This section provides guidance about how the update to ARR may practically be incorporated into studies funded under the NSW FMP.

Data for flood investigations comes from many sources that consider the local conditions. These may include previous studies which may provide calibrated and validated parameters for catchment losses and other factors. Key changes in input data between ARR1987 and ARR2016 are documented in Section 3.5 and summarised in Table 5. Table 11 provides a summary of the tasks involved in standard studies and the relevant ARR Book, tool and section of this guide.

Table 11   Summary of FRM tasks versus relevant ARR books, tools and guide

FRM task	ARR book	Chapter of ARR Book	Related tools	Link	Guide section
Data collection	1	4	ARR Data Hub	http://data.arr-software.org/	3–5 App B
Hydrology			ARR Data Hub	http://data.arr-software.org/	3.5–3.7 App C
• IFD	2	2	RFFE	http://rffe.arr-software.org/	
• ARF	2	4			
• Spatial patterns	2	6			
• Temporal patterns	2	5			
• Losses	5	3			
• Pre-burst	2	5			
• Baseflow	5	4			
Hydraulics	6	4	ARR Project 15: Two-dimensional model report	www.arr-software.org/pdfs/ARR_Project15_Stage2_TwoDimensional_Modelling_DraftReport.pdf	3.5–3.7
		6	Blockage assessment form	www.arr-software.org/pdfs/BLOCKAGE_ASSESSMENT_FORM.pdf	
Climate change	1	6	Interim guideline	http://arr.ga.gov.au/__data/assets/pdf_file/0011/40412/Draft_ARR_interim_guidance_Format.pdf	3.5.7
			NSW guidance		3.7.4
Reviewing models	7		ARR Project 15: Two-dimensional model report	http://www.arr-software.org/pdfs/ARR_Project15_Stage2_TwoDimensional_Modelling_DraftReport.pdf	
Impact/risk assessment	1	5			
Post-processing of data	7	10			
Reporting	7	10			5

4.1   Selecting techniques

The selection of techniques will depend upon the location and the intent of the study. ARR2016 recommends the use of at least two techniques to verify flow estimates. In most cases using two different techniques is sufficient; often the second technique is being used as a general check. When using new methods that have not been derived or tested at multiple locations it is essential that a mainstream technique is also used. Direct rainfall results should always be validated.

Examples for a few different cases are provided below.

Small urban catchment where flooding is mainly from overland flow

- Direct rainfall (see Appendix C) with checking against traditional urban runoff routing model.
- Traditional urban rainfall-runoff model (see Section 4.2).
- Hybrid with rainfall applied to small sub-areas and rainfall excess of hydrographs input into 2D hydraulic model.
- Using either the ensemble of 10 events in hydrological modelling and the mean hydraulics, or the ensemble of 10 events through both hydrological and hydraulic modelling.

Larger urban catchment

As for a small urban catchment as discussed above but the major creek system would be modelled as either 1D and/or 2D in the hydraulic model.

Urban town on a small to medium creek or river

- Traditional rural rainfall-runoff model (see Section 4.2) with a local 2D hydraulic model using the ensemble of 10 events in hydrological modelling and the mean hydraulics, or the ensemble of 10 events through both hydrological and hydraulic modelling.
- Direct rainfall should be used with caution and properly validated. Section 3.6.6 and Appendix C provide more information about direct rainfall model considerations.
- Where a stream gauge of sufficient record length and reliability is available, FFA should be used either at the town or elsewhere to check the model performance.

Town on large creek or river >20,000 km2

Usually FFA with historical event used in a 2D model. A catchment approaching this size will generally have nearby FFA and rarely have appropriate data for whole of catchment runoff events.

4.2   Runoff routing application

Very little has changed since 1987 in terms of the underlying principles of runoff routing; however, advances in technology have changed the way in which it is applied. ARR Book 5 discusses the different approaches. Suggested parameters are included in ARR Book 7.

4.2.1 Inputs to runoff routing methods

IFDs

Refer to Sections 3.5.1 and 3.7.3 and Appendix A.2.

ARFs

ARFs are used to transform point IFD estimates to spatial rainfall estimates (Section 3.5.2).

The ARR Data Hub provides the parameters to be included in ARR Book 2 Chapter 6 Equation 2.6.3 for the location of interest. New ARFs need to be calculated based on the total catchment area upstream of the key location in the study area. It is incorrect, and a common mistake, to apply them on a sub-area basis.

Application of initial and continuing losses and pre-burst rainfall

Industry raised concerns that using the nationally derived information for loss and pre-burst parameters from the ARR Datahub in New South Wales was resulting in a significant bias toward underestimation of flows in studies. This led to OEH commissioning a review of initial and continuing loss parameters and pre-burst developed through the update of ARR 2016. The findings of this review and associated advice to practitioners on losses and pre-burst is provided in Section 3.7.1.

Note that loss values are not provided in the arid zone which covers much of New South Wales west of Hay.

An example of applying pre-burst is shown in the ARR2016 Case Study – Rural (WMAwater 2017a).

Urban losses

Details on how to apply the urban loss method are found in ARR Book 5 Chapter 3. When examining urban losses, the rural losses for the area are still important as they are used to inform some parameters. ARR2016 recommends examining areas within the urban catchment that can be classified as pervious, indirectly connected and effective impervious areas. An example of the application of the urban losses is found in the ARR2016 Case Study – Urban (WMAwater 2017b).

Temporal patterns

ARR2016 recommends the use of an ensemble of temporal patterns (Section 3.6.5), which are based on regions (ARR Figure 2.5.7). ARR Book 2 Chapter 5 discusses temporal patterns.

A set of 10 temporal patterns for each region can be downloaded from the ARR Data Hub. Each set of 10 temporal patterns reproduces a proportion of the front, middle and back loaded events in the historical data set for each region. Where the area of interest is near the boundary of a region a combined set of temporal patterns (taking 10 from each of the relevant regions) or the selection of a combined set that only includes patterns selected from those close to your catchment is consistent with ARR. The temporal pattern download format is defined in Section 5.9.6 Book 2 Chapter 5. Temporal patterns are provided for the bins shown in Figure 8.
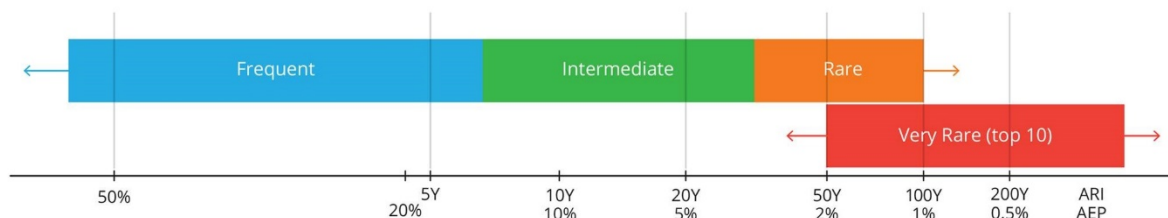
Figure 8   Bins for temporal patterns versus AEP (source: ARR Figure 2.5.12)

Temporal patterns are provided for durations from 15 minutes to seven days (see ARR Table 2.5.5 for the durations). All durations do not need to be modelled for all 10 patterns. Engineering judgement should be used to determine the range of durations to run with the 10

temporal patterns in the catchment modelling software. A critical duration plot should be produced (Figure 9) using the key metric. In this example, a box plot has been used to show the 10 patterns for each duration and the arithmetic mean. This plot was produced using standard MS Excel features.

The critical duration should be checked for at least one AEP in each temporal pattern bin. For example, check for the 1% AEP and apply the same pattern to the 2% AEP. The mean pattern or pattern just above the mean is chosen. The mean may be chosen based on whichever characteristic of the flood is more important; for example, flow, level, or rate of rise.

If inconsistent results are returned, the temporal pattern bins should be smoothed by running 20 patterns where possible using additional data from the secondary bin (Table 12).

A series of areal average temporal patterns have been produced for different sized hypothetical catchments (Table 13). These patterns average the spatial variability of rainfall in each time step to remove some of the variability of actual space-time rainfall fields. These patterns are also available for download on the ARR Data Hub.

ARR Book 3 Chapter 5 Section 5.9 provides advice on the application of temporal patterns and pre-burst. Point temporal patterns should be used for catchments less than 75 km^2. Areal temporal patterns have been derived for a number of different catchment areas and should be used for all catchments greater than 75 km^2. Table 14 provides a guide to applying the areal patterns. Note that the same patterns are used for all AEPs. The critical duration should still be checked with AEP as it may change.

For temporal patterns for very rare and extreme events (> than 1% AEP) refer to ARR Book 8.

Baseflow

For the majority of NSW coastal catchments baseflow represents a very small percentage of the runoff (1–2% of flow) and can generally be ignored. ARR2016 provides a methodology to estimate the magnitude of the baseflow in ARR Book 5 Chapter 4.

The ARR Data Hub gives baseflow parameters for the outlet of a catchment (not the catchment centroid like all other values). In the high rainfall coastal strip in New South Wales (where the majority of the population lives) baseflow can largely be ignored; however, if baseflow is removed from the hydrograph and calibration is undertaken to the surface response, baseflow needs to be added back in to get the total response hydrograph.
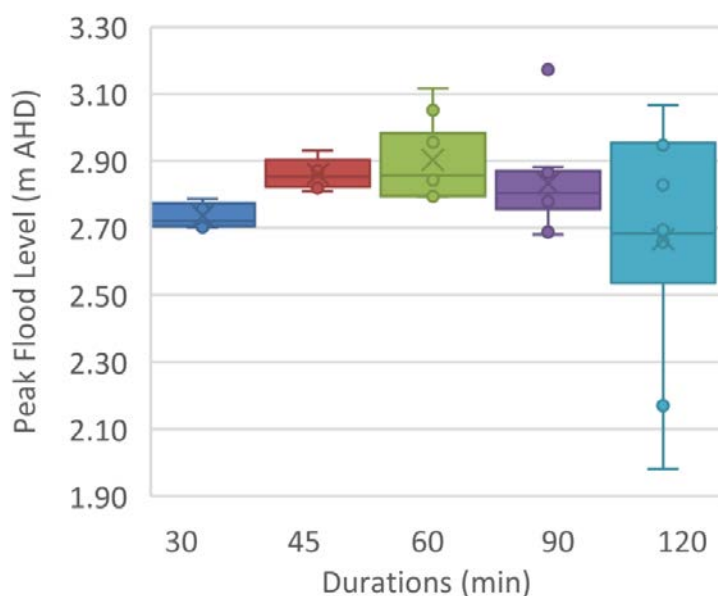
Figure 9   Sample critical duration plot

Table 12   Secondary temporal pattern data to use if required

AEP	Primary ensemble bin	Secondary bin
50%	Frequent	N/A
20%	Frequent	Intermediate
10%	Intermediate	Frequent
5%	Intermediate	Rare
2%	Rare	Intermediate
1%	Rare	N/A

Table 13   Areal temporal patterns areas and durations (source: ARR Table 2.5.7)

Catchment area (km^2)	100, 200, 500, 1000, 2500, 5000, 10000, 20000, 40000
Durations (hours)	12, 18, 24, 36, 48, 72, 96, 120, 144, 168

Table 14   Areal temporal patterns (source: ARR Table 2.5.9)

Range of target catchment areas (km^2)	Catchment area of designated areal temporal pattern set (km^2)
75 – 140	100
140 – 300	200
300 – 700	500
700 – 1,600	1,000
1,600 – 3,500	2,500
3,500 – 7,000	5,000
7,000 – 14,000	10,000
14,000 – 28,000	20,000
28,000 +	40,000

4.3   Simple and ensemble modelling approaches

As discussed in Section 3.6.5, ARR2016 recommends varying ensemble approaches to model the temporal inputs in deriving the design floods, depending on factors such as data availability and project requirements. Figure 6 and Table 9 describe these methods and their typical uses. The remainder of this section describes appropriate procedures for each approach.

4.3.1 Simple design method

The simple design method (Figure 10) is not designed to be used in flood studies and therefore **should not be used** for any studies undertaken under the NSW Floodplain Management Program. This method is similar to the ARR1987 single design event approach and only uses a single design temporal pattern. It is only recommended for rapid assessment.

As part of ARR2016 it was intended that a new AVM pattern would be developed for rapid assessment; however, at the time ARR2016 was released in July 2016 this had not been done. Further research into the application of the AVM needs to be undertaken before new single design event temporal patterns are available.

For rural catchments, where no better local data is available (Section 3.5.4), losses may be extracted from the ARR Data Hub.

