FEDERATION COUNCIL

APPENDIX D
RAND

FEDERATION VILLAGES FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

MARCH 2022

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APPENDIX D
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Project **Federation Villages Floodplain Risk Management Study and Plan**	**Project Number** **118048**
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RAND

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1. BACKGROUND

1.1. Study Area

Rand is located approximately 120 km southwest of Wagga Wagga, and 58 km northwest of Albury. The township is situated on the right bank (north-eastern side) of Billabong Creek, which flows from southeast to northwest through Rand. The creek runs under Four Corners Road at Rand and continues along the southern side of Mahonga Road where it is joined by Wallandoon Creek some 8 km downstream of Rand. Billabong Creek then flows northwest, bypassing Lake Urana, and continues west until its confluence with the Edward River at Moulamein.

The Rand Study Area, presented on Figure D1, centres on the township, which is home to approximately 204 residents (2016 Census).

Rand is largely free from mainstream flood risk, as the developed areas are elevated well above Billabong Creek, and is protected by an informal levee approximately 520 m long. Inside the levee, the land generally slopes away from Billabong Creek to the north/northeast, meaning that internal runoff is not trapped behind the levee but can freely drain to the north. While properties are not directly impacted, flood runners from Billabong Creek can overtop roads around Rand, restricting access during flood events. Further details are provided in Section 5.

1.2. Land Use

The local area predominantly consists of cleared rural land which is used for grazing and agriculture. There is also dense vegetation forming the riparian zone of the creek. The main industries in Rand include beef and cattle farming, grain growing and road freight transport (2016 Census).

Land use in the township is composed of low-density residential development (110 private dwellings (2016)) with some commercial development along the main street (Kindra Street). The major facilities in town include: Australia Post – Rand LPO, Church of England/St. Mathews, grain storage silos and Rand Public School. Rand was formerly the terminus of the Rand railway line from Henty, which opened in 1920 and closed in 1975. Seasonal grain trains service the silos, though the majority of freight is now by road.

Much of the town itself is zoned “RU5 Village” but a significant amount of adjoining land to the northeast is zoned as “R5 Large Lot”. The entire region is otherwise zoned as “RU1 Primary Production”. Billabong Creek runs adjacent to the town on its southeast and is zoned as a “Major River”. The land use zoning is shown on Figure D2. Outside the town boundaries, the main structures on the floodplain are roads and rail, individual farmhouses and other farm related infrastructure.

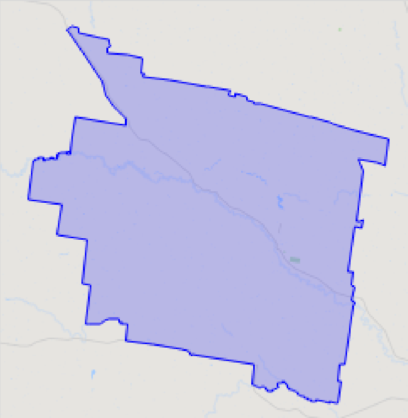
1.3. Demographic Overview

Understanding the social characteristics of the Study Area can help in ensuring appropriate risk management practices are adopted, and shape the methods used for community engagement. Census data regarding house tenure and age distribution can also provide an indication of the community's lived experience with recent flood events, and hence an indication of their flood awareness. According to The Bureau of Meteorology Flood Preparedness Manual (Reference 5), it is also possible, using population census data and other information held by councils and state agencies, to identify the potential number and location of people in an area (or the proportion of the community's population) with special needs or requiring additional support during floods. The Flood Preparedness Manual identifies that, in general, people who belong to the following groups may be considered especially susceptible to the hazards floods pose:

- **The elderly**, especially those living alone and/or frail, who are often unable to respond quickly or without assistance;
- **Those with low incomes**, including the unemployed and others on pensions, who may lack resources which would give them independence of decision making and action;
- **Single-parent families, large families or families with very young children**: these may be characterised by unfavourable adult: child ratios making evacuation difficult;
- **Those lacking access to a motor vehicle** frequently need special transport provision to facilitate escape from threatening floodwaters;
- **Newcomers** (i.e. those residents in their communities for only short periods), who are unlikely to appreciate the flood threat and may have difficulty understanding advice about flooding. They may need special attention in terms of threat education and communication of warnings and other information;
- **Members of Culturally and Linguistically Diverse (CALD) communities**, who need special consideration with respect to the development of preparedness strategies as well as warnings and communications during flood events. Special attention may also be needed if actions which become necessary during floods offend cultural sensitivities;
- **The ill** or **infirm** who need special consideration with respect to mobility, special needs, medications, support and 'management' to ensure they continue to receive appropriate care and information; and
- **Those whose homes are isolated by floods**, creating a potential need for medical evacuation or resupply of essential items.

The following information has been extracted from the 2016 Census for the town of Rand and are relevant to the above considerations. Population Characteristics are compared to the NSW average to identify characteristics distinct to each town.

Rand Demographic Overview



Population: 204
No. of Private Dwellings: 110
No. of lone person households: 27
Property Tenure:

- 80.5% owned (either outright or with a mortgage)
- 9.8% rented

Language

- 96% of people speak only English at home

No. persons over the age of 75: 16
Elderly people are often more frail and may be unable to respond as quickly to flood emergencies without requiring some assistance.
No. single parent families: 10
Single parent families can mean a low adult-to-child ratio within the household and therefore can make evacuation more difficult.

Statistics from: http://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/SSC13311?opendocument#internet

Table D 1: Characteristics of Rand (Australian Bureau of Statistics, 2016)

Characteristic	Rand	NSW
Population Age:		
0 – 14 years	22.9%	18.5%
15 - 64 years	57.2%	65.3%
> 65 years	19.9%	16.2%
Average people per dwelling	2.4	2.6
Own/mortgage property	80.5%	64.5%
Rent property	9.8%	31.8%
Other tenure type/not stated	9.7%	3.7%
No cars at dwelling	3.5%	9.2%
Speak only English at home	96%	68.5%

The characteristics noted above are considered in the community engagement strategy and when evaluating response modification options, such as flood education, warning or evacuation systems. Given the high proportion of households where the only language spoken is English, the delivery of community consultation material and flood warnings/ information in English is deemed appropriate. With a significant proportion of residents over the age of 65 years, online engagement strategies are not as likely to be as effective as face-to-face or postal communications. This was demonstrated in the initial community consultation period, discussed in the main Federation Villages FRMS&P report.

