"ARR 2015 UNPACKED – IMPLICATIONS FOR STORMWATER DESIGN IN WA"

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ABSTRACT

The 1987 Version 3 of "Australian Rainfall and Runoff (ARR) – A Guide to Flood Estimation" published by Engineers Australia (EA) has served as a national industry guideline document for rainfall runoff estimation and design.

Since publication there have been many advances in data collection, assessment techniques, numerical and statistical modelling and changes in thinking about how methods should be applied.

EA has advised that the next Version 4 ARR 2015 will be published in 9 books. EA specifically states that ARR 2015 is a guideline document and that users are required to apply professional judgement and experience in its application.

ARR 2015 includes revised methods for the following which will affect drainage design throughout WA:

- Rainfall intensity;
- Storm rainfall temporal patters; and
- Rainfall runoff coefficients / loss models.

The release of information by EA to date makes it clear that the net impact of these changes will increase estimates of stormwater in certain parts of WA, and decrease them in other parts.

In particular the Busselton coastal area will have increased runoff rainfall stormwater estimates, the Pilbara will have reduced stormwater rainfall estimates and the Perth metro area will be less affected.

The paper describes the implications of these new procedures for local authorities throughout WA in terms of risk management associated with these new methods for drainage calculation and its flood estimation.

1. INTRODUCTION

The ARR website *www.arr.org.au* contains background information on the revision process. This information is summarized in this paper for ease of reference, focusing on aspects of particular importance to WA IPWEA members. In addition the paper draws attention to specific technical issues in the 9 books of ARR 2015 in terms of details on rainfall and runoff estimation. Sections 2 to 7 below are summarized from the ARR website.

2. HISTORY OF ARR

ARR has been published previously in three versions:

- 1958 (Version 1: First Report of the Storm water Standards);
- 1977 (Version 2: Flood Analysis and Design); and
- 1987 (Version 3: A Guide to Flood Estimation).

Version 3 was republished in 1997 as Books (rather than Chapters) with the only update to the 1987 version being the Book on Estimation of Extreme Large Floods updated in 1998: The 1998 version was reprinted in 2001.

Version 4 ARR 2015 is currently in preparation with more extensive dataset and much advanced techniques and approaches. It will be available to be viewed freely on the ARR website. For referencing, the website recommends giving a full reference to specific author, version and chapter. This is partly because it is intended to be a living document, with revisions to documents over time.

3. REVISION PROCESS OF VERSION 4 ARR 2015

The updating of ARR is in two concurrent phases:

- Phase 1 Revision Projects to fill knowledge gaps
- Phase 2 Updating ARR from Version 3 to Version 4.

A list of the Revision projects is given below:

- Project 1 Development of Intensity Frequency Duration Information
- Project 2 Spatial Patterns of Rainfall
- Project 3 Temporal Patterns of Rainfall
- Project 4 Continuous Rainfall Sequences at a Point
- Project 5 Regional Flood Methods
- Project 6 Losses for Design Flood Estimation
- Project 7 Baseflow for Catchment Simulation
- Project 8 Use of Continuous Simulation for Design Flow Determination
- Project 9 Urban Drainage System Hydraulics
- Project 10 Appropriate Safety Criteria for People
- Project 11 Blockage of Hydraulic Structures
- Project 12 Selection of an Approach
- Project 13 Rational Method Developments
- Project 14 Large to Extreme Floods in Urban Areas
- Project 15 Two Dimensional (2D) Modelling in Urban Areas
- Project 16 Storm Patterns for Use in Design Events
- Project 17 Channel Loss Models
- Project 18 Interaction of Coastal Processes and Severe Weather Events
- Project 19 Selection of Climate Change Boundaries
- Project 20 Risk Assessment and Design Life
- Project 21 IT Delivery and Communications Strategy
- Project 22 Technology Integration with Design Methodology
- Project 23 Document Preparation and Publishing
- Project 24 Probabilities of a PMF

The ARR Revision project has 3 stages over 4 years with 24 Revision Projects from the above list, which were identified and undertaken with the aim of filling knowledge gaps. In Stage 1 10 projects were commenced and 19 of 22 projects are running in Stage 2. The remaining two projects will commence in Stage 3.

There are reports on the website for most of the above projects. The most recent Stage 3 reports cover projects 1-5, 8, 11, 12, 13, 18 and 20.

4. LINKAGE BETWEEN REVISION PROJECTS AND ARR 2015

The relationship between Revision Projects and ARR 2015 book numbers are shown in Table 1 below. For example, Book 3 Peak Flow Estimation only has one Revision Project - Project 5. Book 8 Runoff and Urban Areas has four Revision Projects – Projects 9 to 11 and 13.

TABLE 1: ARR BOOKS AND RELATED REVISION PROJECTS

Research Project No. / Book No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Scope & Philosophy	1											■	■						■	■	■	■	■
Rainfall Estimation	2	■	■	■	■												■		■			■	
Peak Flow Estimation	3					■																■	
Catchment Simulation	4								■			■		■								■	■
Flood Hydrograph Estimation	5						■	■										■				■	■
Flood Hydraulics	6															■			■			■	■
Application Of Catchment Modelling Systems	7						■	■	■			■							■			■	■
Large To Extreme Flood Estimation	8														■							■	■
Runoff In Urban Areas	9									■	■	■		■								■	■

ARR Research Projects are managed by a Steering Committee chaired by EA with a Technical Committee with representatives from EA, Universities, CSIRO, Consultants and Geoscience Australia.