For urban catchments, it is recommended that the urban loss method (described in ARR2016 Case Study – Urban (WMAwater 2017b) and advice on direct rainfall considerations (Appendix C) based upon advice in ARR Book 5 Chapter 4) be used. The spatial pattern applied to the rainfall is based on the IFD.
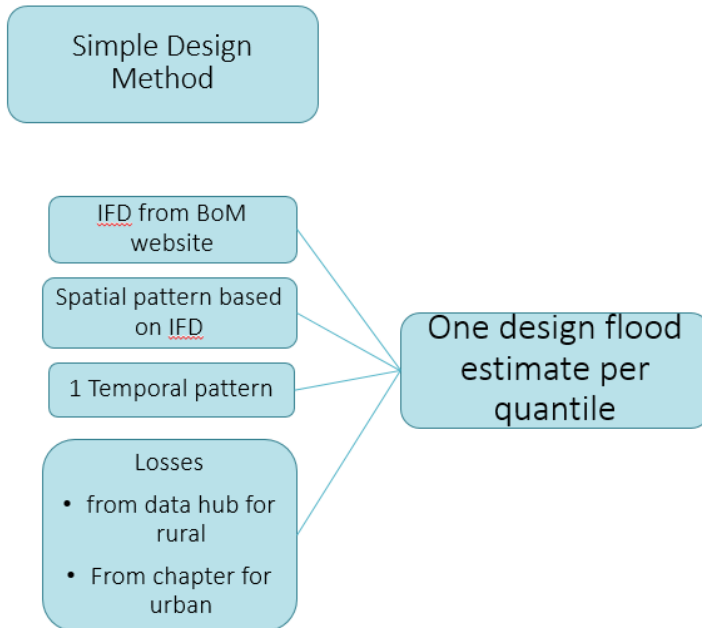
Figure 10 Simple design method

4.3.2 Ensemble in hydrology, mean in hydraulics

The ensemble in hydrology, mean in hydraulics method (Figure 11) is expected to be the most common approach used with ARR2016. The approach runs all 10 temporal patterns through the hydrologic model. The flows at key locations are then plotted and the critical duration determined. Burst loss values determined as per section 3.7.1 are used.

The spatial pattern applied to the rainfall is based on Equation 2.4.1 in ARR Book 2 Chapter 4. For catchments larger than 75 km^2 an areal temporal pattern is used. The mean pattern (typically chosen as the pattern closest to or just above the mean) is then run through the hydraulic model to determine the design flood estimate (an example of this is provided in the ARR2016 Case Study – Rural Catchment (WMAwater 2017a)).

However, there will be cases where several different shaped patterns near the median may need to be run through the hydraulic model. This can account for variations in the drivers for flooding (peak flow or volume) and therefore the pattern that will be relevant to driving factors in different parts of the floodplain.
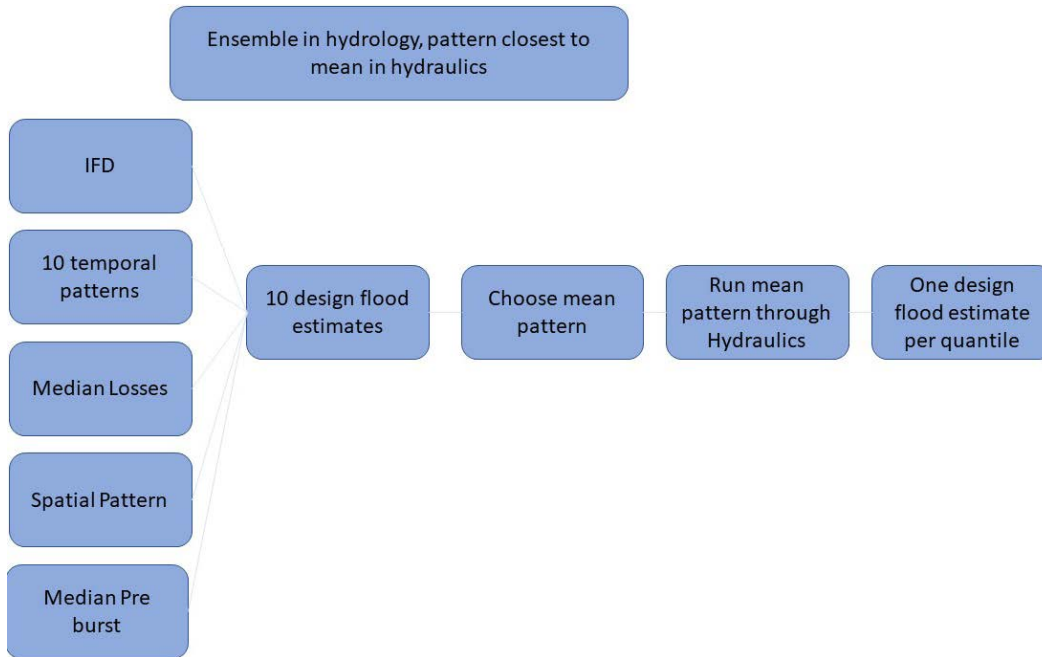
Figure 11 Ensemble in hydrology and mean pattern in hydraulics method

4.3.3 Ensemble in hydrology and hydraulics

The ensemble in hydrology and hydraulics method (Figure 12) involves running all 10 temporal patterns through both the hydrologic and hydraulic models rather than just the hydrology as per the previous section. This produces 10 design flood estimates from which the mean pattern (or pattern just above the mean) is chosen. This then becomes the design flood estimate.
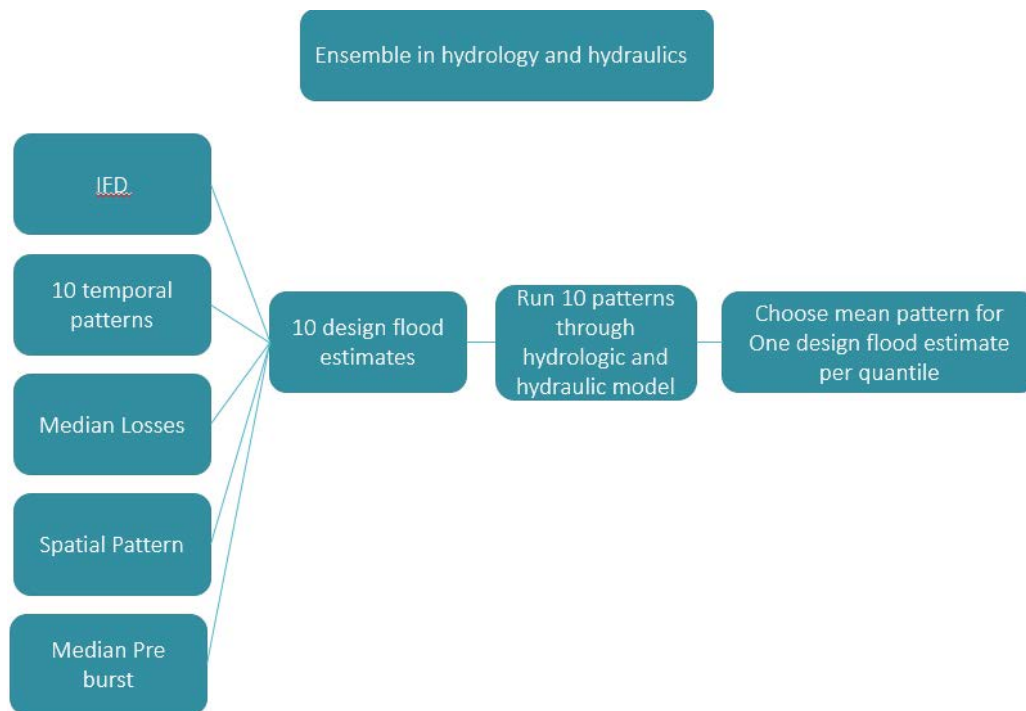
Figure 12 Ensemble in hydrology and hydraulics method

The computational time required for this approach is greater than the 'ensemble in hydrology, mean in hydraulics' approach, but it is relatively simple to use. Computational savings can be made by running the ensemble initially with the hydraulic model set up with a larger grid size (as long as important hydraulic features are still present). Once the representative temporal pattern has been decided, this can be simulated with the hydraulic model with higher resolution.

Additionally, by using this approach the mean can be chosen based on flood characteristics other than flow, such as flood levels which are extracted from the hydraulic model.

4.3.4 Full Monte Carlo

Monte Carlo techniques move from single inputs to ensembles or inputs with variable distributions to be sampled from:

- rainfall
- temporal patterns
- spatial patterns
- losses
- pre-burst
- timing aspects.

Full application of such complex approaches is not expected to be necessary on most flood studies undertaken as part of the NSW Floodplain Management Program. The full Monte Carlo method (Figure 13) should be used on studies of large systems with large populations at risk, such as the Hawkesbury–Nepean or Brisbane rivers, potentially also with additional complications, such as dams with a flood mitigation role. Representing some aspects of the real variability of real events will improve the robustness of design flood estimates and the objective assessment of options.

The full Monte Carlo method involves randomly sampling 1000s of combinations of design flood inputs. It is often applied in combination with a fast running 1D model. A sampling approach may be applied to determine a subset to run in a 2D model.
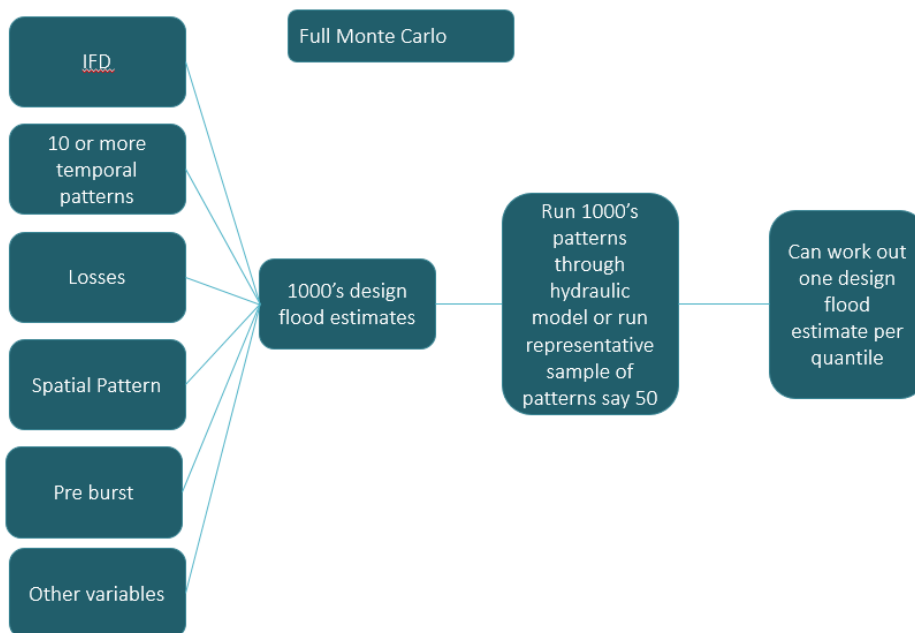
Figure 13 Full Monte Carlo method

5. Reporting and data handover

The ARR2016 Case Studies – Urban Catchment and Rural Catchment provide an understanding of the scope of reporting required to undertake a study with ARR2016 or to examine sensitivity to changes in methodology and design input data.

This section provides some limited guidance on reporting and data handover. It does not negate the need to meet the requirements of grant conditions or contractual arrangements, such as those that stem from specifications developed with the OEH Flood Brief Development Tool. This section clarifies some additional requirements that may need to be considered in transitioning to ARR2016.

5.1 ARR2016 related input data

The project report should clearly identify the data used. In relation to any data used from the ARR Data Hub, the Data Hub assists by standardising reporting on the inputs used and the version used, and by making it clear what input values have been used, so that a study can be reproduced in the future. An appendix to the report should include:

- a copy of either the pdf or text file from the ARR Data Hub and the date the data was accessed (see Appendix A.2)
- IFD print-out for the catchment and its source; in the majority of cases this will be the BoM website.

5.2 Data relating to methodology

Reporting should outline the methodology used in the analysis and provide results and a discussion of these, specifically including:

- software version details
- discussion of the differences from ARR1987 techniques and results (where relevant – for new studies or sensitivity assessment)
- verification of the flow estimates
- box plot of critical durations (Figure 14)
- plots of the hydrographs produced by different temporal patterns (Figure 15)
- clear identification of design inputs and their source, and justification for their use
- if direct rainfall is used, a volume check and unit area runoff comparison to a conventional rainfall-runoff model
- if 10 temporal patterns are run in the hydraulic model or direct rainfall is used, mean grids of each duration ensemble should be produced and enveloped to create a map of one source grid indicating spatially where each duration is critical
- rating curves for flood gauges to support RFFE improvements where applicable (Section 5.3)
- blockage assessment form and the blockage factors used on key structures.
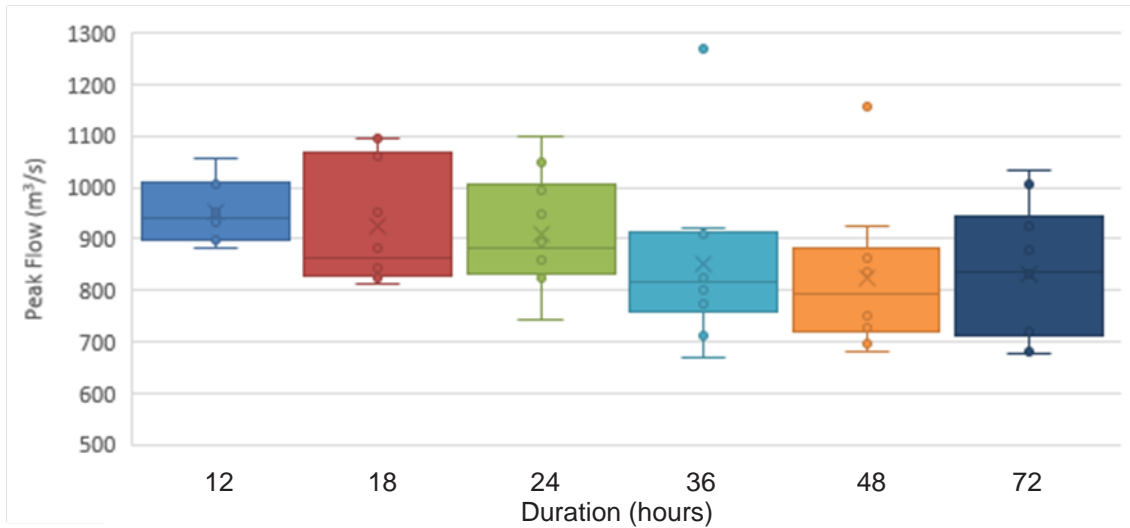
Figure 14 Example of a critical duration box plot
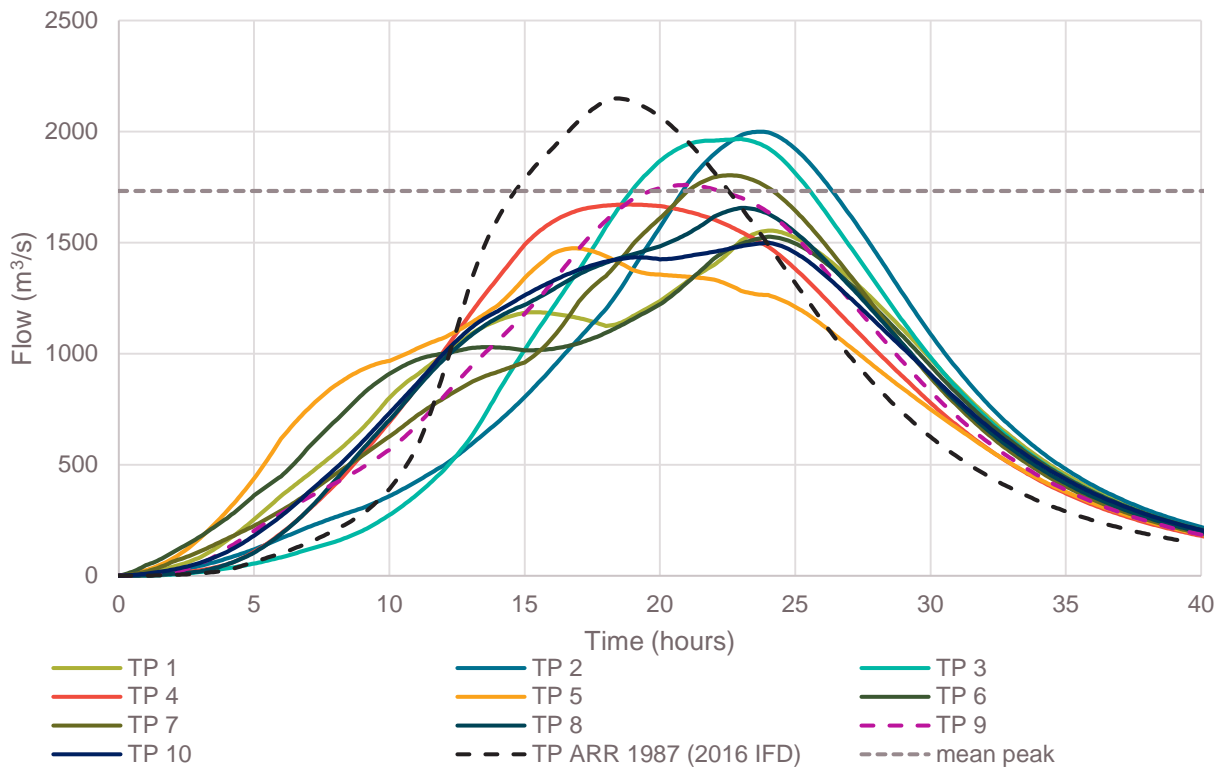
Figure 15 Example of a plot of hydrographs

5.3   Reporting on gauge rating curve review and update

As outlined in Section 3.7.6 where hydraulic modelling for a study includes river gauge locations it should incorporate a review and update of the rating curve for the gauge within the project scope. At the completion of this work the following data should also be handed over:

- ARR Data Hub pdf and text outputs
- hydrology files (and hydraulics if relevant); should include all 10 temporal pattern results
- understanding of what the rating was (Q-H relationship)

- understanding of the new rating curve (Q-H relationship)
- gauge records with old and new flows and dates
- a small report on calibration and validation or an extract from the study report detailing the process of updating the record. This report should include:
  - comparison of parameters to design values and other regional studies (if available); a discussion of how these relate to the normal range
  - discussion of whether there is a bias in fit between rare and frequent events
  - evidence that the calibration has a good balance between shape, peak, volume and timing
- details of rating curve development (if relevant).

5.4 Data handover

Handover of data to the NSW Government should be through the NSW Flood Data Portal and consider the requirements of the relevant grant conditions in relation to intellectual property and any additional requirements in the project brief and associated contract documentation from council.

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WMAwater 2015, *Australian Rainfall and Runoff Revision Project 3: Temporal Patterns of Rainfall, Part 1 – Development of an Events Database*, Stage 3 Report, October 2015, Engineers Australia.

WMAwater 2017a, *ARR2016 Case Study – Rural Catchment*, WMAwater, Sydney NSW.

WMAwater 2017b, *ARR2016 Case Study – Urban Catchment*, WMAwater, Sydney NSW.

WMAwater 2019a, *Review of ARR Design inputs for NSW*, WMAwater, Sydney NSW.

WMAwater 2019b, *Revised 2016 Design Rainfalls Investigations into the Need for and Derivation of Local Techniques*, WMAwater, Sydney, NSW.

Zheng F, Westra S and Leonard M 2014, *Australian Rainfall and Runoff Revision Project 18, Stage 3: Coincidence of fluvial flooding and coastal water levels in estuarine areas*, 145pp.

Appendix A: Using the ARR Data Hub

A.1 The ARR Data Hub

Data for flood investigations comes from a number of sources that consider the local conditions. These may include previous studies which may provide calibrated and validated parameters for catchment losses and other factors.

The ARR Data Hub is a one-stop shop for general design inputs. The aim of the ARR Data Hub is to enable users to download inputs at the start of each study rather than hardcoding them into software. Care should be taken, and engineering judgement applied when using values from the ARR Data Hub. It needs to be used with care in consideration of other available data and the local flood context, with Table 15 providing some general advice on when this data should be used.

Table 15 ARR data application

Data	Use
River and catchment region check	Check
IFD	Link to BoM
ARF	Recommended
Temporal patterns	Recommended
Losses	In the absence of data
Pre-burst rainfall	Recommended
Climate change factors	In the absence of location-specific studies
Baseflow	In the absence of local data

The ARR Data Hub facilitates the more frequent update of ARR and enables rapid incorporation of future changes and advances into industry techniques. It has a map-based interface which allows users to check they are extracting results at the correct location. Data can be extracted for a point location or shapefile (Figure 16).

The following data can be found on the ARR Data Hub:

- river and catchment region check
- link to IFD
- areal reduction factors (ARF)
- temporal patterns
- losses
- pre-burst rainfall
- climate change factors
- baseflow factors.

Data is output at the resolution identified in Table 16.

The nature of the gridding method and input data used to develop the different inputs means the inputs have slightly different extents; for example, the pre-burst returned no value in the Brunswick River. In some locations, the continuing loss would return a value but not the initial loss. The information has been revised and will be released on the ARR Data Hub in the next release in 2018. In the interim, the nearest value should be used. If this occurs with other inputs the same approach is recommended.
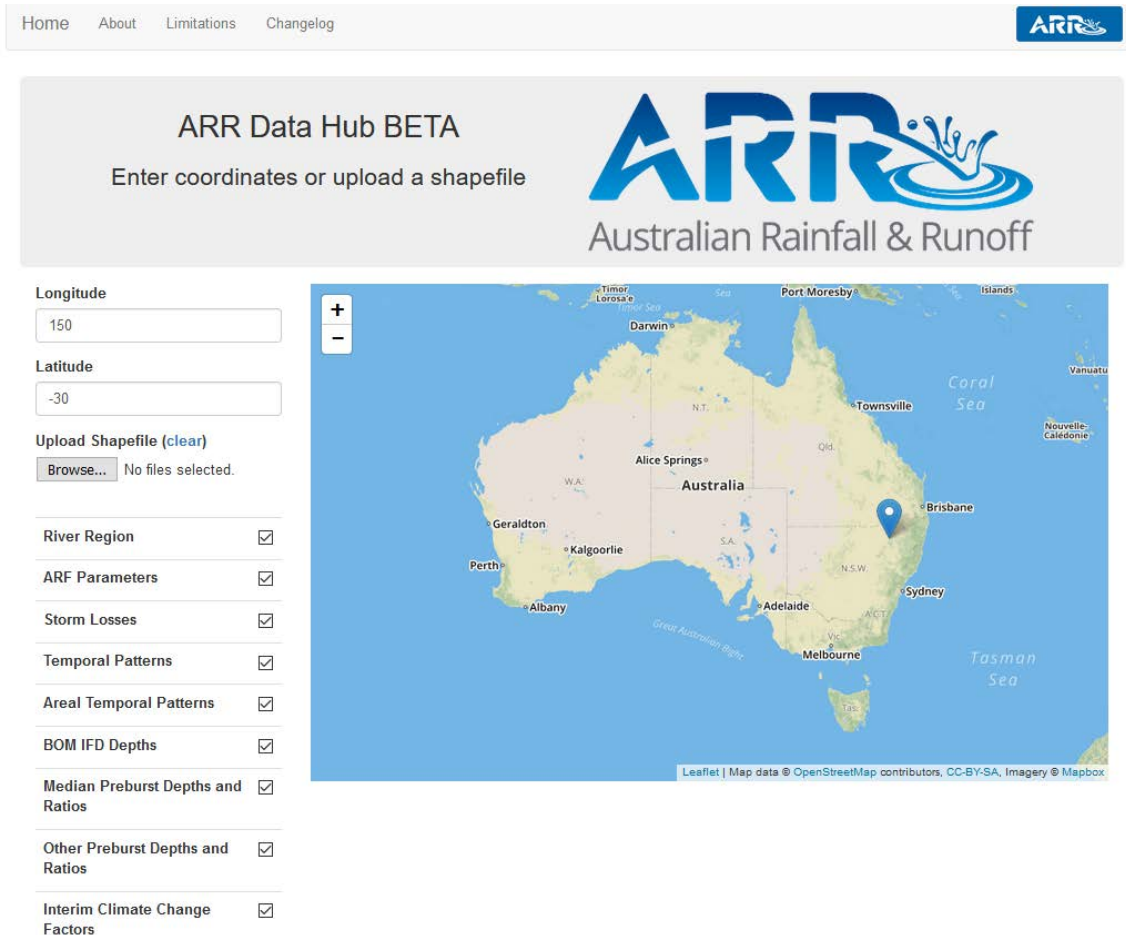
Figure 16 ARR Data Hub – landing page

Table 16   ARR data resolution

Data	Output
River and catchment region check	Shapefile
IFD link	Point only
ARF	Shapefile
Temporal patterns	Shapefile
Losses	Grid at 15 km x 15 km
Pre-burst rainfall	Grid at 10 km x 10 km
Climate change factors	Shapefile

The results page, an example of which is shown in Figure 17, provides a check that the location is in the correct river basin. Also, under 'Selected Regions' clicking 'show' will display the region that has been sampled for the different parameters (Figure 18). Note that for losses it will show a single cell.

The ARR Data Hub provides metadata on all datasets and a change log. It is important that all studies record the metadata on all input data from all sources.

Note that baseflow is for catchment outlets and so is not selected when using the 'select all' feature. Information on the way the data is sampled can be found in Babister et al. (2016, http://data.arr-software.org/publications). A change log is provided which documents any changes and the version.

The ARR Data Hub can be called directly by software. Appendix A provides a sample ARR Data Hub output. A pdf or text file of the Data Hub outputs can be generated and downloaded, as shown in Figure 19. Figure 20 shows a sample text file. This output can facilitate validation that the correct data was used in the study and assist in reproduction of results and future studies. **All studies funded under the NSW FMP are to incorporate the ARR Data Hub output in final reporting.**

The ARR Data Hub is currently maintained by industry. The ARR Data Hub website has a facility for submitting questions to the authors.

Figure 17 ARR Data Hub – example of results

Figure 18 Example region – ARF parameters selected for display

Figure 19 ARR Data Hub – download screen

```
Results - ARR Data Hub
[STARTTXT]

Input Data Information
[INPUTDATA]
Latitude,-30.0
Longitude,150.0
[END_INPUTDATA]

River Region
[RIVREG]
Division,Murray-Darling Basin
RivRegNum,19.0
River Region,Gwydir River
[RIVREG_META]
Time Accessed,11 April 2017 12:11PM
Version,2016_v1
[END_RIVREG]

ARF Parameters
[LONGARF]
Zone,Semi-arid Inland QLD
a,1.59E-01
b,2.83E-01
c,2.50E-01
d,3.08E-01
e,7.30E-07
f,1.00E+00
g,3.90E-02
h,0.00E+00
i,0.00E+00
[LONGARF_META]
Time Accessed,11 April 2017 12:11PM
Version,2016_v1
[END_LONGARF]

Storm Losses
[LOSSES]
Storm Initial Losses (mm),54.0
Storm Continuing Losses (mm/h),0.4
[LOSSES_META]
Time Accessed,11 April 2017 12:11PM
Version,2016_v1
[END_LOSSES]

Temporal Patterns
[TP]
CODE,CS
LABEL,Central Slopes
[TP_META]
Time Accessed,11 April 2017 12:11PM
Version,2016_v1
[END_TP]

Areal Temporal Patterns
[ATP]
CODE,CS
LABEL,Central Slopes
[ATP_META]
Time Accessed,11 April 2017 12:11PM
Version,2016_v1
```

Figure 20 ARR Data Hub – example of a txt file

A.2 Intensity–Frequency–Duration (IFD) depths

Broadscale maps of New South Wales showing the differences between the 2016 and 1987 IFDs are available in Appendix F. The IFDs are available from the BoM website as point values (Figure 21). Locations can be input as:

- latitude, longitude
- degrees, minutes and seconds
- eastings, northings.