In addition to communication strategies, census data can be used as an indicator of a community's vulnerability in regard to flood risk management. In particular, aged residents are more likely to be frail and physically unable to respond as quickly to flood emergencies. Provision of assistance to such residents should be a key consideration when developing flood evacuation systems and the lead time with which warnings are provided. The family composition within a residence can also affect flood awareness and capacity to respond. In Rand there are 27 lone person households, who are at greater risk of being unaware of flood warnings or evacuation orders.

There are also a number of single-parent families, which can mean a low adult-child ratio and result in difficulties preparing for and safely undertaking evacuations.

1.4. Local Environment

Rand is a sparsely urbanised village, surrounded by native vegetation. Much of the town is perched well above Billabong Creek, and the local topography slopes away from the creek (rather than towards it). A site visit was undertaken by WMAwater staff on the 8th August 2018 to inspect the Study Area, specifically the flooding hotspots identified by Council and to gather information on hydraulic structures such as bridges and culverts.

Billabong Creek is adjacent to the south-western edge of the town and is an important resource for agriculture, farming and domestic water supplies for residents in the Greater Hume area and downstream. The creek is densely vegetated with concerns of having high salt loads. A salt interception scheme was introduced in 1997 to increase salinity levels. Approximately 1500 megalitres of freshwater is pumped into the creek to prevent 3000 tonnes of salt from entering annually, significantly reducing the water salinity. Additional benefits of the scheme include an improvement in water quality and flow, enhancing the biodiversity of the surrounding regions and improving the growth of native vegetation.

The use of on-site sewage management systems (OSSMS) in the Federation Council area has brought attention to the issues on the negative impacts by these systems. OSSMS are miniature sewage treatment plants. If poorly designed and maintained, it will cause problematic effects including public health risk, water pollution of local creeks/rivers, agricultural land degradation and local amenity issues. OSSMS is used on properties in Rand where there is no reticulated sewerage system. Several dwellings in the township are situated on smaller lots with insufficient space for the application of wastewater disposal, leading to effluent runoff into neighbouring lands and overloading nutrients in the soil. As a flood prone town, this runoff may also contribute to overflow and contamination of the creek and surface water. Rand relies on a groundwater supply for its potable drinking water, thus environmental protection of the town as well as Billabong Creek are a high priority. Council recently adopted an OSSMS strategy in November 2018 providing a management framework, allowing effective regulation of the system as well as the protection of the environment and public health associated with the system (Federation Council 2018).

2. PREVIOUS STUDIES

2.1. Flood Study Report for Rand, Jacobs, 2017 (Reference 4)

The Flood Study Report for the village of Rand, completed for Council in 2017 by Jacobs, provided estimation of mainstream flooding and local overland flow for the town. Billabong Creek is the main source of flooding for Rand, which drains a catchment area of approximately 2,620 km^2 to Walbundrie, 17 km upstream (southeast) of Rand.

A thorough review of the flood models established in the Flood Study is documented in Section 4, and briefly summarised as follows:

- A broadscale hydrologic model (RORB) was established for the entire Billabong Creek catchment to Walbundrie, and calibrated to the 2010, 2011 and 2012 flood events using information from the Walbundrie gauge (No. 410091). Design flows were estimated based on ARR 1987 methodologies;
- A MIKE11 hydraulic model was adopted from Reference 12 to route design flows from the Walbundrie gauge through to the upstream boundary of the Rand study area, where the resulting hydrographs are used as inflows into the TUFLOW model;
- An XP-RAFTS hydrologic model was established to convert rainfall to runoff within the local catchment of Rand itself (using ARR 1987 methodologies); and
- A TUFLOW hydraulic model was developed to estimate design flood behaviour using mainstream inflows for Billabong Creek from the MIKE11 hydraulic model, and local inflows from the XP-RAFTS hydrologic model.

A flood frequency analysis was undertaken for Billabong Creek at Walbundrie gauge based on observed flow data for 1965 to 2014 including the flood event of 1931 which is considered as the largest flood in Billabong Creek at Walbundrie gauge. However, the results of the FFA were not used in the estimation of design flows, rather the RORB model was used with inputs and methodologies provided by ARR 1987. The FFA was used to validate the result of the RORB model.

The above models were utilised to define design flood behaviour for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and the PMF. The key findings from the report on Rand are summarised below:

- Outcomes from the flood modelling for the design events were used to prepare flood extent maps, provisional hazard maps, flood hydraulic categories (i.e. floodway, flood storage and flood fringe areas) and a flood planning area map;
- Modelling results indicated no major hydraulic controls in Rand;
- A section of Urana Road near the intersection with Western Road is cut-off in the 20% AEP event;
- Areas located north-east of Gibeen Street are subject to shallow flooding from local catchment runoff in the 20% AEP event;

- A number of properties located along Billabong Creek west of Mahonga Road from its intersection with Five Mile Road are subject to shallow flooding from the creek in the 1% AEP event;
- Although the township would be cut off from the adjoining towns in the PMF event, the majority of residential properties located within the township are not subject to flooding in the PMF event;
- The Four Corners Road Bridge was not estimated to be overtopped in the PMF; and
- The informal Rand levee is overtopped in the PMF event only. However, the informal levee may fail during major flood events due to improper construction and poor maintenance.

2.2. Flood Intelligence Collection and Review for 24 Towns and Villages in the Murray and Murrumbidgee Regions following the March 2012 Flood, Final Report, June 2013 (Reference 10)

This report was completed for the NSW State Emergency Service (SES) in 2013 to develop an understanding of flood behaviour in the Riverina. The March 2012 event affected a number of towns and villages, including Tumbarumba, Great Hume, Urana, Tumut, Gundagai, Wagga Wagga, Lockhart, Coolamon, Narrandera and Griffith. The report provides general information about the floods in the region, including rainfall data, flood extents, Velocity and timing. For each of the villages reported on, the document provides a description of affected buildings, properties, roads and key response actions and evacuations. The key findings from Rand are summarised below:

- The 1931 flood is the highest recorded Billabong Creek flood with recorded peak flood depth of 9.65 m at Walbundrie (streamflow gauge 410091);
- Flood heights at Rand appear to be naturally regulated by the effluent flows that remove water from Billabong Creek between Walbundrie and Rand. These flows are diverted towards Nowranie and Wangamong Creeks and result in suppressed flood heights at Rand. For example, the difference in flood heights at Rand between the 2011 and 2012 events was only 0.15 m, despite there being a difference of over 1 m at Walbundrie. This produces a very ‘flat’ hydrograph range at Rand;
- The peak flood travel time between Walbundrie and Rand is estimated between 6 to 9 hours;
- Flood depths on the Billabong Creek floodplain are generally shallow with low velocities; and
- Flood heights at the Rand staff gauge are provided for the 2010, 2011 and 2012 flood events along with local resident reports of flood behaviour for the 2012 event, and several photographs of the 2010 flood event.