5. ARR FUNDING

Stage 1 and 2 were funded by Federal Department of Climate Change and Energy Efficiency. The Bureau of Meteorology (BoM) has been funding Stage 2 and 3 of the Intensity-Frequency-Duration (IFD) revision. Geoscience Australia will fund Engineers Australia $5.15 million over three years to complete the vital third and final stage. Funding was conditional on ARR 2015 being made available free of charge (ARR 1987 was sold by EA).

6. ARR INDUSTRY LAUNCH HOBART DECEMBER 2015

At the EA Hydrology & Water Resources Symposium Hobart 2015 ARR 2015 Books 1, 2, 3, 6, 8, 9 were launched as advance drafts; Books 4, 5 & 7 are undergoing internal consistency checks prior to publication. ARR is published under the auspices of the EA National Committee on Water Engineering (NCWE) which has a major responsibility for the periodic review of ARR.

7. POLICY STATEMENTS

The ARR website contains a number of policy statements regarding ARR:

- **ARR Policy Statement:** This statement describes the ARR review process as an open and transparent one with all books freely available and data online.

- **Flood Frequency Analysis:** This statement notes that the draft chapter on flood frequency analysis (Book IV of ARR 1998) largely replaces ARR 1987 and should be used in an appropriate manner.
- **IFD Developed by Other Agencies:** This states that EA and BOM do not endorse use of IFD developed by other agencies. This is because ARR 1987 and ARR 2015 (with revised IFD's published 2013) aim to provide neutrality of Annual Exceedance Probability (AEP) which may not be the case with alternative IFD's. Neutrality here means that rainfall of a certain AEP (such as 1%) will result in a flood of the same AEP (e.g. 1%).
- **Use of IFD 2013:** Guidance on the use of the "New IFD" (i.e. the IFD's published by BOM in 2013) is summarized below.
  - ARR 1987 aimed for AEP neutrality;
  - ARR 2015 also aims for AEP neutrality and so updates to other design flooding inputs are needed to ensure new design flood estimates are produced with the same AEP as the new 2013 IFD design rainfall;
  - It cannot be assumed that using the 2013 IFD design rainfall with ARR 1987 techniques and design parameters would deliver a more reliable estimate of the design flood;
  - In most cases it would be prudent to use the ARR 1987 design parameters and conduct sensitivity testing with the ARR 2015 design parameters (including the 2013 IFD design rainfalls) as they become available.
  - The 2013 IFD design rainfalls should definitely not **BE USED IN CONJUNCTION WITH THE FOLLOWING TECHNIQUES:**
    - Probabilistic Rational Method (PRM);
    - Other regional flood techniques based on ARR 1987 IFD design rainfall.

If seeking consistency across a number of flood estimation studies, ARR 1987 design parameters should continue to be used with sensitivity testing with the 2013 IFD design rainfalls until the entire suite of ARR 2015 techniques and design parameters is available. If undertaking a one-off flood estimation study, a choice can be made, on a case-by-case basis, to use the 2013 IFD design rainfalls and other revised ARR design parameters as they become available. In addition, careful consideration should be given before using the 2013 IFD design rainfalls with the Average Variability Method (AVM) temporal patterns and design losses from ARR 1987.

8. DOWNLOADS AND SOFTWARE

ARR 2015 Books and Chapters can be downloaded for free in an open e-book format (epub) at http://www.arr.org.au/arr-guideline/books-and-chapters/. Free epub readers are available for download.

Enabling software for application of ARR 2015 can be accessed at http://www.arr.org.au/downloads-and-software/software/ for the following:

- Multisite rainfall simulator (Continuous Rainfall – Project 4);
- Regional Flood Frequency Estimation (Project 5);

- Interaction of Coastal and Catchment Flooding (Project 18).

Data supporting the guidelines such as spatial datasets for baseflow, ARF, IFD, and temporal patterns are downloaded at http://www.arr.org.au/downloads-and-software/data/.

PowerPoint presentations by ARR team members at major cities throughout Australia since 2009 together with the Revision Projects reports to which ARR 2015 will be accessible at http://www.arr.org.au/downloads-and-software/.

9. CORRECT AEP & ARI TERMINOLOGY

The term X year ARI has caused confusion both within the industry and with the community and other stakeholders. It has been interpreted by many to imply that the periods between exceedances of a given event magnitude. ARR 2015 will adopt probability terminology that differs from that used in ARR87. The preferred new terminology is AEP and EY.

Annual Exceedance Probability (AEP) expresses the probability of an event occurring or being exceeded in any one year. Additionally, AEP are to be expressed as an exceedance probability using percentage probability; for example, the 1% AEP design flood discharge. Extreme flood probabilities associated with dam spillways are one example of a situation where percentage probability is not appropriate. In these cases, it is recommended that the probability be expressed as 1 in x AEP. Note that it is incorrect to express ARI as 1 in x year ARI or AEP as 1 in x year AEP.

For more frequent events an annualised exceedance probability is misleading and confusing. Furthermore, a recurrence interval approach also is misleading where strong seasonality is experienced. Consequently, events more frequent than 50% AEP should be expressed as x Exceedances per Year (EY). For example, 2 EY is equivalent to a design event with a 6 month recurrence interval when there is no seasonality in flood occurrence, and 4 EY equivalent to a design event 3 months occurrence interval.