The conditions of use and coordinates caveat must be accepted before the data can be accessed. The ARR Data Hub will prefill the information on the BoM website so you can be sure you are extracting the data at the same point. However, the user must still accept the caveats on the BoM page.

Figure 21 IFD location and caveat

IFDs are provided for the following ranges (note: these are different to the terminology in Section 3.4):

- Very Frequent – 12 EY to 0.2 EY (ARR2016 terminology Very Frequent)
- IFDs (Frequent – Infrequent) – 63.2 to 1% AEP (ARR2016 terminology Frequent – Rare)
- Rare – 1 in 100 to 1 in 2000 AEP (ARR2016 Very Rare).

Standard durations for IFD extraction are:

- 1 to 30 minutes
- 1 to 12 hours
- 24 to 168 hours.

Note: non-standard durations can be specified.

The ARR2016 IFDs are provided as depths (mm) as a default; however, mm/h are also available. IFDs can be extracted as a table (Figure 22) or a chart (Figure 23).
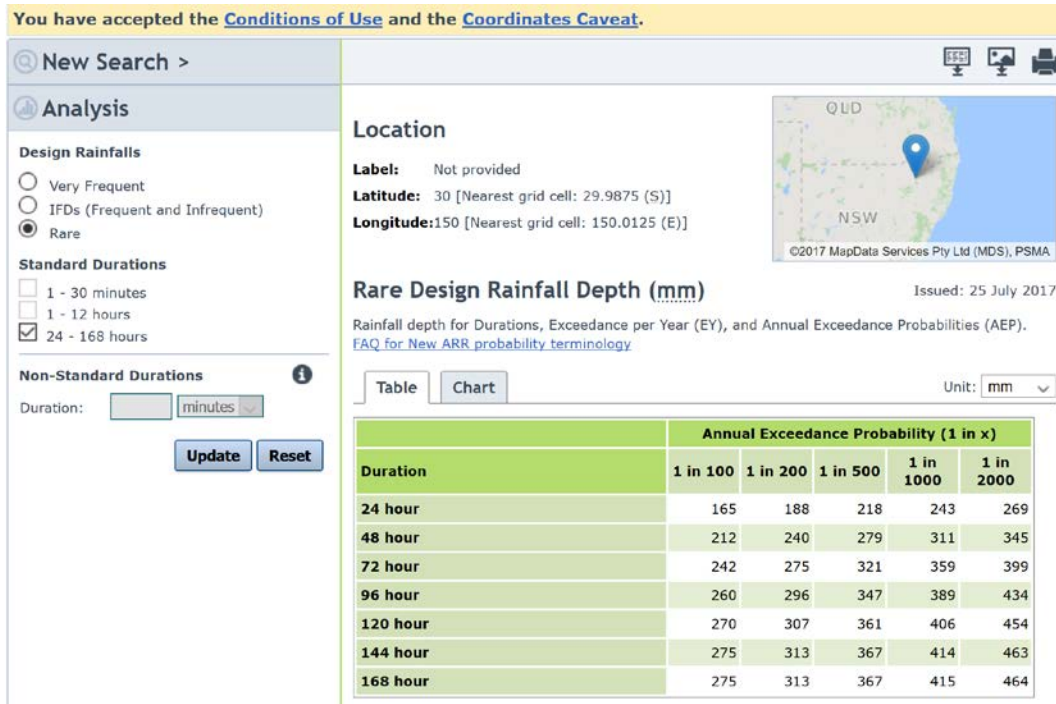
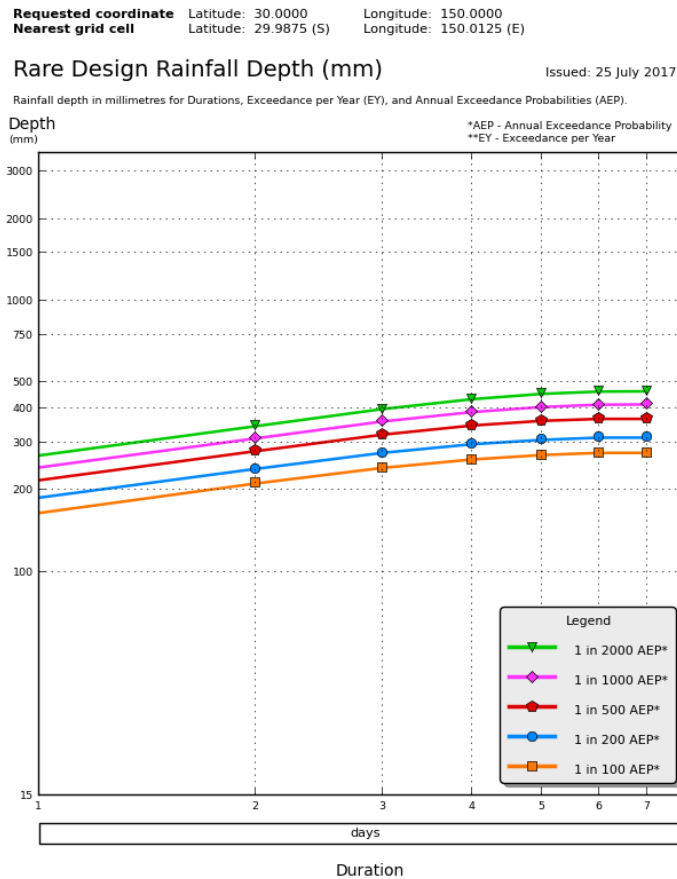**Figure 22 Example output IFD – table**

Figure 23 Example output IFD – chart

The ARR1987 IFDs can still be downloaded at
www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml; however, these IFDs should not be
used for new studies using ARR2016 methodologies.

There are places in New South Wales where IFDs may differ from the BoM information, as
discussed in Section 3.7.3.

Spatially distributing the IFD is recommended for catchments >20 km^2 and in areas with
reasonable spatial variability (refer to *ARR2016 Case Study – Rural Catchment*, WMAwater
2017a). Using the sub-catchment centroid works well where there are many sub-areas (refer
to *ARR2016 Case Study – Urban Catchment*, WMAwater 2017b).

Point vs shapefile example

Table 17 and Figure 24 compare the use of a spatial distribution and the catchment centroid
data from the ARR Data Hub and the BoM website, for the Georges River Catchment.

Table 17   Example of catchment average and centroid loss parameters

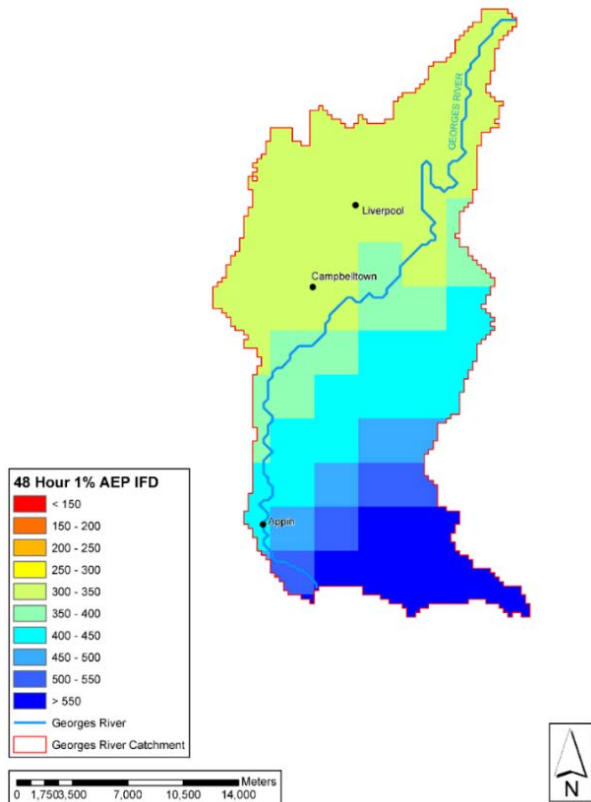| Parameter	Catchment average	Centroid
Storm initial loss (mm)	43	45
Storm continuing loss (mm/hr)	2.5	2.4
1%AEP_48hr Pre-burst_depth (mm)	29.2	14.2
1%AEP_48hr Pre-burst_ratio	0.095	0.047

Figure 24 Example Georges River Catchment 48-hour 1% AEP IFD

A.3 Example of ARR Data Hub output

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	152.817
Latitude	-30.511
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show

Region Information

Data Category	Region
River Region	Bellinger River
ARF Parameters	East Coast North

Data

River Region

Division	South East Coast (NSW)
RivRegNum	5
River Region	Bellinger River
Polygon Intersection Percentage	99.98

Layer Info

Time Accessed	02 March 2017 04:17PM
Version	2016_v1

ARF Parameters

Long Duration ARF

$$Areal\ reduction\ factor = Min\left\{1, \left[1 - a\left(Area^b - c\log_{10}Duration\right)Duration^{-d}\right.\right.$$
$$+\,eArea^f Duration^g\left(0.3 + \log_{10}AEP\right)$$
$$\left.\left.+\,h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	East Coast North
a	0.327
b	0.241
c	0.448
d	0.36
e	0.00096
f	0.48
g	-0.21
h	0.012
i	-0.0013
Polygon Intersection Percentage	99.91

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36}\right.$$
$$+\,2.26\ \text{x}\ 10^{-3}\ \text{x}\ Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right)$$
$$\left.+\,0.0141\ \text{x}\ Area^{0.213}\ \text{x}\ 10^{-0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Layer Info

Time Accessed	02 March 2017 04:17PM
Version	2016_v1

Storm Losses

Storm Initial Losses (mm)	33.0
Storm Continuing Losses (mm/h)	3.7

Layer Info

Time Accessed	02 March 2017 04:17PM
Version	2016_v1

Temporal Patterns | Download (.zip)

CODE	ECsouth
LABEL	East Coast South
Polygon Intersection Percentage	100.0

Layer Info

Time Accessed	02 March 2017 04:17PM
Version	2016_v1

Areal Temporal Patterns | Download (.zip)

CODE	ECsouth
LABEL	East Coast South
Polygon Intersection Percentage	100.0

Layer Info

Time Accessed	02 March 2017 04:17PM
Version	2016_v1

BOM IFD Depths

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?
year=2016&coordinate_type=dd&latitude=-30.5107564611&longitude=152.817101565&sdmin=true&sdhr=
to obtain the IFD depths for catchment centroid from the BoM website

Appendix B: Regional Flood Frequency Estimation (RFFE)

This section discusses the application and limitations of RFFE, while Section 3.6.4 discusses the role of RFFE in replacing the Probabilistic Rational Method (PRM).

B.1 RFFE application

An online application has been developed for ease and consistency of application of this method. RFFE can be accessed at http://rffe.arr-software.org/. This site is currently maintained by industry rather than Geoscience Australia or Engineers Australia.

Section 3.7.6 discusses review and update of rating curves at river gauge locations, which can provide a basis for improving the estimates of the RFFE. The intention is for the RFFE method to be updated when rating curves and new data becomes available. Any changes will be noted at http://rffe.arr-software.org/changelog.html and users signed up to the ARR distribution list will be notified. The limitations of the method are documented in ARR Book 3 Chapter 3 Section 12 and at http://rffe.arr-software.org/limits.html.

The RFFE website landing page is shown in Figure 25. The following input data is required:

- catchment outlet latitude and longitude (used for catchment characteristics)
- catchment centroid latitude and longitude (used for the rainfall value)
- catchment area (km^2).
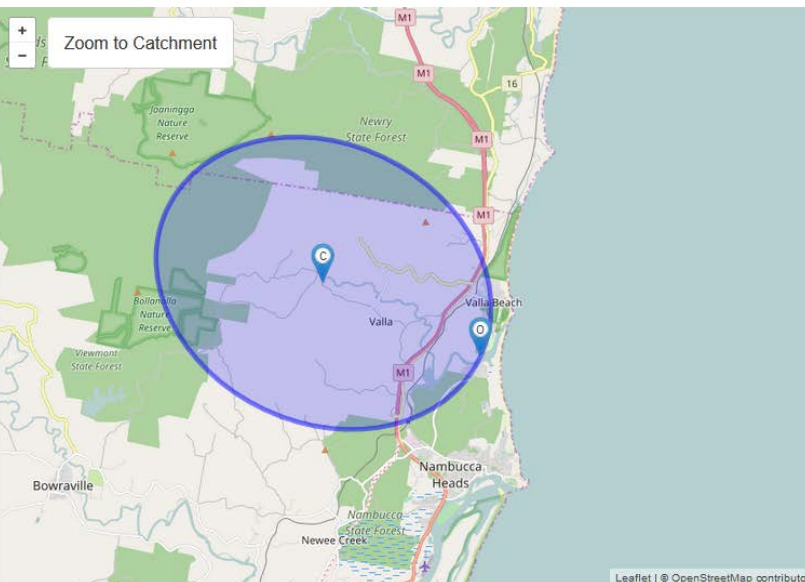
The results of the RFFE are sensitive to the distance between the centroid and the outlet so care should be taken to ensure this is correct.

Figure 25 RFFE – landing page

The tool can be used to zoom to the catchment to ensure the correct input data has been used. The centroid and outlet can be relocated using the pins. An oval shape representing the catchment, based on the entered information, will display. Warnings will be issued if the shape or size of the catchment is outside those recommended for this method. An example of the results page is shown in Figure 26. Key features are:

- input data summary
- discharge for the 50% to 1% AEP (along with confidence limits)
- statistics for use in FFA
- location of the nearest gauges.