2.3. Billabong Creek Floodplain Management Plan, Phase A: Data Review and Flood Behaviour (Reference 12)

Bewsher Consulting was engaged by the NSW Department of Land and Water Conservation in 1999 to undertake a floodplain management plan for Billabong Creek in two phases. The phase A of the study included the flood data, overview of the past flood events and influences, flood frequency analysis, flood extend mapping, investigating flood behaviour via MIKE11 to simulate the flooding conditions for a several past events (i.e. 1970, 1974, 1981, 1988 and 1995). Phase B of the study included the application of MIKE11 model to estimate flow distribution in the floodways for a range of floodplain management options. The Billabong Creek Floodplain Management Plan (DNR 2006) identifies a network of floodways across the Billabong Creek floodplain that need to be kept clear of obstructions, such as levees or other flood control works to ensure the free flow of floodwater within Billabong Creek and across the floodplain. The design flood selected in the Plan (DNR 2006) is a combination of two historical flood events including the 1983 event (25-year average recurrence interval) and the 1974 flood (32-year average recurrence interval) adopted for the upper floodplain and the lower floodplain, respectively.

The MIKE11 model was adopted directly for use in the Flood Study (Reference 4) to route flows between Walbundrie and Rand. This is discussed further in Section 4.3.1.

3. AVAILABLE DATA

3.1. Site Visit

A site inspection was carried out by WMAwater staff accompanied by Council staff on 9th August 2018 to gain an overall appreciation of the study area, and to identify areas of Rand that experienced the greatest flood risk. A subsequent site visit was undertaken on 18th October 2018 following the community consultation session to visit locations where issues had been raised by residents, including several culverts that had been noted to be of insufficient capacity. Figure D3 contains a selection of photographs taken during the site inspection.

3.2. Topographic Data

Light Detection and Ranging (LiDAR) survey of the Study Area and its immediate surroundings was provided for the study by NSW Land and Property Information (LPI). LiDAR is aerial survey data that provides a detailed topographic representation of the ground with a survey mark approximately every square metre. The data for the Rand area was collected in 2013 and used for the 2017 Rand Flood Study (Reference 4). Grid data of 1 m, 5 m and 10 m squares were provided for the ground surface. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The horizontal accuracy of the data was 0.8 m at 95% confidence intervals (CI), while the vertical accuracy was 0.3 m at 95% CI. A digital elevation model was sampled using the 1 m grid data. Shuttle Radar Topography Mission (SRTM) data was also provided to produce a 30 m resolution DEM. Seven SRTM tiles covering the local government area were provided, which were used to delineate catchment boundaries for Billabong Creek as part of Reference 4. The DEM is provided on Figure D4.

3.3. Aerial Photography

Aerial photography was provided by Council. Rand is covered by the 'Walbundrie' tile, captured in 2010. It has a 0.5 m resolution and was provided as a geo-referenced raster.

3.4. Hydraulic Structures

Details of key hydraulic structures within the Study Area, including culverts and bridges, shown on Figure D5, were obtained from the Flood Study (Reference 4), including the Mahonga Road Culvert (0.6m dia.) and Urana Road Culvert (0.9m x 0.45m). Topographic survey undertaken as part of the Flood Study by TJ Hinchcliffe and Associates in 2015 provided the following:

- Details for the bridge (Four Corners Road/ Kindra Road crossing Billabong Creek) which include deck and underside levels, length, width, railing height, location and width of piers and photographs;
- Details of the Rand levee including spot heights along its 520 m length, details of a culvert crossing the levee and photographs; and

- Levels of the manual gauge located upstream of the Four Corners Road/ Kindra Road bridge. The 4 m mark on one gauge is at 152.74 mAHD and the 6 m mark on the other is at 154.87 mAHD. This indicates a difference of 0.13 m between the two gauges which are located approximately 5 m apart.

3.5. Pit and Pipe Network

Local stormwater drainage is conveyed towards Billabong Creek via a series of roadside table drains and culverts beneath driveways, with a limited number of culverts beneath roads. The kerb and gutter system is intermittent and allows water to drain directly from roads into the adjacent table drains. Rand does not have a sub-surface stormwater drainage network, and as such no pit and pipe details were provided.

3.6. Floor Level Database

A key outcome of the current study is a flood damages assessment. To complete this aspect of the study, floor level estimates are required to undertake a broad assessment of flood affectation. While the assessment uses floor level data for individual properties, the results are not an indicator of individual flood risk exposure but part of a regional assessment of flood risk exposure. For each property, the floor level estimation captured the following descriptors:

- Ground Level (in mAHD);
- Indication of house size (number of storeys);
- Location of the front entrance to the property; and
- Local Environmental Plans (LEP) land use (residential, commercial, industrial, primary production, or public recreation and infrastructure).

The floor level data base includes all properties within the PMF extent. WMAwater used LiDAR data and visual inspection to estimate floor levels for all properties within the PMF extent. A summary of the total floor level estimates is provided in Table D 2 below.

Table D 2: Floor Level Database – Rand

Property Type	No. Included in Damages Assessment
Residential	30
Non-Residential	13
Total	43

3.7. Design Rainfall (ARR 2019) IFD

The design flood modelling inputs and methodology applied in the Flood Study (Reference 4) were based on Australian Rainfall and Runoff 1987. Late in the Flood Study project in 2016, a substantial update to the ARR guidelines was released with a subsequent update released in 2019. Following discussion with NSW DPIE (then Office of Environment and Heritage) and Council, it was decided that the design flood modelling produced in the Flood Study was to be updated to implement the methodologies provided in ARR 2019, as these represent best practice and would increase the longevity of the outputs of the Study. ARR 2019 IFD information was obtained from the Bureau of Meteorology (BoM) via the ARR 2019 Data Hub, with IFDs and all other metadata provided in Attachment 1. Section 5 describes the processes used to update the hydrologic and hydraulic models to implement ARR 2019 methodologies.

4. FLOOD MODELLING REVISIONS AND UPDATES

The Flood Study for Rand (Reference 4) was completed in November 2017 by Jacobs for Federation (Council) in accordance with the NSW Government's Flood Prone Land Policy. The Flood Study aimed to determine design flood behaviour in the area and used hydrologic models (XP-RAFTS for local overland flow and RORB for riverine flooding) and hydraulic models (MIKE11 and TUFLOW). Flood Frequency Analysis was undertaken for Billabong Creek at Walbundrie Gauge, though the results were not used directly in design peak flow estimation (RORB used instead). Figure D6 shows the XP-RAFTS and TUFLOW model extent. The RORB model boundary (i.e. Billabong Creek catchment) and MIKE11 schematic model were documented in the Flood Study (Reference 4).