10. FLOOD ESTIMATION ON UNGAUGED CATCHMENTS

The Regional Flood Frequency Estimation RFFE Method divides Australia into a number of zones (see Figure 1). A RFFE software application has been developed, which allows flow estimates to be made based on catchment location, area and shape – available on the website http://rffe.arr.org.au/ The predictors for flood estimation are catchment area, catchment shape factor (distance from outlet to central divided by square root of catchment area) IFD 2013 1 in 2 and 1 in 50 AEP 6 hour rainfall.

The uncertainty with RFFE is large with mean relative errors of 50 to 60%. More over RFFE does not include urbanised or catchments regulated by water storages (dams). Catchment representativeness remains an issue due to sparse gauge coverage and RFFE is a high priority for further research.

For WA Book 3 Chapter 1 references alternative methods developed by Flavell and by Davies & Yip (2013) and suggest that this could be used as locally developed alternatives to the ARR 2015 methods for the Pilbara Region of WA.

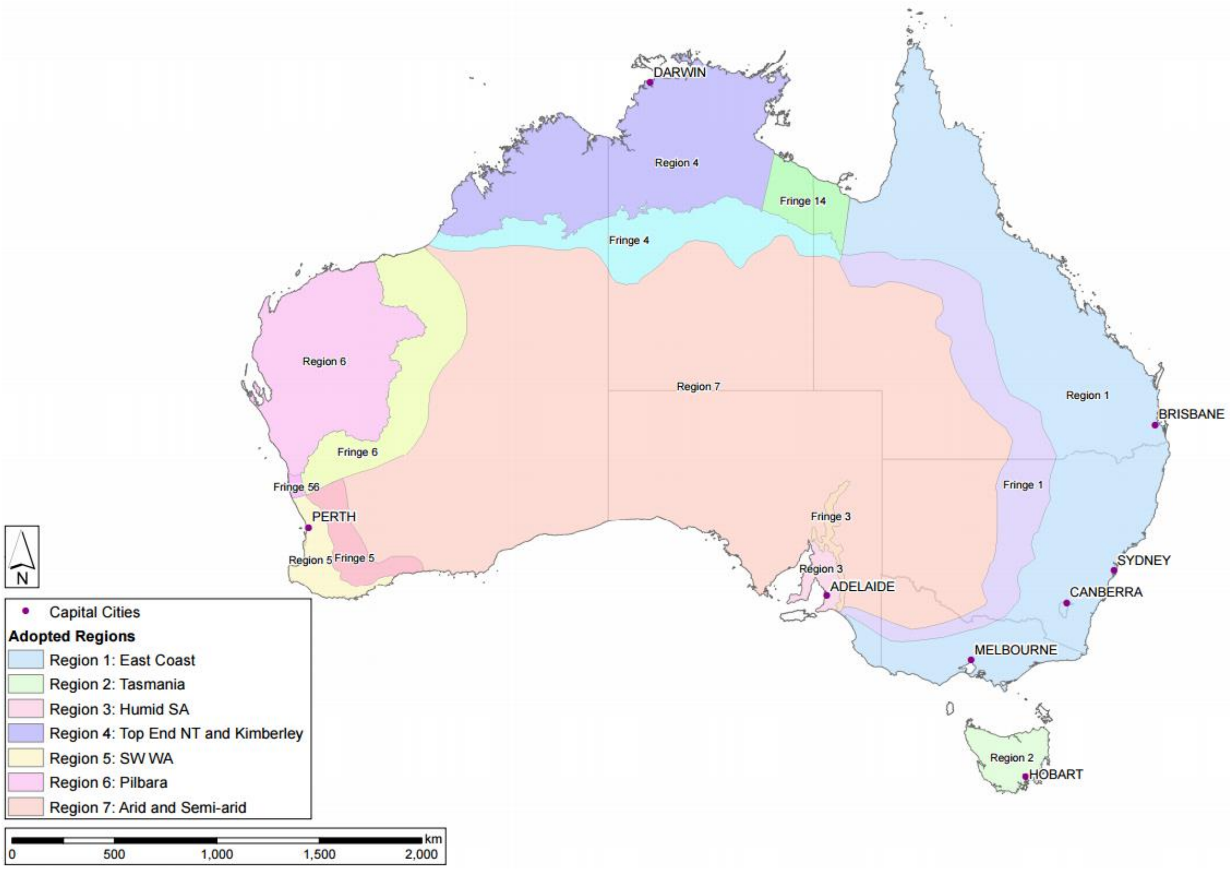

Figure 1: RFEE regions

11. COMPARISON BETWEEN ARR 1987 IFD AND ARR 2015 IFD

Davies et al (2014) presented a preiminary analysis which is developed further below.

Figure 2 shows the percentage difference across WA between ARR(1987) and BoM(2013) for a particular AEP and storm duration namely 2% AEP and 1hr duration.

Figure 2 colour pallette shows the LGAs of WA where the BoM(2013) IFD exceeds the ARR(1987) in red, and where it is less than in green.

Areas of increase include the majority of inland WA, part of the Wheatbelt and in particular the coastal regions of Busselton, Margaret River and Albany. Areas of decrease include most of the coastal areas with the Pilbara the most marked.