The following plots are provided showing the results for the catchment of interest compared to nearby gauges to allow users to check if the RFFE is producing sensible results:

- 1% AEP flow vs catchment area (Figure 27)
- shape factor vs catchment area (Figure 28)
- intensity vs catchment area (Figure 29)
- bias correct factor vs catchment area (Figure 30).

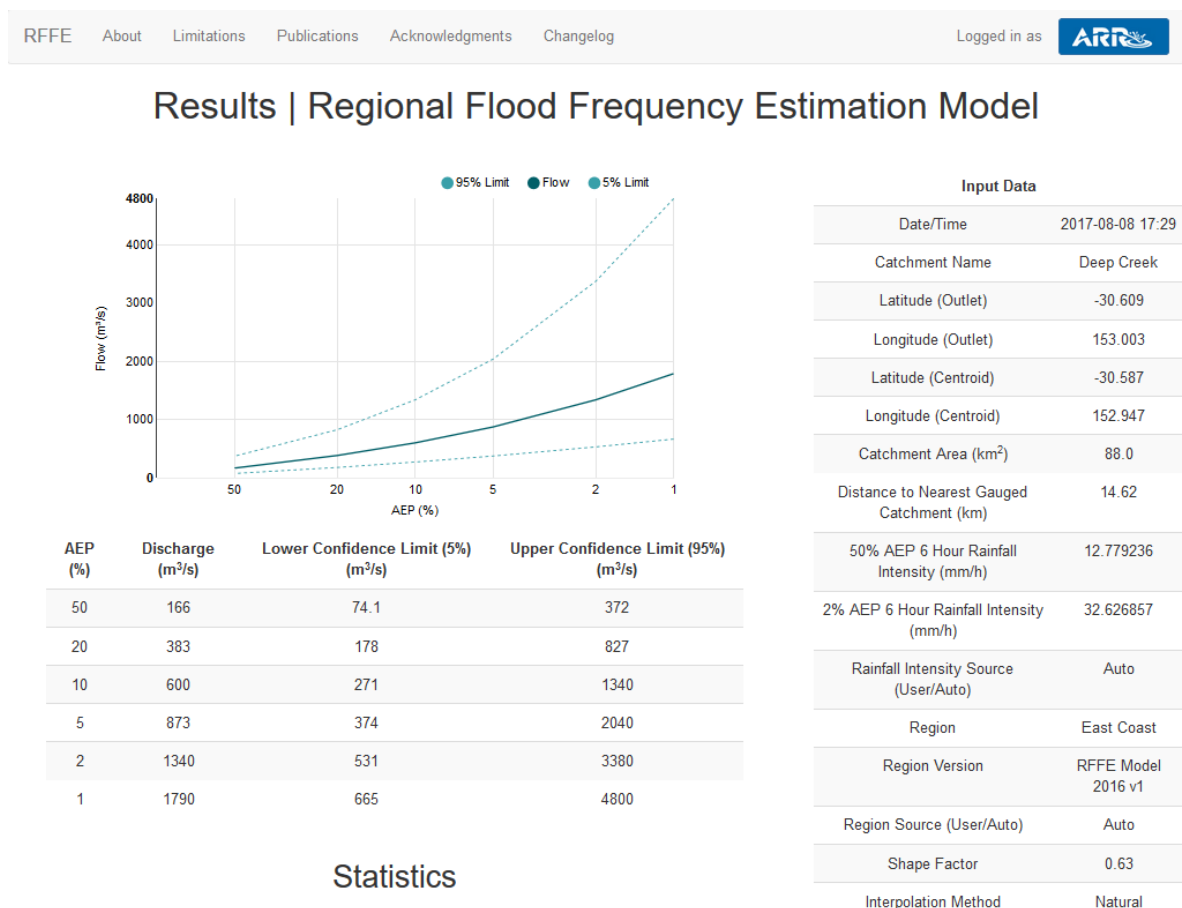Any suspected issues with the RFFE output can be lodged at an email address provided on the site.
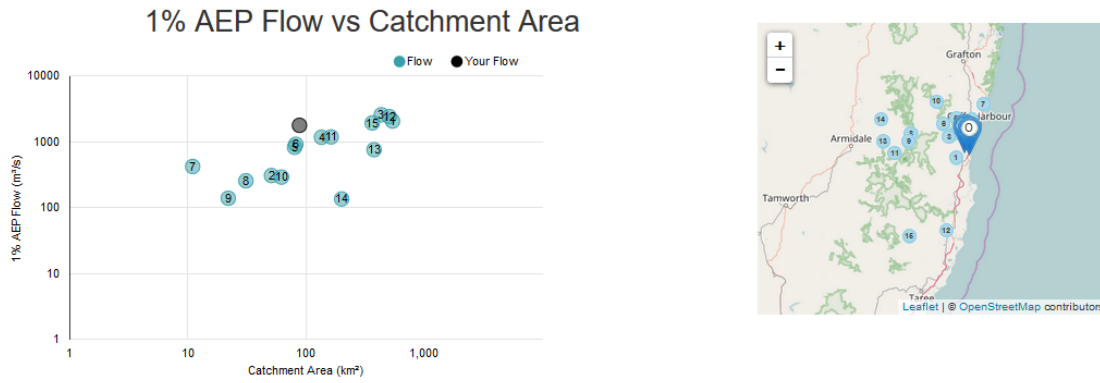

Figure 26 RFFE – results

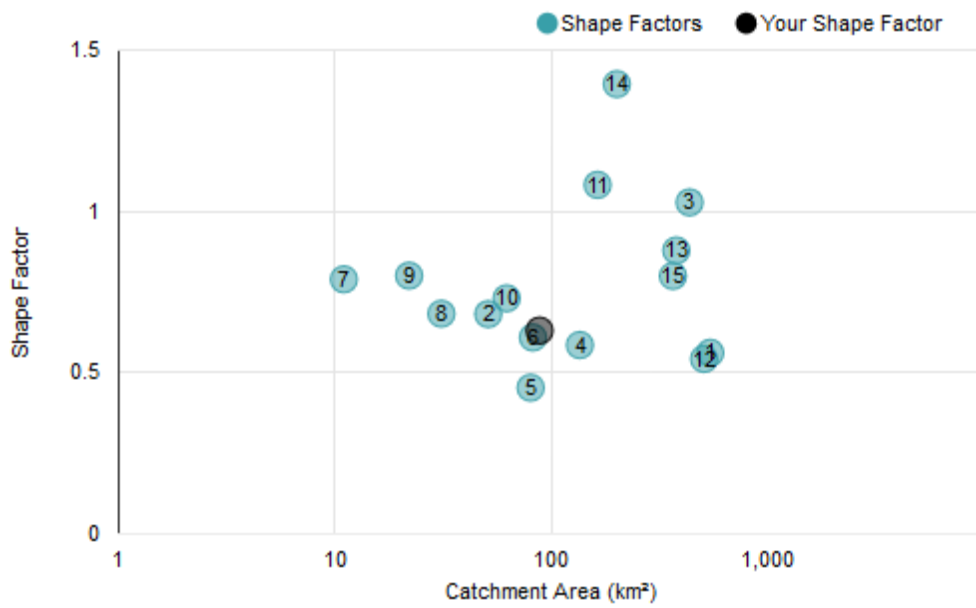**Figure 27 RFFE – 1% AEP flow vs catchment area**

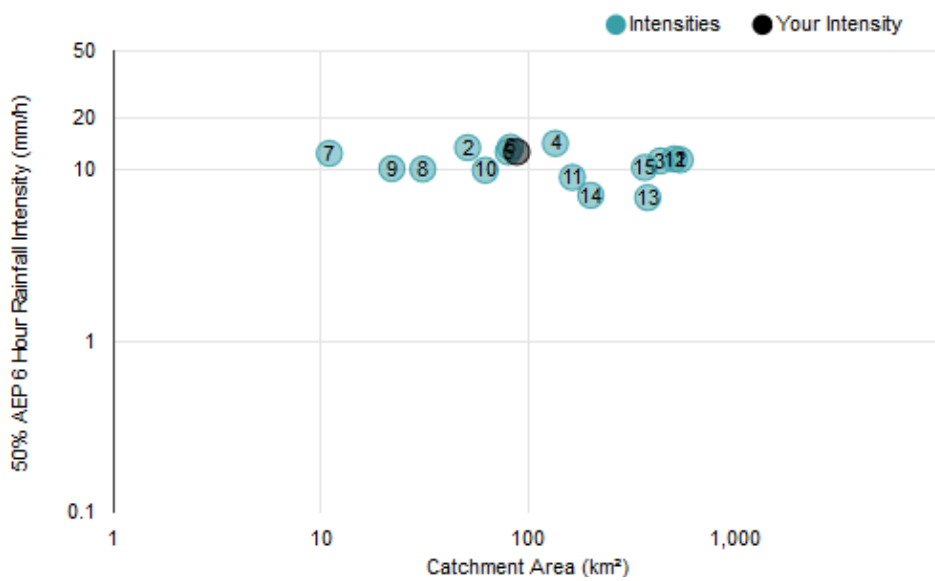**Figure 28 RFFE – shape factor vs catchment area**

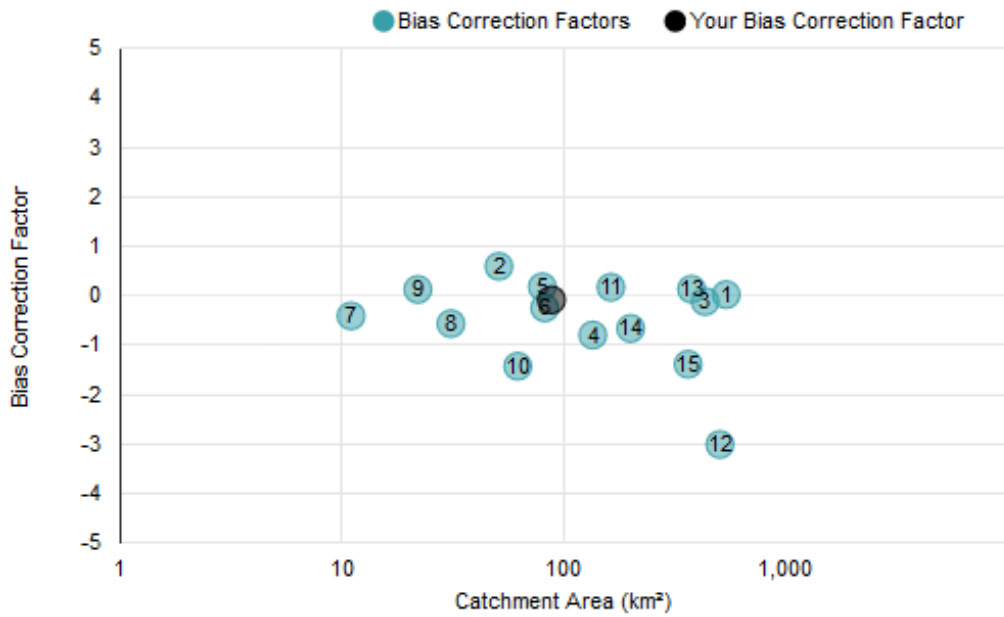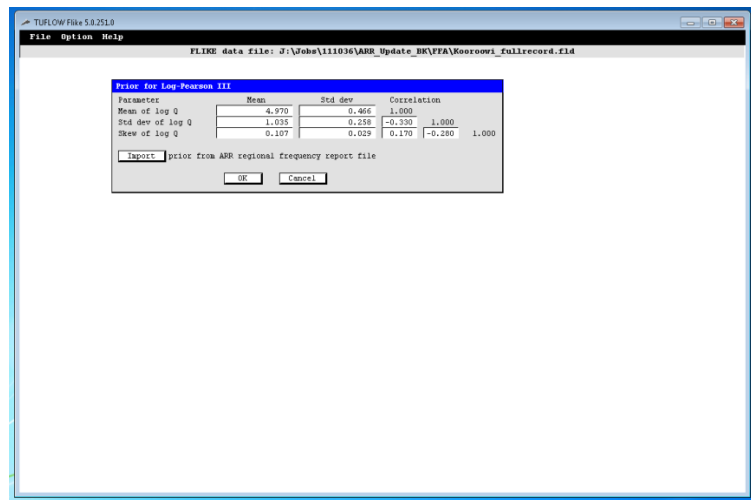**Figure 29 RFFE – intensity vs catchment area**

Figure 30 RFFE – bias correction factor vs catchment area

Using RFFE as prior information

The statistics provided by the RFFE can be incorporated as prior information in the Flike software when undertaking FFA to inform the skew of the curve (Figure 31). They can be imported from the text file downloaded from the RFFE website or entered manually from the RFFE statistics.

Figure 31 Using RFFE as prior information in Flike

It is important to check that the nearby gauge doesn't have a short record. This can be easily checked by downloading the nearby gauges in a csv format, provided on the results page in the download section.

B.2 Limitations of RFFE

Catchments for which the RFFE model cannot be applied include:

- urban catchments where more than 10% of the catchment has residential or urban development
- catchments where the hydraulic constraints or storages significantly alter the natural rainfall-runoff behaviour (e.g. dams, detention basins, weirs, bridges, stream morphology)
- catchments where large-scale land clearing has taken place
- catchments that have been significantly affected by agricultural activities, construction of drainage or irrigation infrastructure, soil conservation works or mining activities.