The various models were reviewed by WMAwater to determine the suitability for use in the Floodplain Risk Management Study. The review found that the models were largely fit for use in the FRMS&P with minor amendments as described below, and updates to ARR 2019 methodologies described in Section 5.

4.1. Flood Frequency Analysis

The Rand Flood Study (Reference 4) completed a Flood Frequency Analysis (FFA) using the available annual peak flows for Billabong Creek at Walbundrie Gauge (No. 410091). An Annual Maximum Series was formed from the gauge data from 1965 to 2014, omitting 1997 due to missing data (that could not be estimated using other gauges). TUFLOW's FLIKE (BMT WBM 2015) (Reference 8) was used to undertake a flood frequency analysis, which determined that a Log Pearson Type III (LP3) distribution fitted the data most suitably, using a Bayesian inference for two scenarios: with and without the 1931 peak flow included as a censored event.

The results from the scenario that did *not* include the 1931 peak flow as a censored event were selected for use in this FRMS&P for two main reasons:

- When censoring the 1931 event, the Flood Study (Reference 4) did not account for the years (of missing data) between 1931 and 1965, and as such is likely to have overestimated the influence of the 1931 peak flow in the statistical analysis;
- The 1931 event is reported to have peaked at 9.65 m at the Walbundrie Gauge (No. 410091) (Reference 12), however:
    - While both Reference 12 and Reference 4 cite this level as equating to a flow of 50,000 ML/day ((~575 m^3/s).) (and used this flow in the FFA);
    - Review of three available rating curves from Water NSW (1981-1995, 1995-1998, and 1998-2005) indicated that 9.65 m relates to of 61,715 ML/day.
    - With no further information to clarify this discrepancy, for example evidence regarding a change in rating curve or datum, the stage-discharge relationship at the gauge during the 1931 event contains a high degree of uncertainty, and inclusion of the 1931 peak flow as a censored event is not considered to improve the FFA.

The FFA results were not used directly in the Flood Study, rather, the RORB model was calibrated to the 2010 and 2012 events at Walbundrie Gauge, and verified using the 2011 event. However, the results of the FFA described above were used to validate the design flows produced in this FRMS&P and to inform the selection of initial and continuing losses for application to the updated RORB model (in accordance with ARR 2019 and guidance from the NSW Government (Reference 13).

4.2. Hydrologic Modelling

4.2.1. XP-RAFTS (Local Overland Flow)

The local catchment draining to Rand village was modelled using XP-RAFTS (2018 version). The XP-RAFTS model was updated from Version 2013 to 2018 model for the efficient application of ARR 2019 methodologies (see Section 5). The IFD data and loss parameters used in the design modelling are documented in Section 5.2 - 5.7 and presented in Attachment 1.

4.2.1.1. Model Extent

The Flood Study (Reference 4) developed an XP-RAFTS hydrologic model that covered the entirely of the local Rand catchment (approximately 2.87 km^2), shown on Figure D6. The catchment boundary was reviewed in conjunction with the available LiDAR data confirming the boundary appropriately represented the local Rand catchment. The catchment was divided into 8 sub-catchments, delineated based on the 1 m LiDAR data, shown on Figure D4. The sub-catchment discretisation was deemed appropriate and was adopted for use in the current Rand FRMS&P.

4.2.1.2. Model Parameters

The parameters used in the Flood Study for the XP-RAFTS hydrologic model simulation were assessed for suitability in the FRMS&P. The XP-RAFTS model parameters have been adopted without modification from the Flood Study (Reference 4) and are presented in Table D 3. It is noted that the slope assigned to sub-catchment No. 4 is significantly higher than the surrounding sub-catchments. However, sub-catchment 4 covers the steeply sloping area between Billabong Creek and Kindra Street, and a slope of 3.1% is representative of the topography in this area.

The Flood Study assigned a Manning's 'n' roughness parameter to each sub-catchment based on review of available aerial photography over the catchment from 2008. The assigned parameters, listed in Table D 3 are within the acceptable range typically used for these surface types. The Flood Study assigned impervious fraction across the catchment based on available aerial photography. The impervious fractions is considered appropriate.

Table D 3: XP-RAFTS model sub-catchment data for Rand's local catchments

Sub-catchment No.	Area (ha)	Slope (%)	Impervious fraction (%)	Hydraulic Roughness (Manning's 'n' value)
1	177.5	0.8	10	0.035
2	5.5	0.6	5	0.03
3	43.2	0.5	10	0.035
4	34.3	3.1	20	0.03
5	1.9	0.3	5	0.03
6	5.3	1.4	5	0.06
7	11.4	1.1	5	0.03
8	8.1	0.4	5	0.03

4.2.2. RORB Model (Mainstream Flow in Billabong Creek)

4.2.2.1. Model Extent

The Billabong Creek catchment to Walbundrie was modelled using RORB (Version 6.42), which is commonly used in Australia with the capability to simulate both linear and non-liner catchment behaviour. The Billabong Creek sub-catchment delineation was based on 30 m SRTM DEM, covering an area of 2,620 km^2 with a total of 71 sub-catchments. The model was assigned a nominal impervious fraction of 5% across the catchment, which is considered reasonable given the limited development within the catchment. The RORB extent and sub-catchment delineation were adopted for this FRMS&P without modification.

4.2.2.2. Model Parameters

The RORB model adopted the following parameters:

- Catchment linearity ('*m*') was retained at the recommended 0.8; and
- Catchment Lag *('kc')* value was set at 122 for the catchment draining to the Billabong Creek gauge at Walbundrie.

The above parameters were adopted on the basis of calibration results, and were adopted for use in this FRMS&P without modification.

Note: The RORB model was re-run to produce design discharge hydrographs using ARR 2019 methodologies. The IFD data, temporal patterns and loss parameters used in the design modelling are documented in Sections 5.2 - 5.7.

4.3. Hydraulic Modelling

4.3.1. MIKE11

To route flows between Walbundrie Gauge, and Billabong Creek upstream of Rand, a MIKE11 model was developed in the Billabong Creek Floodplain Management Plan (Bewsher 2002, Reference 12) and was adopted by Jacobs for use in the Flood Study (Reference 4).