Assuming rainfall temporal patterns and runoff rates do not change between ARR(1987) and 2015, Figure 2 indicates areas where runoff estimates will increase and decrease.

Similarly, Figure 3 shows the same palette for 1% AEP and 1hr duration storms –with very similar variation as Figure 2. Figures 2 and 3 relate to short duration storms and therefore small catchments such as those in urban areas.

Figure 4 shows 1% AEP and 24 duration differences.

Figure 5 shows a generalised map for 1% AEP across all durations indicating increase in IFD for most of the South-West, particularly Busselton and Augusta-Margaret River.

The implications for local government engineering is that hydraulic structures may need to be re-accessed in terms of their flood risk.

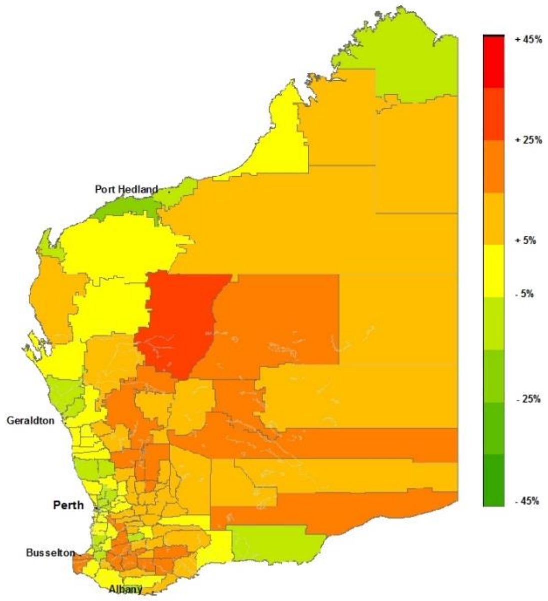

Figure 2: Percentage difference across Western Australia between ARR(1987) and BoM(2013) IFDs for 2% AEP and 1 hr duration

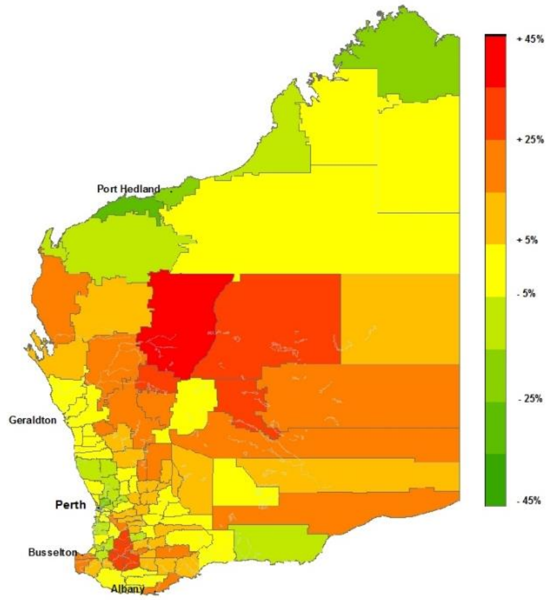

Figure 3: Percentage difference across Western Australia between ARR(1987) and BoM(2013) IFDs for 1% AEP and 1 hr duration

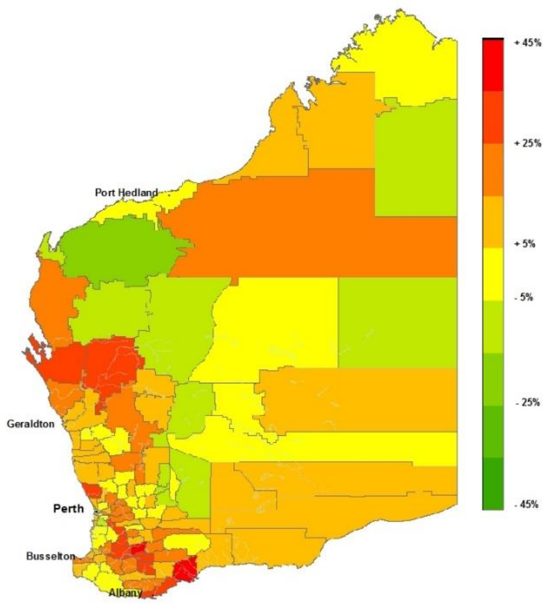

Figure 4: Percentage difference across Western Australia between ARR(1987) and BoM(2013) IFDs for 1% AEP and 24 hr duration

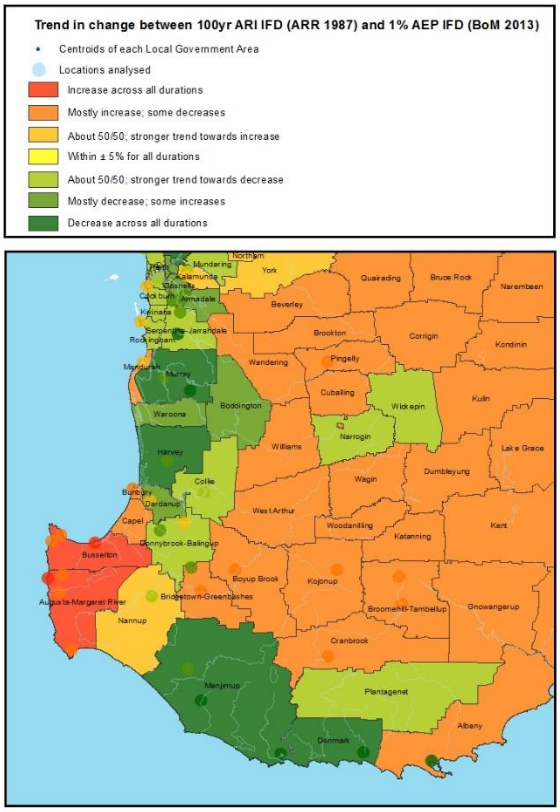

Figure 5: Trend in change in IFD for 1% AEP

Tables 2 to 4 present rainfall intensity differences between 1987 and 2013 for Perth, Busselton and Port Hedland for all AEP and durations calculated as:

Percentage difference = (2013(BoM) – ARR87) x 100 ÷ ARR87.

TABLE 2 PERTH - DIFFERENCES BETWEEN ARR87 AND 2013 (BOM) REVISED IFD – ALL DURATIONS & SELECTED AEPS

DURATION	1 EY/1yr ARI	10% AEP/10yr ARI	5% AEP/20yr ARI	2% AEP/50yr ARI	1% AEP/100yr ARI
5Mins	16.7%	-4.2%	-8.5%	-14.2%	-17.7%
10Mins	14.2%	-2.9%	-6.2%	-11.4%	-15.2%
30Mins	10.7%	-0.4%	-3.4%	-6.5%	-8.9%
1Hr	9.5%	0.3%	-1.5%	-3.5%	-5.0%
2Hrs	9.4%	2.2%	1.4%	1.6%	1.6%
3Hrs	8.7%	3.7%	4.2%	5.3%	6.3%
6Hrs	8.2%	6.2%	7.9%	11.4%	14.0%
12Hrs	7.3%	6.4%	8.3%	11.9%	15.1%
24Hrs	6.0%	2.6%	3.1%	4.1%	5.1%
48Hrs	7.4%	-2.7%	-5.3%	-8.7%	-11.3%
72Hrs	11.5%	-3.5%	-8.1%	-13.7%	-17.7%

TABLE 3 BUSSELTON - DIFFERENCES BETWEEN ARR87 AND 2013 (BOM) REVISED IFD – ALL DURATIONS & SELECTED AEPS

DURATION	1 EY/1yr ARI	10% AEP/10yr ARI	5% AEP/20yr ARI	2% AEP/50yr ARI	1% AEP/100yr ARI
5Mins	40.8%	17.1%	12.1%	5.4%	1.0%
10Mins	34.7%	19.2%	15.0%	9.5%	5.2%
30Mins	29.3%	24.4%	23.3%	21.0%	19.1%
1Hr	26.4%	25.9%	26.2%	26.6%	26.5%
2Hrs	24.3%	26.7%	28.5%	30.0%	31.5%
3Hrs	22.3%	26.6%	28.7%	31.5%	32.7%
6Hrs	19.0%	25.5%	28.0%	30.9%	33.2%
12Hrs	13.8%	21.8%	24.6%	27.4%	29.4%
24Hrs	7.4%	15.5%	17.7%	20.1%	21.6%
48Hrs	2.0%	8.1%	9.3%	10.6%	10.9%
72Hrs	2.3%	5.1%	5.6%	5.9%	5.3%

TABLE 4 PORT HEDLAND - DIFFERENCES BETWEEN ARR87 AND 2013 (BOM) REVISED IFD – ALL DURATIONS & SELECTED AEPS

DURATION	1 EY/1yr ARI	10% AEP/10yr ARI	5% AEP/20yr ARI	2% AEP/50yr ARI	1% AEP/100yr ARI
5Mins	-20.6%	-29.2%	-31.1%	-32.4%	-33.4%
10Mins	-11.9%	-21.8%	-24.0%	-26.4%	-28.0%
30Mins	-10.7%	-25.0%	-28.1%	-31.1%	-32.9%
1Hr	-11.8%	-28.0%	-31.2%	-34.2%	-36.4%
2Hrs	-10.2%	-27.3%	-30.6%	-33.7%	-35.6%
3Hrs	-7.5%	-24.7%	-28.1%	-31.1%	-33.0%
6Hrs	0.0%	-17.2%	-20.4%	-23.7%	-25.8%
12Hrs	7.5%	-8.3%	-11.8%	-15.2%	-17.7%
24Hrs	11.5%	-3.8%	-7.7%	-11.5%	-14.0%
48Hrs	11.6%	-6.0%	-10.8%	-15.3%	-18.0%
72Hrs	12.6%	-8.4%	-14.1%	-19.3%	-21.9%

12. SELECTION OF APPROACH – UNGAUGED CATCHMENT FLOOD ESTIMATION

As discussed in Section 7 above, ARR 1987 aimed for AEP neutrality. In this way a Y AEP rainfall results in a Y AEP flood. Parameters such as loss models, temporal and spatial patterns are "probability neutral" to achieve this (see Figure 6).