Catchments, where RFFE model estimates have lower accuracy, include:

- catchments with an area less than 0.5 km^2 or greater than 1000 km^2 (will prompt a warning on the website)
- catchments located further than 300 km from the nearest gauged catchment location used to develop the RFFE technique (will prompt a warning on the website)
- catchments in the arid areas (the RFFE technique for the arid areas is based on a very small number of gauged catchments spanning a vast area of Australia). At the time this document was published, RFFE in the arid region is unavailable.

Catchments, where RFFE model estimates may be inaccurate or biased, are catchments with atypical characteristics (i.e. flood characteristics that are distinctly different from typical gauged catchments in the region). In such situations, hydrological judgement must be exercised to assess if any adjustment of the RFFE is required (based on comparison of relevant catchment characteristics). To support such an assessment, the RFFE model output describes the set of gauged catchments used in developing the model, which are located closest to the ungauged catchment of interest. The following additional catchment attributes may need to be considered as a basis for adjustments to the flood estimates obtained directly from the RFFE model:

- natural flood storage – large flood storage areas in catchments with extensive floodplains or swamps have the effect of attenuating flood peaks; flood estimates from the RFFE model would thus tend to overestimate peak flows and they could be regarded as upper bound flood estimates for these catchments.
- drainage efficiency – steep catchments, streams with little vegetation along banks, catchments affected by large-scale drainage or flood protection works can be expected to produce faster flood flows, less attenuation and thus higher peak flows; flood estimates from the RFFE model would thus tend to underestimate peak flows and they could be regarded as lower bound flood estimates for these catchments.

For flood estimation in catchments with atypical catchment characteristics, it is desirable to examine the flood records of a gauged catchment with similar catchment attributes as a basis for adjustments to the flood estimates produced by the RFFE model. Alternatively, simulation of a runoff routing model may be used to examine the accuracy of the RFFE results.

Appendix C: Direct rainfall considerations

There are a number of issues associated with direct rainfall methods (DRMs). DRM is still relatively new and untested and therefore caution needs to be exercised when using this approach.

Practitioners need to ensure that DRM is appropriate for the catchment being examined and for floodplain risk management purposes in the study area as discussed in Section 3.6.6. This includes a range of essential checks to confirm that the results from the DRM are sensible and valid.

This section describes a few key checks that should be undertaken as part of the modelling process; however, checks should not be limited to the ones listed here. Calibration and verification of DRM is also considered mandatory wherever possible. Other issues to consider when undertaking DRM can be found in the ARR2016 document (Ball et al. 2016) or in the report for Project 15: 2D modelling (Babister & Barton 2012).

C.1 Runoff volume checks

Direct rainfall models are prone to trapping water on the grid. In traditional hydraulic modelling approaches it is standard practice to check the volume balance, but in direct rainfall models it is important to check the volume of runoff is correct. A simple loss model can calculate rainfall excess, which is the volume of rainfall that becomes runoff. The losses represent the volume of water that does not turn into runoff. Losses include depression storage that needs to be filled before runoff commences. It is very easy to double count depression storage as a 2D model includes some depression storage and noisy LiDAR data can cause very large amounts of artificial depression storage. With a traditional rainfall-runoff routing model, over 99% of rainfall excess turns into runoff and the same should be occurring with a direct rainfall model, other than water legitimately trapped in storage areas (i.e. detention basins, dams or underground car parks).

Figure 32 shows a plot of the volume/area results for a modelling scenario where losses are simply applied to a direct rainfall model. In this example, the volumes on the catchment have been divided by the area to present a cumulative depth curve. This is directly comparable to the IFD depth, the depth of the losses applied, and the depth of water remaining on the grid. In Figure 32, it is evident that the average depth of water remaining on the grid is approximately 15 mm. This is the volume of water that fills depression storage at the start of the storm. This could be compensated for by reducing the initial loss by the depth of water remaining on the grid. Another way of accounting for this volume is by using a restart file which applies the final time step as initial conditions for the design simulation; however, an issue with this is that legitimate storage areas can be filled with water, which has potential to impact the model results.

Table 18 presents an example of the results of a volume check undertaken on a direct rainfall model. The volume of water left on the grid at the end of the simulation was calculated. The total volume error was calculated to be <1%.
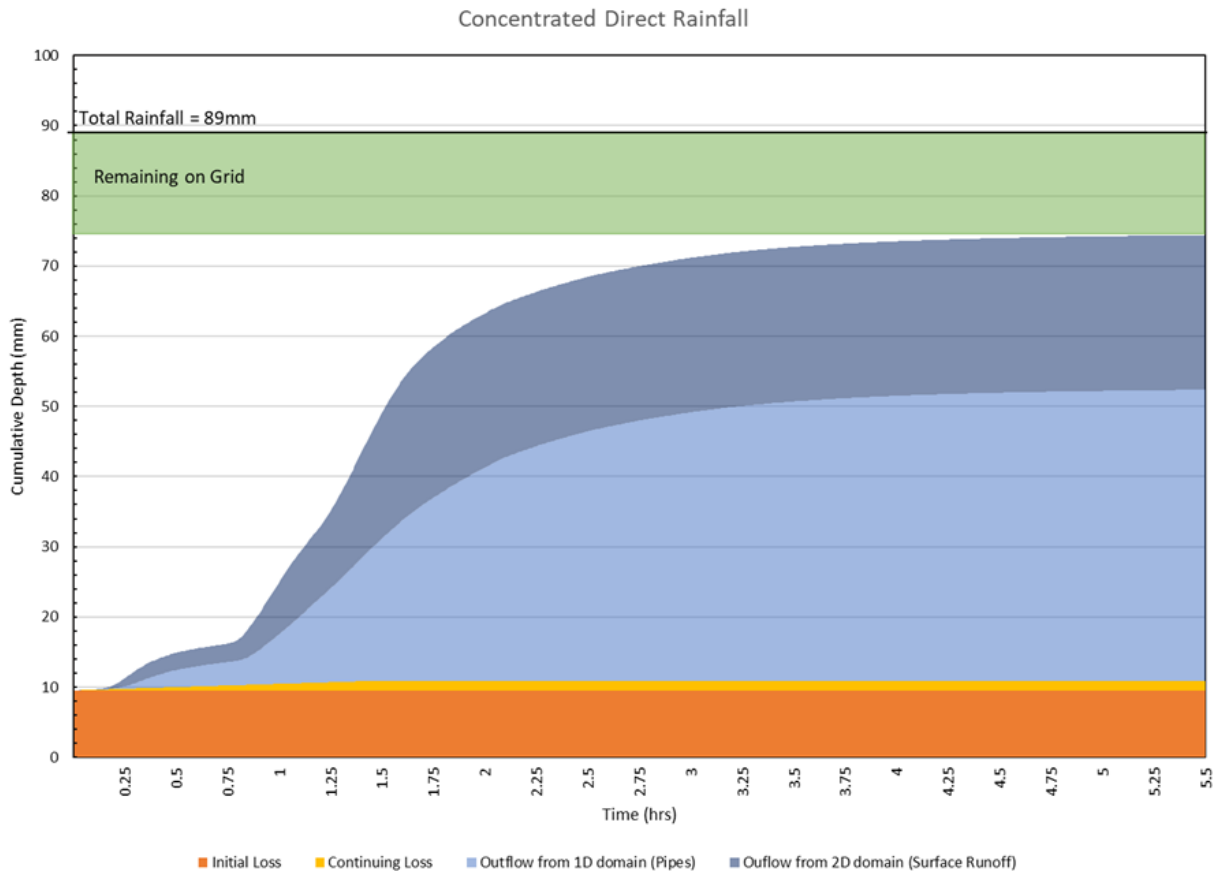
Figure 32 Runoff volume check

Table 18 Total volume check

Parameter	Volume (m³)
Inflow (rainfall minus losses)	41,112
Outflow (1D and 2D elements)	31,866
Runoff left on grid (including in pipes)	9,249
Volume balance error	-3
Total volume error %	0%

C.2 Unit area runoff comparison to a conventional rainfall-runoff model

Table 19 is an example of the reporting of a flow comparison undertaken between a direct rainfall approach and a traditional rainfall-runoff model routed through a 2D model. The comparison shows a 5% decrease in flows when using the direct rainfall approach. The location has an upstream catchment area of approximately 1.8 hectares, giving a unit flow of 0.58 m³/s/ha for the direct rainfall approach.

Table 19 Overland flow at checkpoint – 1% AEP

Method	Flow (m³/s)
Direct rainfall	1.07
Rainfall-runoff model	1.13

Appendix D: At-site IFD analysis

The Intensity–Frequency–Duration (IFD) depth curves produced for ARR2016 pool data from nearby gauges, which produces a more reliable estimate in most cases. However, it is not unexpected that in areas with localised weather effects the IFD may not match well with observed data. An at-site analysis can be used to check for bias in the IFD grid. This can be done one of two ways:

- independent at-site IFD analysis
- comparing the plotting position to the BoM IFD for the relevant durations.

The at-site record annual maxima should be plotted against the IFD using the plotting formula in ARR2016 (ARR Book 3 Chapter 2 Section 2.6.2). For short records, it is not unexpected that the events may plot above or below the IFD as the IFD pools data from surrounding gauges to give an overall fit.

It is also possible that reasonable record length gauges may not fit the IFD well; however, if there is a distinct under or overestimate of a number of gauges in an area then it may be worth undertaking a local adjustment.

At-site analysis of rainfall gauges can be done on any gauge with a long enough record. A number of considerations should be taken into account when undertaking an at-site analysis. These include:

- Daily rainfall records – care should be taken when using daily records to undertake a restricted to unrestricted rainfall conversion (ARR Book 2 Chapter 3 Section 3.4.3). The conversion is done as the daily records may not capture the most intense 24 hours.
- Record length of all gauges used in the analysis – gauges must have a minimum of 10 years record length to be considered, but at least 25 years is preferable. Only one or two gauges considered in the analysis should have less than 25 years of record; however, short records should not be discounted if they capture an extreme event.
- Number of gauges – how many gauges are needed depends on how many are available and the size of the catchment. At least three should be used on small catchments.
- Distance from the catchment – if using gauges outside the catchment consider similarity in meteorological processes (i.e. along the coast as opposed to inland).
- Spatial variation – spatial variation within the catchment is not always shown by where the gauges are located. Where possible a comparison of gauge rainfall with radar rainfall may be useful to make some assumptions about spatial variability.

If the at-site analysis is not the same as the IFD it is not necessarily incorrect to use the IFD. The IFD considers multiple locations compared to at-site data. If a consistent bias (under or overestimation) is shown, then consideration of use of the at-site data is recommended.

Instead of using just one at-site analysis for an entire catchment, a distribution based on the combination of more than one gauge within the catchment or area can be derived. If multiple IFDs are required for spatial variation, the mean of each gauge can be used but the standard deviation and skew can be pooled from multiple gauges, especially gauges with long records (>50 years).

Appendix E: What to look for in reviewing studies and models in ARR2016

Some important aspects to consider when reviewing studies and models that are developed considering ARR2016 are listed below.

Data management

- What design inputs have been used and what is their source and their justification for use?

- Has a copy of the ARR Data Hub print-out been included in the report as an appendix (see Appendix A)?

- Is the software version documented?

Hydrological modelling

- If reliable and appropriate information is available for flood frequency analysis, has FFA been undertaken and if not why not?

- Has an alternative method been used to verify flows and is this documented?

- Are model parameters within the recommended range, do they reflect the local experience and are they considered fit for purpose for this study?

- Have calibrated and validated parameters been used? If not has this been justified?

- Has an ensemble of 10 patterns been used?

- Has the pattern closest to the mean pattern been chosen?

- Have other patterns which are quite different but produced similar peaks been identified for consideration in hydraulic modelling?

- Are critical duration box plots presented?

- Are spatially distributed IFDs used for catchments >20 km and in areas with reasonable spatial variability?

- Are hydrologic modelling results noted that produce greatest volume, peak flow, and shortest timing?

- Has any comparison to results from any previous studies or to ARR1987 (where relevant) been made and any significant changes justified?

Hydraulic modelling

- Are Mannings parameters within the range recommended in ARR Project 15 Two-dimensional modelling report?

- If a number of or all 10 events have been carried through to the hydraulic model or direct rainfall has been used, has a mean critical duration map been prepared?

- If direct rainfall has been used:
  - Has its use for this study been fully justified and fully documented?
  - Have the limitations of this methodology been fully documented?
  - Has a conventional calibrated and validated rainfall-runoff model been developed and used to test reasonableness of any direct rainfall methods results? As a minimum this involves:

- – a volume check
- – a unit area runoff comparison
- – a comparison of peak flows
- – a comparison of timing
- – a comparison with historic flood behaviour
  - ○ Have any discrepancies been reasonably justified?

Calibration and validation

Does reporting:

- compare parameters to design values and other regional studies and are they in normal range?
- indicate there is a bias in fit between rare and frequent events?
- indicate the calibration has a good balance between, shape, peak, volume and timing?
- provide rating gauge information (if relevant)?
- provide an updated rating relationship file containing updated flows for the new rating relationship?