The MIKE11 model was used to simulate the discharge in Billabong Creek for 20%, 10%, 5%, 2%, 1% AEP events and an extreme event for application to the upstream boundary of the TUFLOW model. Inflow hydrographs produced by the RORB model for the design events were used as inputs in the MIKE11 model. Discharge hydrographs generated by the MIKE11 model at cross section “BILLABONG CREEK 36862.5” were extracted and used as mainstream inflows for use in the TUFLOW model. The MIKE11 model was adopted for use in the FRMS&P without modification.

It is noted also that the Billabong Creek MIKE11 model was used for the estimation of inflows for the simulation of flooding in both Oaklands and Urana:

- Peak flows at cross section “Nowranie 43910” were extracted for use in the Nowranie Creek TUFLOW model for the estimation of mainstream flooding at Oaklands. The flood modelling methodologies and results established for Oaklands are documented in Appendix C; and
- Peak flows at the following cross-sections were used as upstream inflows for the Urana TUFLOW model: “Urangeline 97507.5”, “Tombstones 25100” and “U/S RAIL 1 4732.33”. The flood modelling methodologies and results established for Urana are documented in Appendix E**.** Furthermore, the MIKE11 model itself was utilised to route design flows from the Urangeline Creek catchment (derived from the corresponding RORB model) towards Urana, to ensure the interaction between Urangeline Creek and flood runners of Billabong Creek were appropriately represented.

4.3.2. TUFLOW

A combined 1D-2D TUFLOW model was developed for Rand in the Flood Study (Reference 4). TUFLOW is an industry-standard modelling platform well suited for use in FRMS&Ps as the DEM can be readily modified to efficiently assess a range of flood modification options such as levees, basins, and channel modifications.

In 2017, TUFLOW offered Heavily Parallelised Computing (HPC) an alternate 2D Shallow Water Equation (SWE) solver to TUFLOW Classic. Whereas TUFLOW Classic is limited to running a simulation on a single CPU core, HPC provides parallelisation of the TUFLOW model allowing modellers to run a single TUFLOW model across multiple CPU cores or GPU graphics cards. Simulations using GPU hardware has been shown to provide significantly quicker model run times than those modelled using CPU cores.

As such, the TUFLOW model established in the Flood Study were updated and run using what is commonly referred to as ‘GPU’, using TUFLOW Version 2018-03-AB_iSP_w64. Results were compared to ensure both CPU and GPU produced consistent results, and the GPU models were adopted for use in the FRMS&P.

This was particularly advantageous as updating to ARR 2019 is computationally demanding, and quicker model run times allowed for the efficient application of the ARR 2019 methodologies (described further in Section 5).

4.3.2.1. Model Extent

The TUFLOW hydraulic model extent (from the Rand Flood Study, Reference 4) includes a 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use, and a 2D representation of the obstructions to flow, including buildings. The TUFLOW hydraulic model extent is covers an area of approximately 12 km^2, from approximately 2.5 km upstream of Four Corners Road, to approximately 4 km downstream of the same bridge, centring on Billabong Creek. The TUFLOW extent is presented on Figure D5.

4.3.2.2. Model Topography

The 2D model terrain used in the Flood Study (Reference 4) was derived from 1 m resolution LiDAR provided in 2014, sampled to produce a digital elevation model (DEM) based on a 5 m grid The grid size was selected to appropriately represent the flood behaviour and balance model run time. The DEM was adopted for use in the FRMS&P without modification.

4.3.2.3. Bridges and Culverts

The model used in the Flood Study (Reference 4) included one bridge (Four Corners Road) and one culvert through the levee near Mahonga Road north of Railway Parade. The bridge and culverts were modelled as 2D and 1D elements respectively, in the Flood Study using data obtained from the topographic survey by TJ Hinchcliffe and Associates in 2015. The representation of hydraulic structures was considered appropriate, and has been adopted for use in the current study without modification.

One additional culvert south of Rand has been added to the 1D network, based on assumed dimensions of 0.9 m wide x 0.45 m high. This location was flagged by the community as a sag point in Urana Road where standing water could restrict access for days at a time. While incorporating the culvert does not materially change flood behaviour in the 1% AEP event (as the road is already well overtopped), it is important to update the base case before modelling options pertaining to improving access along Urana Road (discussed in Section 7.2.1).

4.3.2.4. Buildings

The Flood Study (Reference 4) represented buildings by 'nulling out' structures from the computational grid to effectively exclude any flow from entering buildings. While this is not necessarily realistic (as the flow can enter buildings), it is an appropriate method that simulates the obstruction that buildings can impose on floodwaters. The buildings GIS layer was reviewed using aerial imagery from 2019 (GoogleEarth) to confirm no significant changes had occurred, and was adopted for use in the FRMS&P without modification.

4.3.2.5. Roughness Parameters

In the Flood Study (Reference 4), ground surfaces were assigned a hydraulic roughness parameter based on land use and aerial imagery captured in 2010. Aerial photography of the area obtained from Google Maps in 2019 was investigated indicating no changes in the land use; therefore, the Manning's 'n' coefficients adopted in the Flood Study were applied in the current FRMS&P. Table D 4 lists the Manning's 'n' coefficient applied to define catchment surface roughness while Figure D7 illustrates their spatial distribution. The Manning's 'n' values assigned to densely vegetated area are considered to be at the upper limit of appropriate values, however have been adopted without modification for use in the FRMS&P. The spatial application of the Manning's 'n' coefficients was also deemed appropriate.

Table D 4: TUFLOW model hydraulic roughness values

Land use type	Manning's coefficient
Watercourse	0.045
Low-density residential area	0.08
Open rural area	0.045
Densely vegetated area	0.12
Road and paved areas	0.02
Railway	0.05
Paved	0.02

4.3.2.6. Inflows – Overland Flow

The simulated hydrographs produced by the XP-RAFTS model were input as local inflow hydrographs in the TUFLOW model. The inflow locations are shown on Figure D5. For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the XP-RAFTS model. These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model.

4.3.2.7. Inflows – Mainstream Flooding

Design hydrographs for Billabong Creek at Walbundrie Gauge were produced by the RORB hydrologic model. From the gauge, flows were routed through to Rand using the MIKE 11 model (to account for braiding and the various offtakes that exist between Walbundrie and Rand). Simulated flow hydrographs at MIKE11 cross section 'Billabong Creek 36862.5' were adopted as inflow hydrograph in the TUFLOW model for Rand.