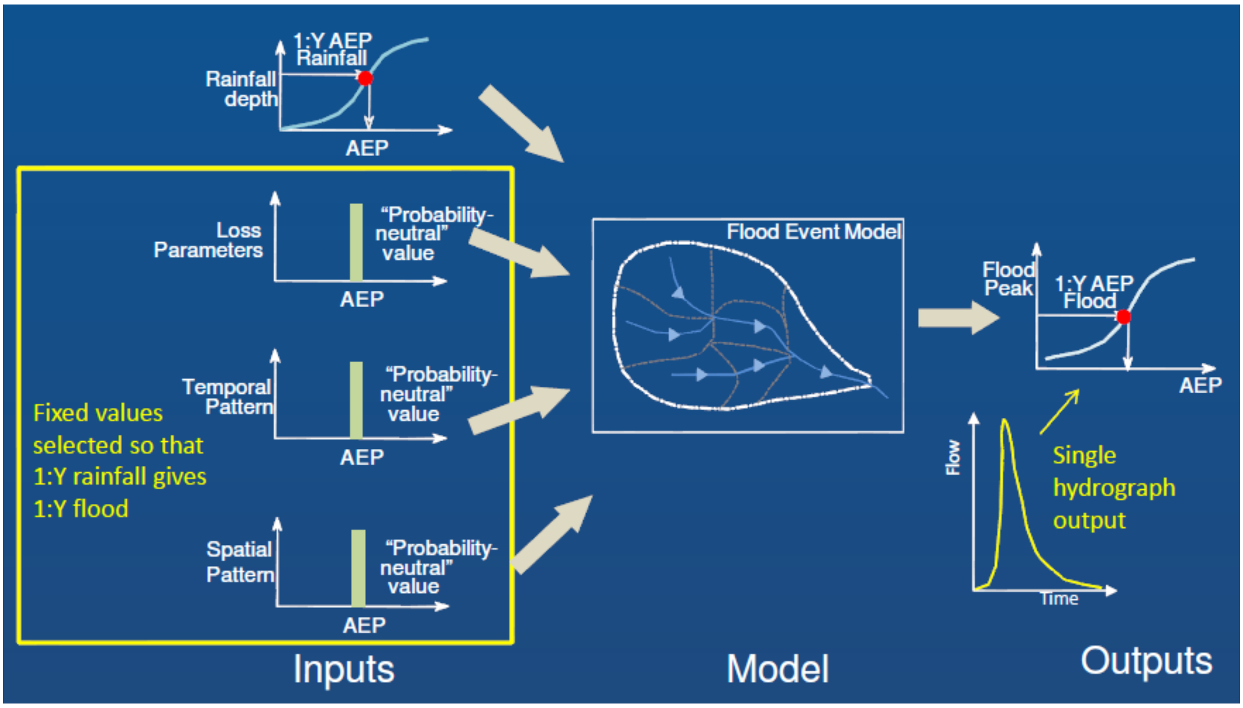

Figure 6: Single Event Approach (ARR, 2015)

In ARR 1987 there was only a single temporal pattern for each AEP and duration. The patterns provided in ARR 1987 were an average of a number of potential temporal patterns.

However in ARR 2015 a number of temporal patterns will be provided for use. In this way, the temporal pattern as shown in Figure 6, rather than being a fixed value, may be a number of values (see Figure 7). This will result in a range of hydrographs being generated for each AEP and duration, and is referred to as being an Ensemble Approach.

In this approach the Y AEP flood peak rate is calculated by the arithmetic mean of the peaks.

Potentially there may be 10-20 temporal patterns for each AEP and storm duration.

If the unknowns extend to the loss model and spatial patterns, and all inputs are stochastically sampled, this is a Monte Carlo Event Approach (see Figure 8) and can generate a very large (>1,000) number of peak flow estimates. The Y AEP estimate is then calculated based on a frequency analysis of the derived peaks.