Reporting

- Has the new ARR terminology been used?
- Have sensitivities been tested and reported?
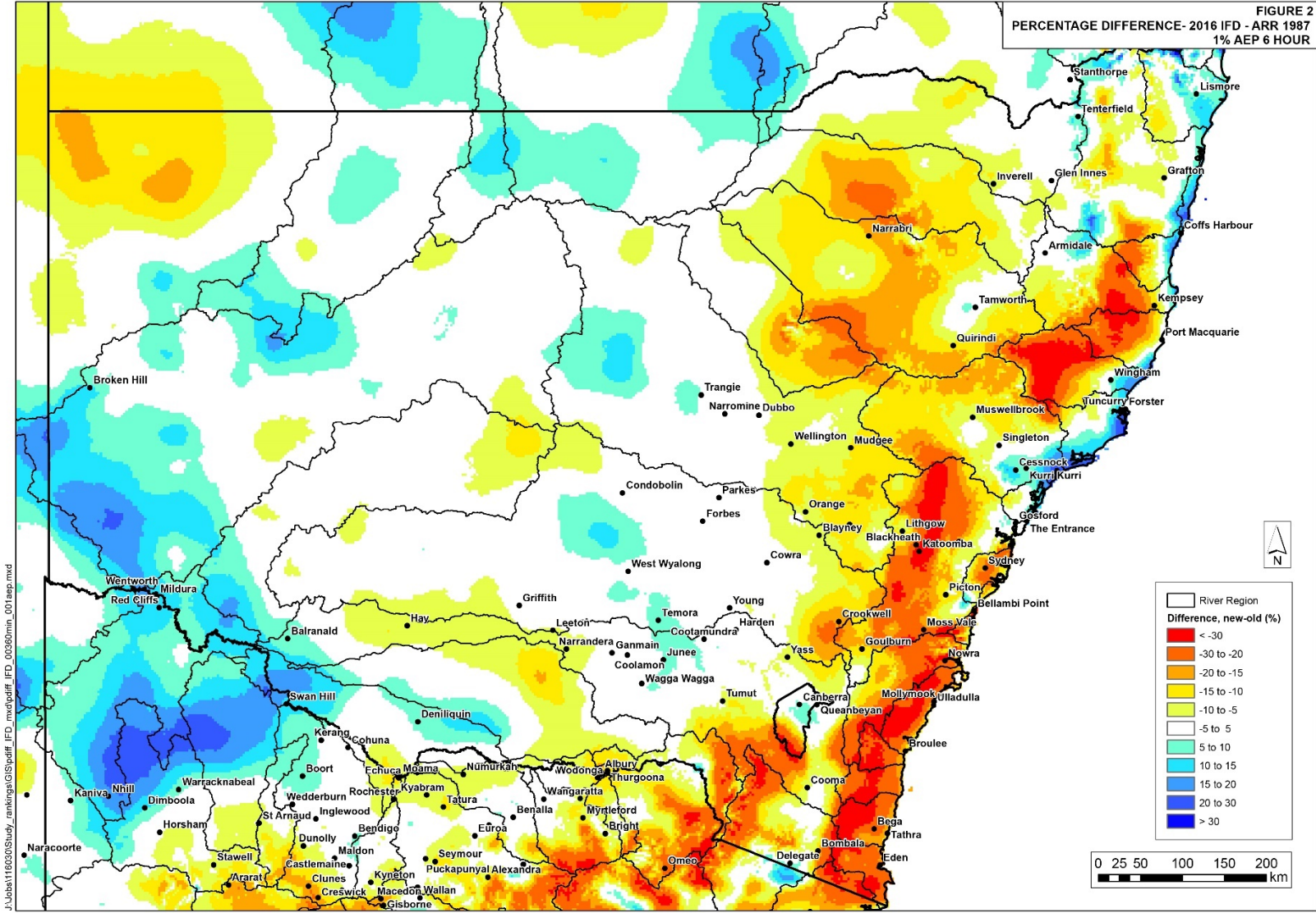- Does the report fully justify the results?

Data handover

- Is all data documented?
- Has data been handed over via the NSW Flood Data Portal in accordance with the requirements of the portal, and grant and contract conditions?
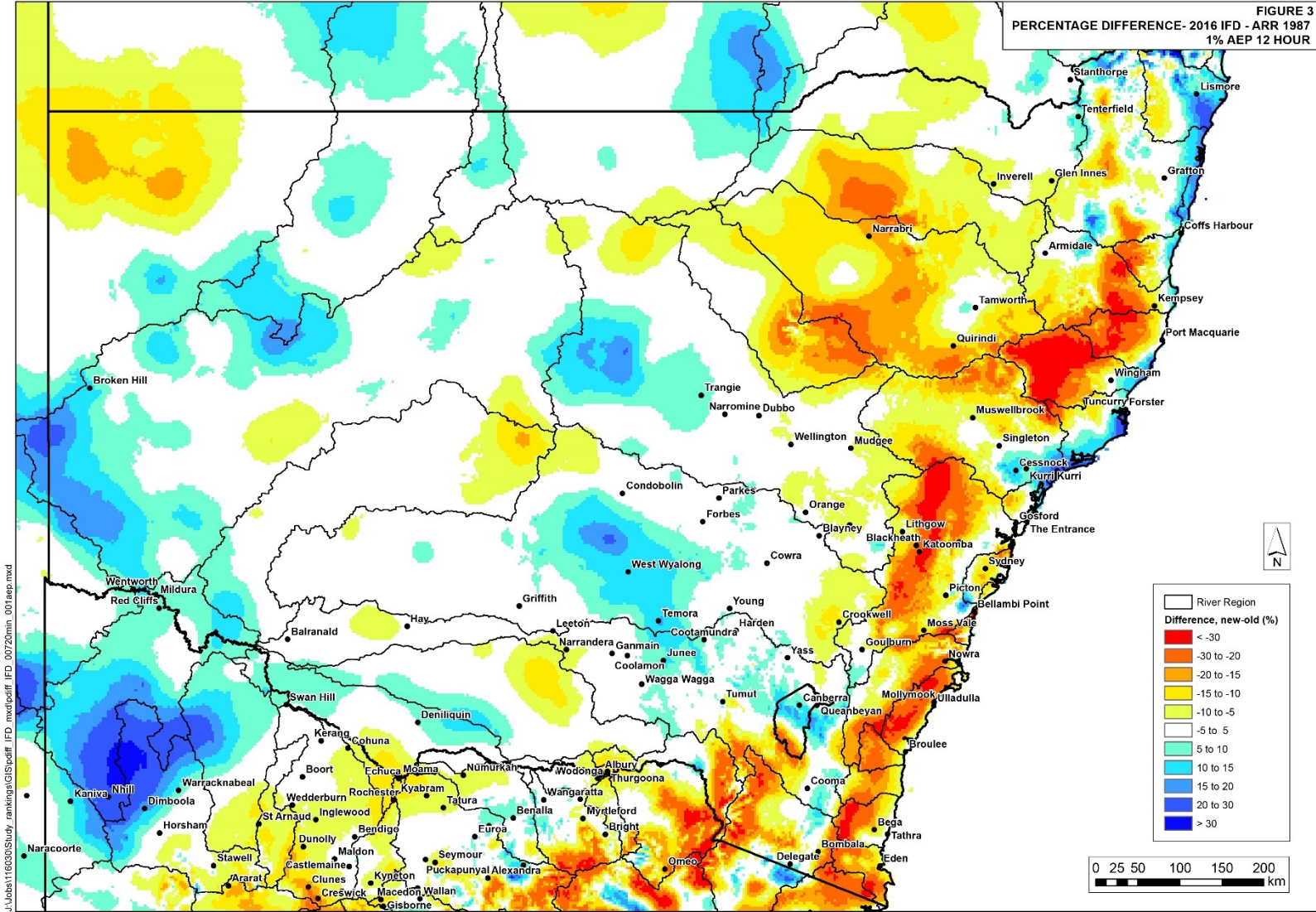
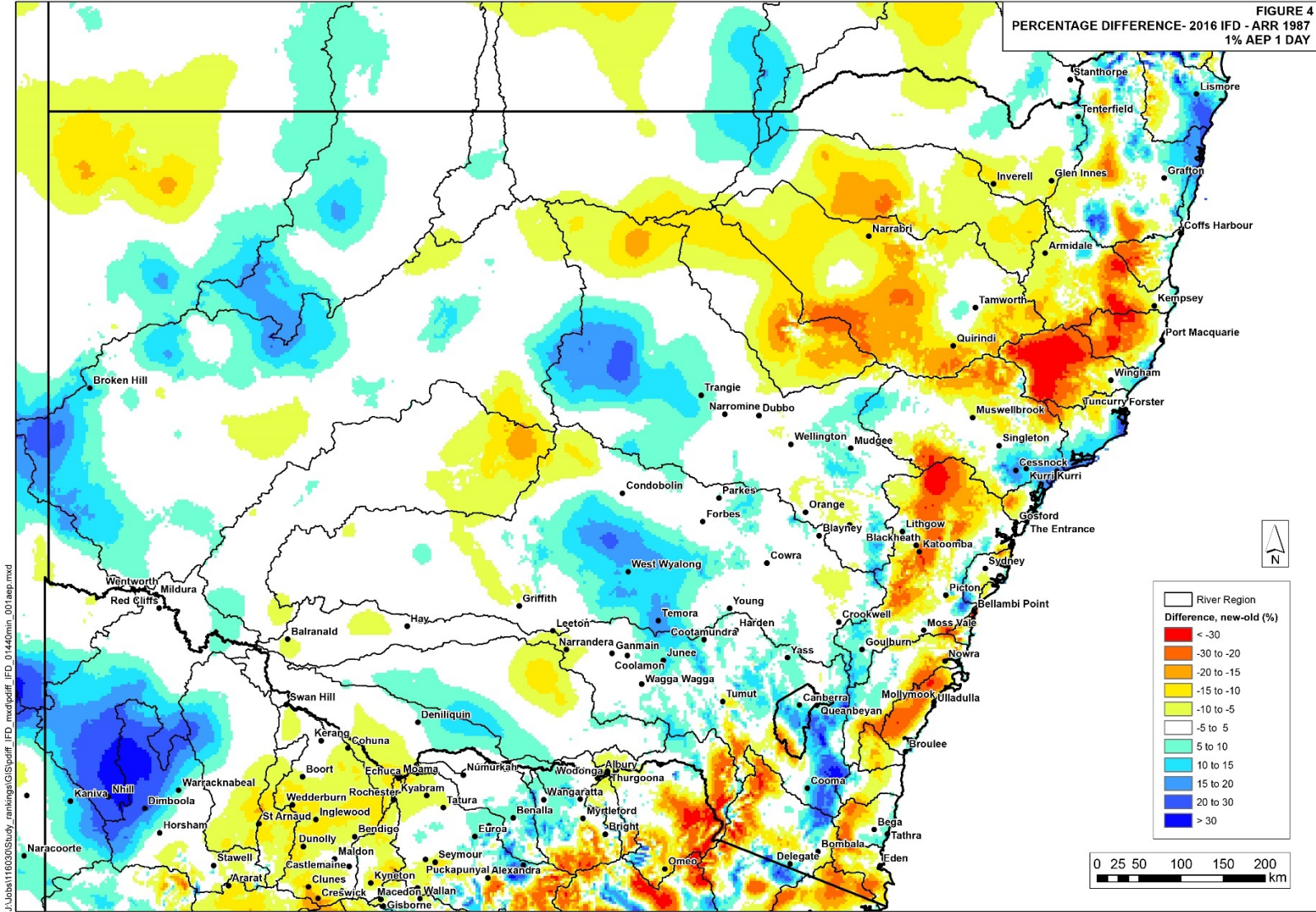# Appendix F: Maps of IFD comparisons between 1987 and 2016 and climate change zones
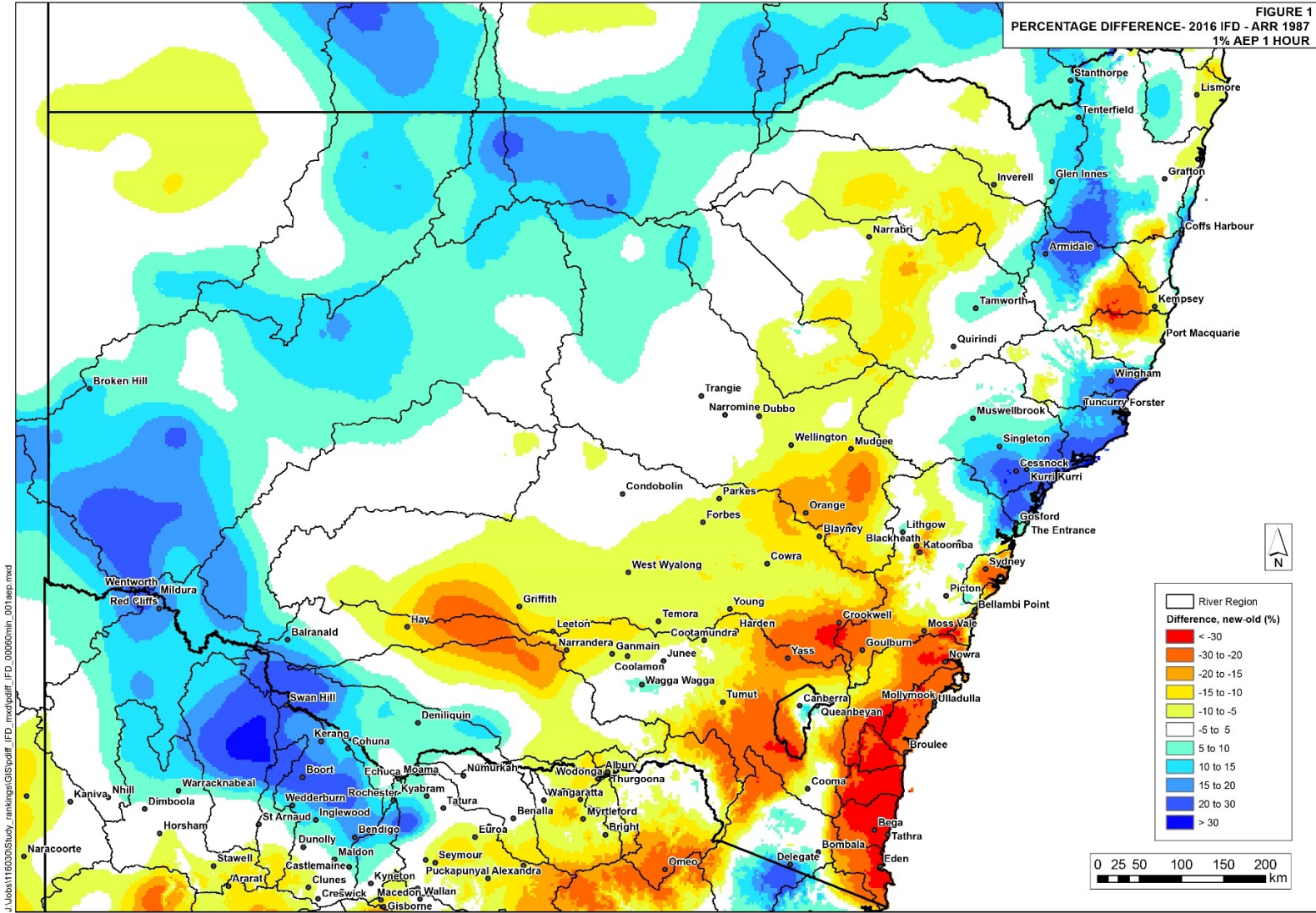
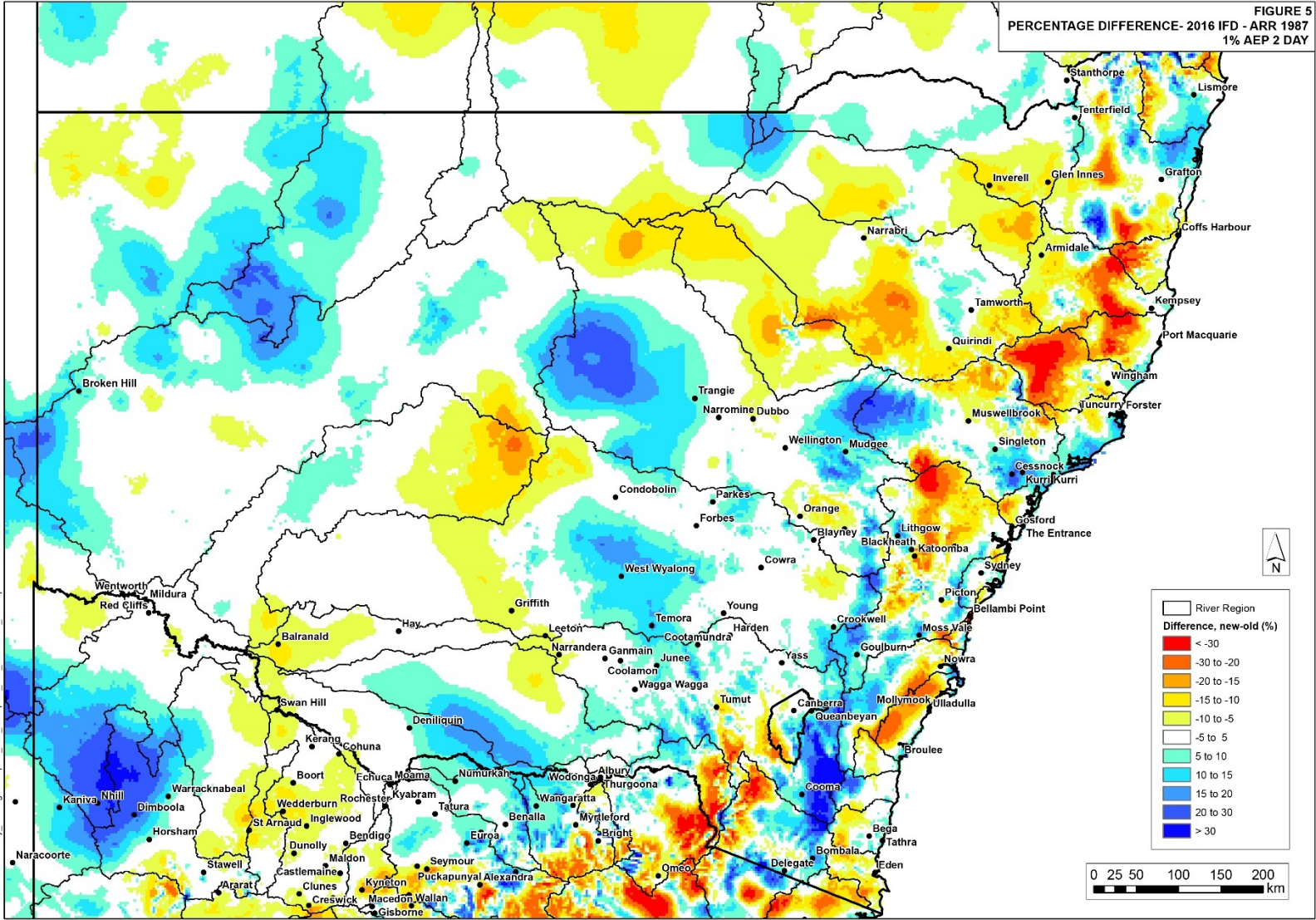Map 1   Percentage difference 2016 to 1987 IFDs 1% AEP – 1 hour