4.3.2.8. Downstream Boundary Conditions

Due to the complex nature of the topography and floodplain, a number of downstream height time boundary conditions were applied to the western boundary of the TUFLOW model:

- Billabong Creek channel itself;
- Billabong Creek overbank area;
- Billabong Creek secondary channel;

These downstream boundaries were located some 3.5 km downstream of Five Mile Road to eliminate the potential influence of tailwater conditions on flood levels in the Study Area. Seven additional breakout boundaries were defined, located on the south-western boundary of the model to extract flows breaking out of Billabong Creek towards Nowranie Creek, and four along the northern edge to allow outflows from Billabong Creek breaking out downstream of the Rand Levee. These boundaries were placed at minimum 1.2 km away from the main Billabong Creek channel and used a normal depth condition. The downstream boundary locations and conditions were deemed appropriate and were adopted without modification for use in this FRMS&P.

5. DESIGN FLOOD MODELLING

5.1. Overview

Rand is affected by mainstream flooding from Billabong Creek, as well as overland flow from the local catchment surrounding the town. The Rand Flood Study (Reference 4), used rainfall-runoff hydrologic models to estimate design hydrographs for both the mainstream and local runoff design flood behaviour:

- A RORB hydrologic model for the broader Billabong Creek Catchment to Walbundrie (with flows then routed to the TUFLOW inflow boundary via the MIKE11 model); and
- An XP-RAFTS hydrologic model for the local Rand catchment (with inflow hydrographs applied directly to the TUFLOW model).

The hydrologic and hydraulic models developed as part of the Flood Study (Reference 4) have been adopted for use in design flood modelling.

The inputs and guidance for using these types of models come from Australian Rainfall and Runoff (ARR) guidelines, and as such, both are subject to revision under the updated ARR 2019 methodologies. The 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events have been simulated using the ARR 2019 guidelines. Broadly, the ARR2019 methodologies apply consistently across the two models, with some differences in terms of input data and parameters due to the different catchment locations, sizes and characteristics. The modelling approach is outlined in the subsequent sections, with specific inflow data and parameters for each model provided in Attachment 1.

The probable maximum precipitation (PMP) has also been simulated based on the Bureau of Meteorology (BoM) guidelines.

5.2. ARR 2019 Update

The Australian Rainfall and Runoff (ARR) guidelines were updated in 2016, and revised in 2019, due to the availability of numerous technological developments, a significantly larger dataset since the previous edition (1987) and development of updated methodologies. A key input to the process is information derived from rainfall gauges, and the dataset now includes a larger number of rainfall gauges which continuously recorded rainfall (pluviometers) and a longer record of storms, including additional rainfall data recorded between 1983 and 2012.

Three major changes have been made to the ARR 1987 approach (Reference 1) to develop ARR 2019 (Reference 2):

1. The recommended Intensity, Frequency and Duration (IFD) rainfall data, pre-burst, and initial and continuing loss values across Australia have been updated based on analysis of available records;

2. ARR 2019 recommends an ensemble assessment of 10 temporal patterns for each storm duration. The temporal pattern producing the mean level within each duration is selected. The *critical duration* is the duration for which the selected temporal pattern produces the maximum flood level;
3. The inclusion of Areal Reduction Factors (ARFs) based on Australian data for short (12 hours and less), long duration (larger than 24 hours) and durations between 12 and 24 hours.

Following discussion with the then NSW Office of Environment and Heritage (now DPIE) and Council, it was decided that the design flood modelling produced in the Flood Study was to be updated to implement the methodologies provided in ARR 2019, as these represent best practice and would increase the longevity of the outputs of the Study. The subsequent sections describe the application of ARR 2019 as they relate to local overland flow modelling in Rand (using the local XP-RAFTS model), and mainstream flooding in Billabong Creek (using the RORB model of the Billabong Creek catchment to Walbundrie).

5.3. ARR 2019 IFD Data

Design rainfalls (ARR 2019 IFDs) were obtained from the Bureau of Meteorology (BoM) for specific AEP and duration combinations across the catchment. The IFDs applicable to the local XP-RAFTS and mainstream RORB hydrologic models have been provided directly from the ARR 2019 Data Hub in Attachment 1.

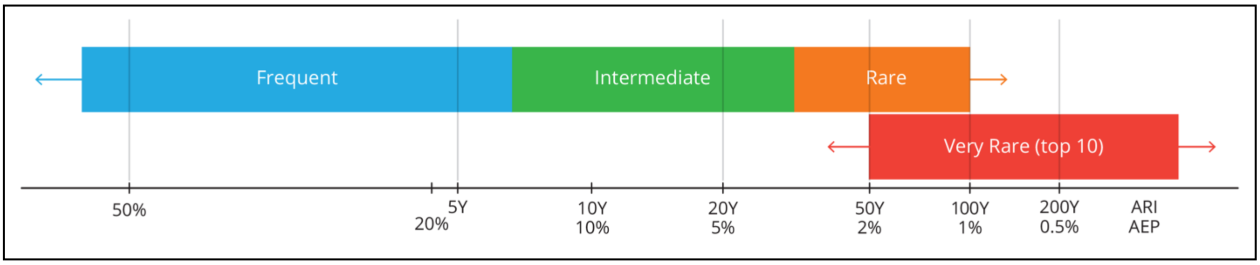
5.4. ARR 2019 Temporal Patterns

Temporal patterns describe how rain falls over time and form a component of storm hydrograph estimation. Previously, with ARR 1987 guidelines (Reference 1), a single temporal pattern was adopted for each rainfall event duration. However, ARR 2019 (Reference 2) discusses the potential deficiencies of adopting a single temporal pattern. It is widely accepted that there is a large variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the revised temporal patterns have adopted an ensemble of ten different temporal patterns for a particular design rainfall event. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to produce the median catchment response.

As hydrologic modelling has advanced and more rainfall data has become available, the use of realistic temporal patterns allows a better understanding of the catchment response. The ARR 1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the 2019 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The ARR 2019 method provides patterns for 12 climatic regions across Australia, with the Rand catchment falling within the Southern Semi-arid region.

ARR 2019 provides patterns for each duration which are sub-divided into three temporal pattern bins based on the frequency of the events. Diagram D 1 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. At the time of the assessment, the "very rare" bin was unavailable, and temporal patterns from the Rare bin were used in this flood study update. There are ten temporal patterns for each AEP/duration in ARR 2019 that have been utilised in this study for the 20% event to 0.2% AEP events.

Diagram D 1 : Temporal Pattern Bins



Temporal patterns for this study were obtained from the ARR 2019 data hub (Reference 2, http://data.arr-software.org/). A summary of the data hub information at the catchment centroids (local and mainstream) is presented in Attachment 1. The method employed to estimate the PMP utilises a single temporal pattern (Reference 6).