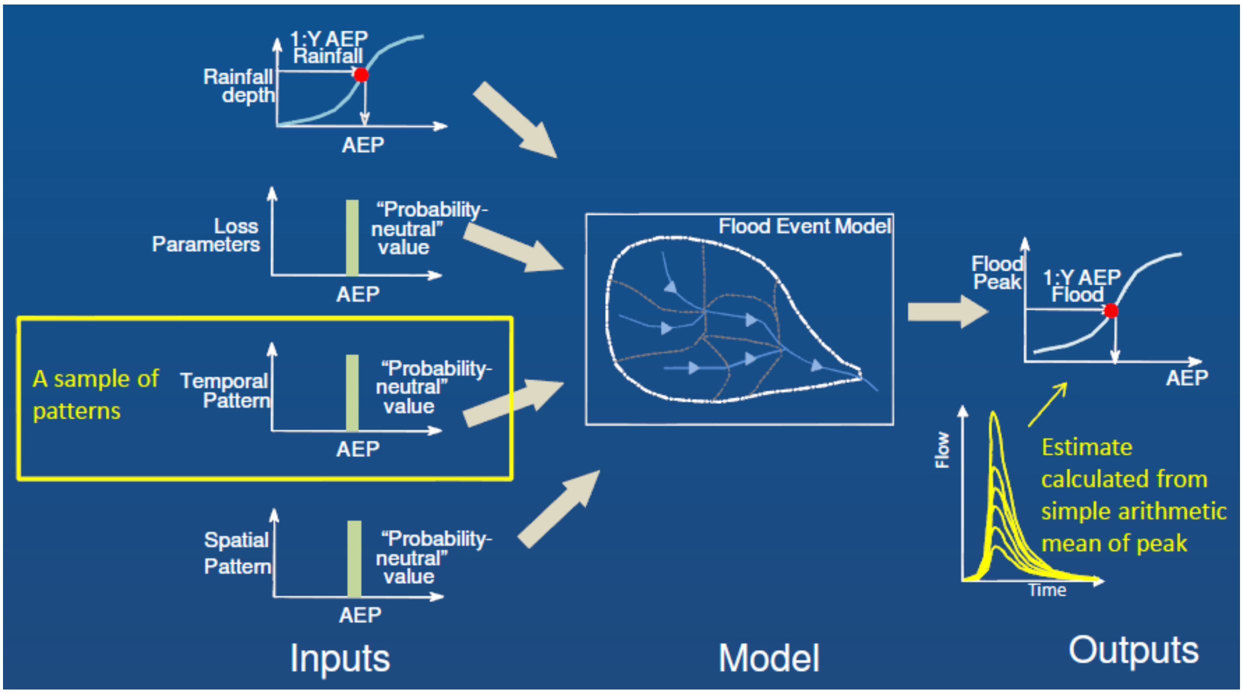

Figure 7: Ensemble Event Approach (ARR, 2015)

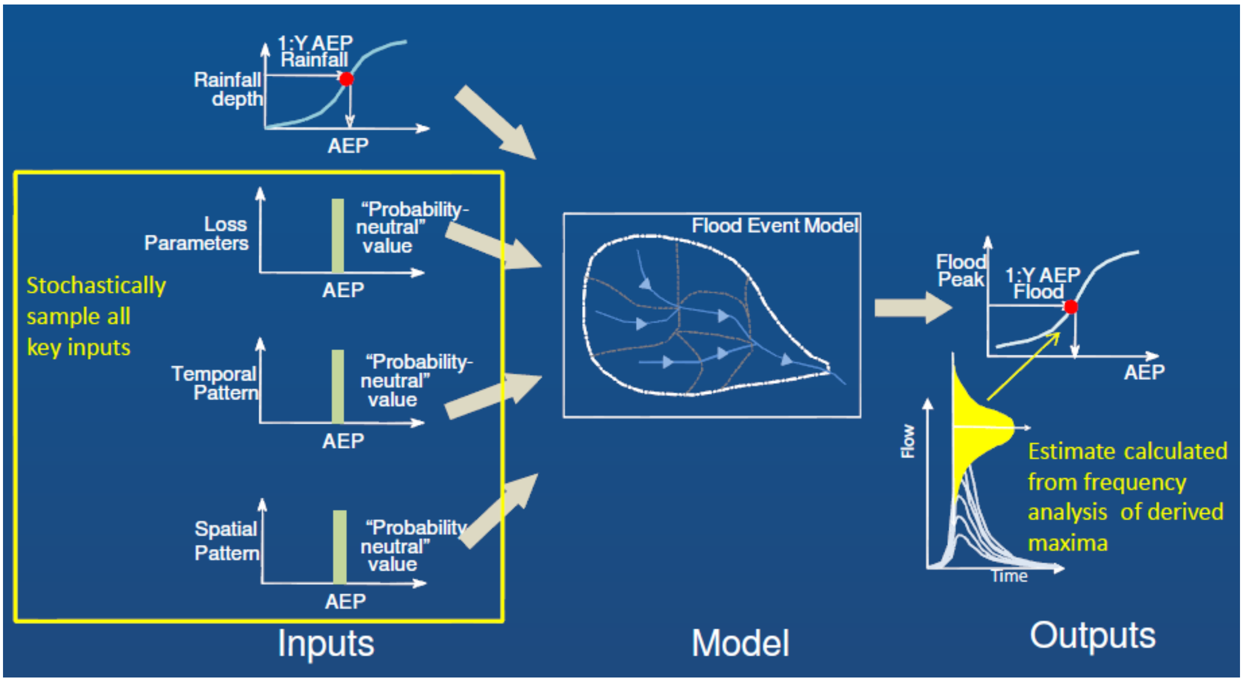

Figure 8: Monte Carlo Event Approach (ARR, 2015)

In addition to the suite of temporal patterns is the consideration of "critical burst" and "pre-burst" rainfall. The "critical burst" rainfall may be part of the AEP event, however the "pre-burst" rainfall may impact on the available initial loss of a catchment with (partial) filling of storages.

Figure 9 provides an example of rainfall depth over time showing "pre-burst" and "critical burst" rainfall.