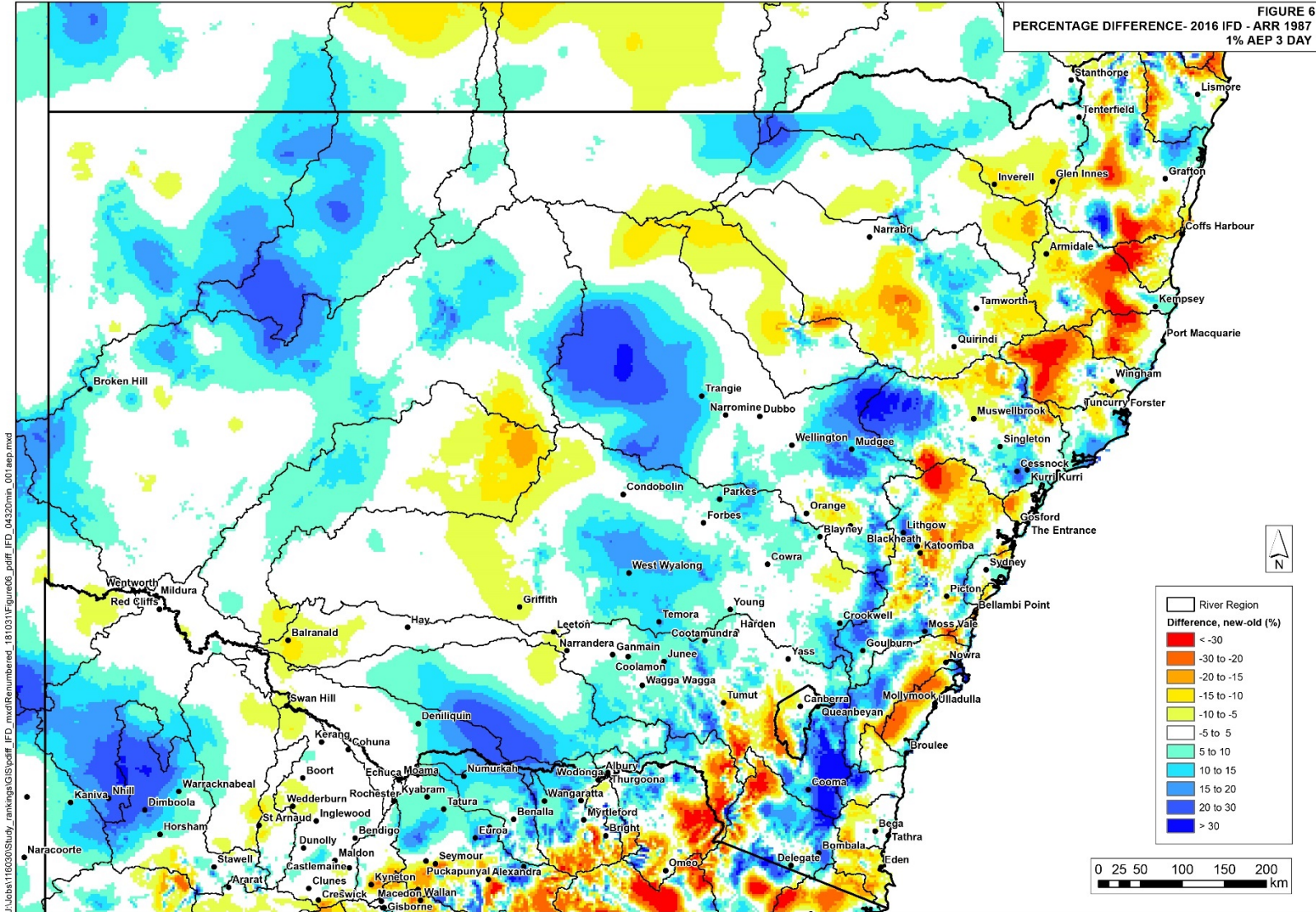**Map 2   Percent difference 2016 to 1987 IFDs 1% AEP – 6 hour**

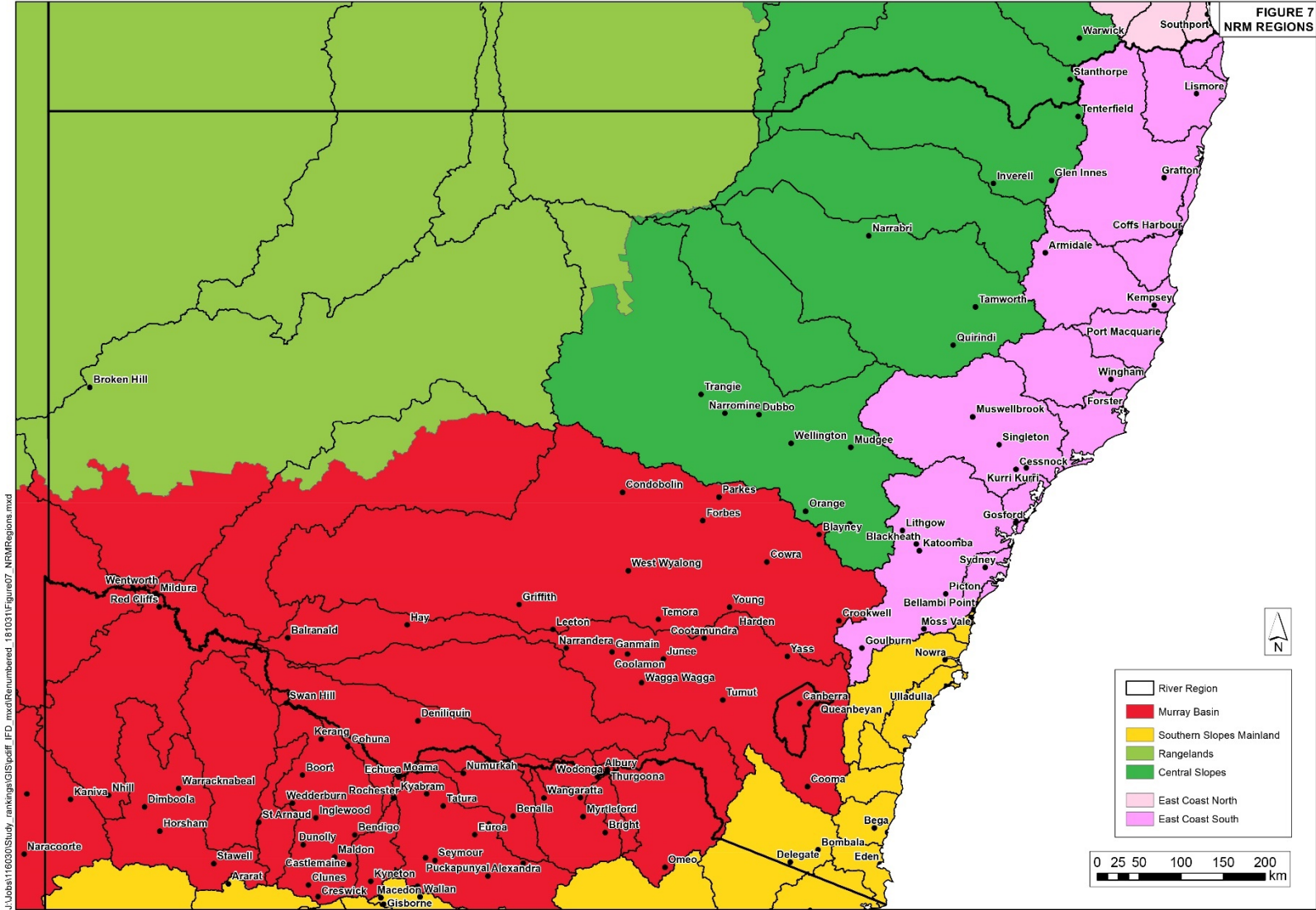**Map 3   Percent difference 2016 to 1987 IFDs 1% AEP – 12 hour**

FIGURE 4
PERCENTAGE DIFFERENCE- 2016 IFD - ARR 1987
1% AEP 1 DAY

Map 4   Percent difference 2016 to 1987 IFDs 1% AEP – 1 day

Map 5   Percent difference 2016 to 1987 IFDs 1% AEP – 2 day

Map 6   Percent difference 2016 to 1987 IFDs 1% AEP – 3 day

Map 7   NRM regions