5.5. Rainfall Losses

Both the local (XP-RAFTS) and mainstream (RORB) hydrologic models use initial and continuing loss parameters to represent the infiltration and evaporation mechanisms that reduce the amount of rainfall that is converted into runoff. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the filling of localised depressions, and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

5.5.1. Local Catchment (XP-RAFTS)

Design rainfall initial and continuing losses were obtained from the ARR 2019 data hub (http://data.arr-software.org/). Based on the recent guideline developed by NSW DPIE (Reference 13), in the absence of calibrated losses (i.e. calibrated to flows at a stream gauge) in the catchment or nearby, the continuing loss value provided by the ARR 2019 Data Hub is to be multiplied by a factor of 0.4. In the local Rand catchment, the continuing loss is therefore taken as: 0.4 × 3.4 mm/hr = 1.36 mm/hr, applied consistently to all design events. This is used in conjunction with probability neutral burst initial loss values (presented in Attachment 1) which vary with AEP event and duration.

5.5.2. Billabong Creek Catchment (RORB)

Following guidance from OEH (now NSW DPIE) (Reference 13), calibrated losses derived from the Flood Study (Reference 4) were used as a basis for selection of initial and continuing losses to be applied to the RORB model. Three calibration events were assessed in the Flood Study, all achieving reasonable calibration with an adopted continuing loss of 2.1mm/hr. Adopted initial loss varied from 32 – 83 mm. In addition, initial and continuing losses were obtained from the ARR 2019 data hub (http://data.arr-software.org/) for comparison. The storm initial loss was shown to be 23mm. Applying guidance from NSW DPIE (Reference 13), the continuing loss value provided by the ARR 2019 Data Hub is to be multiplied by a factor of 0.4. At the Walbundrie Gauge, the continuing loss is therefore taken as: 0.4 × 4.0 mm/hr = 1.6 mm/hr, slightly less than that used for the calibration events.

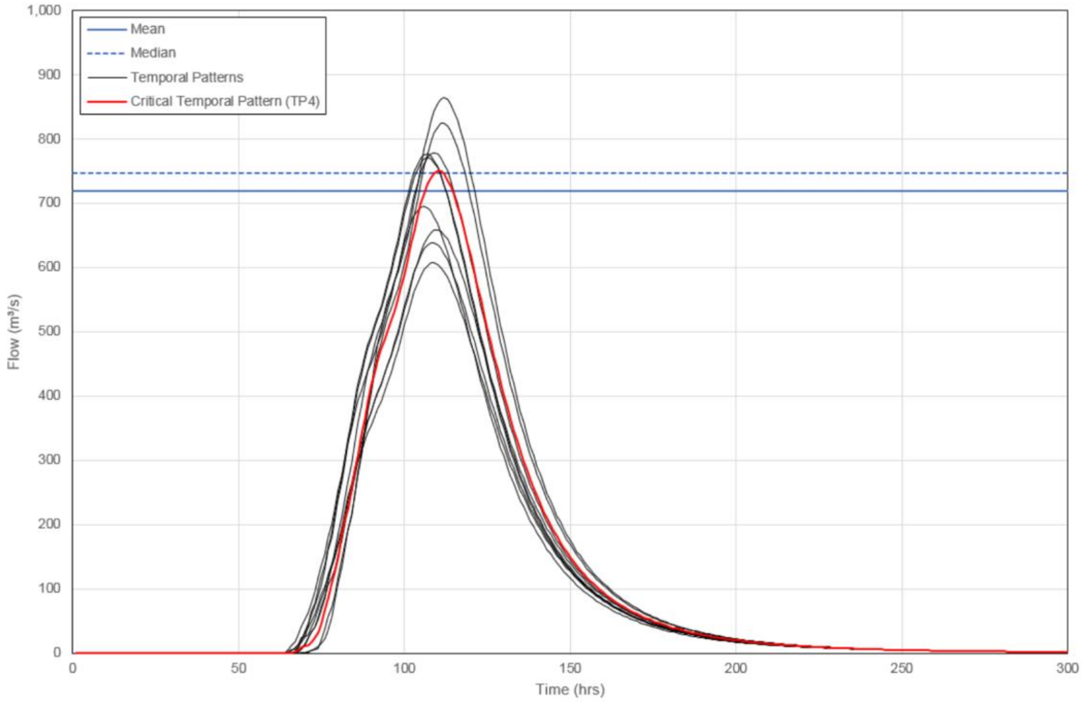
Following application of the ARR2019 design rainfall data, an ensemble of temporal patterns were considered for a range of durations and these losses were adjusted to ensure the representative peak design flows at the Walbundrie Gauge were consistent with the peak design flows derived from the Flood Frequency Analysis (described in Section 4.1). An initial loss of 0 mm and a continuing loss of 1 mm/hr were adopted for the PMP event (as was adopted in the Flood Study). The adopted loss parameters for the Billabong Creek RORB model are provided in Table D 5.

Table D 5: RORB Model - Initial and Continuing Loss Parameters

	Flood Study (Reference 4) ARR 1987		FRMS (This Study) ARR 2019		Design Peak Discharges At Walbundrie Gauge (m^3/s)		
Event	Initial Loss (mm)	Continuing Loss (mm/hr)	Initial Loss (mm)	Continuing Loss (mm/hr)	Peak Flow (FFA) (m^3/s)	RORB (ARR 1987)	RORB (ARR 2019)
20% AEP	5	2.5	19.2	2.1	220	259	201
10% AEP	5	2.5	18.6	2.1	341	326	340
5% AEP	5	2.5	19	2.1	450	446	467
2% AEP	5	2.5	17.1	2.5	568	602	582
1% AEP	10	2.5	12.1	2.5	639	663	751*
0.5% AEP	10	2.5	14.7	2.5	NA	821	796
0.2% AEP	10	2.5	14.7	2.5	NA	1053	1061
PMF	0	1	0	1	NA	13,149	13,182