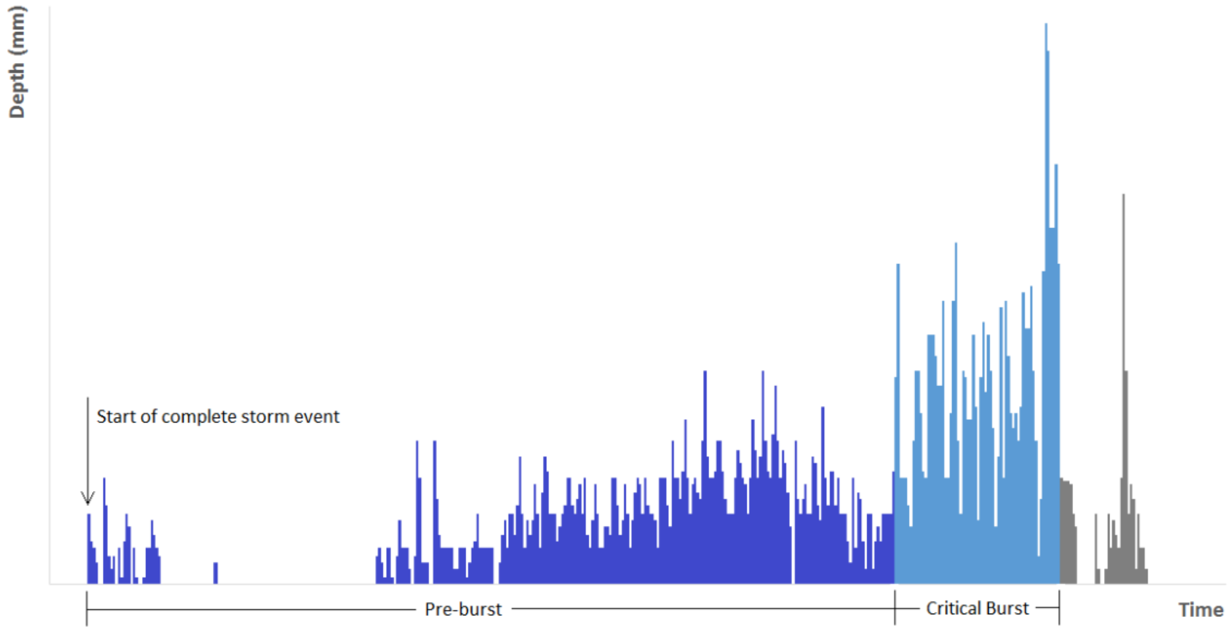

Figure 9: "Pre-Burst" and "Critical Curst" Rainfall (ARR, 2015)

13. URBAN RUNOFF

Book 9 Runoff in urban areas is currently available as a draft. For WA there appears to be no new information regarding runoff coefficients, so that the changes to rainfall IFDs become dominant. For the Swan Coastal Plain sands, local knowledge and testing (for example JDA (2015a, b), Davies et al (2016)) may be more relevant for loss models.

For urban flood estimation there is limited data available to develop and test flood estimate methods. Testing was carried out for a small number of catchments where there was enough data for at site flood frequency analysis (FFA). Testing included comparison of several different currently available hydrology models against the FFA.

For WSUD, implementation needs to be considered for frequent design frequencies, but not necessarily for rarer design frequencies. WSUD techniques change the loss models and storage characteristics of a catchment.

The ARR website states "*an important aspect of this discussion relates to limitations of the Rational method and the changes in approach necessary for consideration of volume-based problems rather than peak flow based problems*." This statement follows from the Research Project No. 13 Rational Method development: Urban Rational Method Review which concluded that the Rational Method should be replaced by hydrograph methods which use rainfall temporal patterns and produced both peak flow as well as a runoff volume, rather than only peak flow.

14. BLOCKAGE OF HYDRAULIC STRUCTURES

With respect to Project 11 Blockage of Hydraulic Structures, the report dated February 2015 is titled "Blockage of Hydraulic Structures: Blockage Guidelines, and applies to culverts and small bridges over drainage channels (rather than major bridge structures) and to inlet structures (i.e. pits) to urban drainage systems. As such, the Guideline is directly applicable to all local governments in Australia with responsibility for these type of structures.

The Guidelines apply to blockage during flood events, with the intention that the Guidelines will incorporate the uncertainty associated with blockage so that appropriate risk management practices can be applied by users.

The Guidelines are not a definitive approach, but an attempt to provide an approach that allows a consistent analysis methodology, while not becoming too extreme in either directions since there are risks in either under- or over-estimating the influence of blockage.

The Guidelines provide guidance on an appropriate level of investigation and results in an estimate of % open area blockage for both floating and non-floating material.

15. WORKING GROUPS TRIALING ARR 2015

Working groups have been formed by EA to trial various new procedures in new ARR 2015. Several members of the EA Hydrology and Water Resources Panel WA have been involved in this process.

The second author was on the Working Group trialing application of Project 11 Blockage of Hydraulic Structures which resulted in Blockage Guidelines.

16. REFERENCES

ARR (2015) ARR Workshop, Hobart 7 December 2015.

Davies, J.R., Serafini, G., Green, W. (2014) Comparison between Rainfall IFD in ARR (1987) and BoM (2013) for Western Australia. Engineers Australia Hydrology and Water Resources Conference Perth, February 2014.

Davies, J.R., Yip, E. (2013) Pilbara Region Flood Frequency Analysis. Institute of Public Works Engineering Australia (WA) Annual State Conference March 2013.

Davies, J.R., Rogers, A.D., Bott, D., Barnett, J.C. (2016) How Many Holes Does One Soakwell Need?, IPWEA State Conference Fremantle 9-11 March 2016.

Institute of Engineers Australia (1987) (ARR87) Australian Rainfall & Runoff – A Guide to Flood Estimation. Volumes 1 & 2. Institute of Engineers Australia, Barton, ACT.

JDA Consultant Hydrologists (2015a) Rivergums, Baldivis: Rainfall Runoff Testing. Prepared for Cedar Woods. Ref: J5925b 30/1/15.

JDA Consultant Hydrologists (2015b) Harrisdale Green: Soakwell Infiltration Testing (SIT). Prepared for Cedar Woods. Ref: J5060bh 7/10/15.