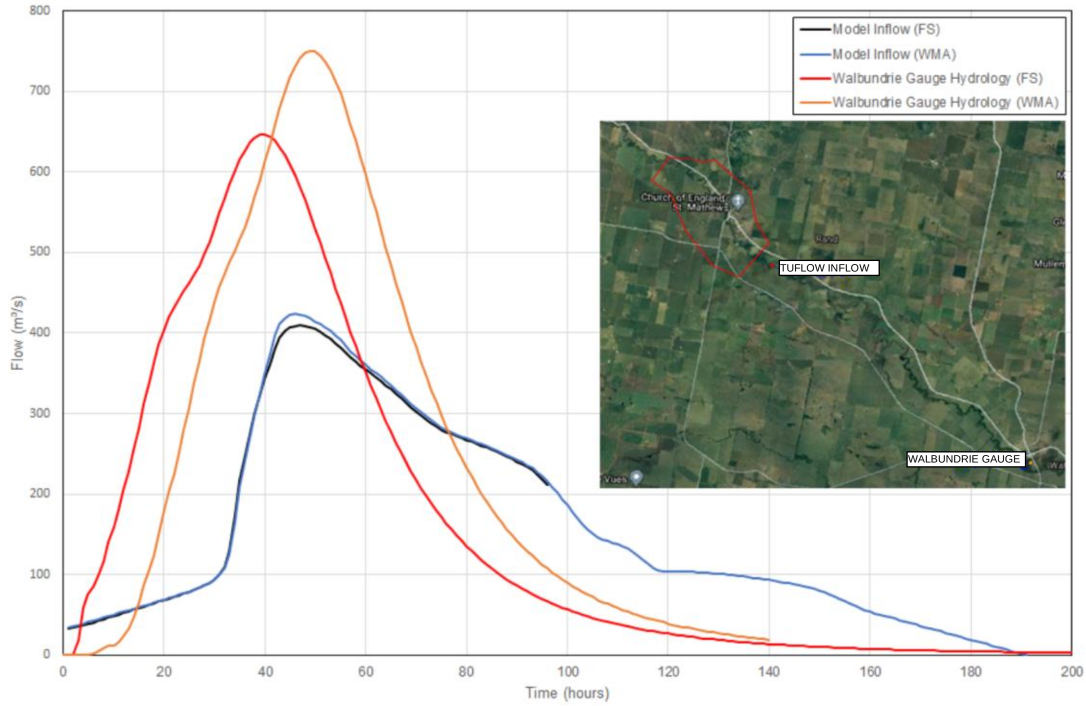
It is noted that the peak design discharge for the 1% AEP event at Walbundrie gauge is approximately 15% higher than the estimated flow derived from the FFA, this is a result of the selected temporal pattern from the ensemble. A reasonable gap exists between the temporal pattern producing the peak flow just below and just above the mean. As shown below in Diagram D 2. To ensure consistency across events, the temporal pattern producing the peak flow above the mean was selected, despite the one below being a better match to the FFA.

Diagram D 2: Flow Hydrographs – 1% AEP Ensemble 1440 Hour Duation



The flow at Walbundrie Gauge is routed to the Rand TUFLOW model inflow location using the MIKE11 model, which replicates the system of braided creeks extracting flow towards Nowraine and Wangamong Creeks away from Rand. The resulting difference between the Flood Study peak inflow (which is a closer match to the FFA) and the FRMS&P inflow is less pronounced as a result (see Diagram D 3 and Section 6.3.1).

Diagram D 3: Inflow Hydrogrph Comparison – 1% AEP Event



5.6. Areal Reduction Factors

Areal Reduction Factors (ARF) are an estimate of how the intensity of a design rainfall event varies over a catchment, based on the assumption that large catchments will not have a uniform depth of rainfall over the entire catchment. The ARF were ARR 2019 Data Hub, and applied in the XP-RAFTS and RORB models for the full suite of design storm events. The ARF varies with AEP and duration and the resulting set of ARFs for the design storms are provided in Attachment 1.

5.7. Critical Duration Assessment

To determine the critical duration (the duration of rainfall over the catchment that will result in the greatest depth of flooding, or the greatest peak flow), two separate approaches were taken for each of the flood mechanisms present in Rand. These are described below:

5.7.1. Local Catchment

ARR 2019 recommends that an ensemble approach is used, where 10 temporal patterns (see Section 5.4) are analysed for each storm duration in the TUFLOW hydraulic model. Given the computational demands of so many model runs, the number of storm durations to be tested was shortlisted based on results from the hydrologic model, with the 60-minute, 120-minute and 180-minute durations found to result in the highest mean peak flows across the floodplain. Using the TUFLOW results, a representative temporal pattern was selected based on statistical analysis of the results of the ensemble (i.e. identification of the pattern producing peak flood levels just above the mean for the critical duration). Further description of the assessment method and box plots for each AEP duration are presented in Attachment 1. Table D 7 presents a summary of the critical duration and adopted temporal pattern for each design flood event for the local catchment.

The derived peak flows from the updated XP-RAFTS model are similar to those derived in the Flood Study using the methods described in ARR87.

Table D 6: Peak Design Flow Comparison

	XP-RAFTS Sub-catchment					
	1		2		3	
Event	Flood Study (ARR87)	FRMS (ARR19)	Flood Study (ARR87)	FRMS (ARR19)	Flood Study (ARR87)	FRMS (ARR19)
20% AEP	3.20	3.98	0.82	1.03	0.05	0.07
10% AEP	4.36	5.23	1.12	1.36	0.06	0.08
5% AEP	5.7	6.73	1.51	1.74	0.09	0.11
1% AEP	10.30	10.55	2.62	2.68	0.26	0.14
0.5% AEP	12.90	12.28	3.24	3.12	0.20	0.16
0.2% AEP	17.76	14.88	4.47	3.76	0.28	0.19
PMF	142.74	143.99	36.20	35.48	1.89	1.92

5.7.2. Billabong Creek Catchment

The Billabong Creek RORB model was used to determine the peak flows produced by each of the ten temporal patterns, across all storm durations, and each design flood event, using data from the ARR Data Hub (See metadata provided in Attachment 1). The peak flows resulting at the Walbundrie Gauge (for each duration and temporal pattern) were analysed to determine the duration that produced the highest mean flow, and within that duration, the 'representative temporal pattern' (i.e. the temporal pattern that produced the peak flow just above the mean peak flow). The resulting flows were then validated by comparing the design results from the RORB model to the design peak flows determined by the Flood Frequency Analysis at the Walbundrie Gauge. Further description of the assessment method and box plots for each AEP duration are presented in Attachment 1. Table D 7 presents a summary of the critical duration and adopted temporal pattern for each design flood event for the Billabong Creek catchment.

Table D 7: Adopted durations and temporal patterns for design flood events

	Local Catchment (XP-RAFTS)			Billabong Creek Catchment (RORB)		
Event	Critical Duration (min)	Adopted Temporal Pattern	Peak flood discharge (m^3/s) at the catchment outlet	Critical Duration (min)	Adopted Temporal Pattern	Peak flood discharge (m^3/s) at the catchment outlet
20% AEP	180	TP4: 3983	8.5	1440	TP8: 4157	201
10% AEP	120	TP6: 3944	9.2	1440	TP10: 4148	340
5% AEP	120	TP6: 3944	11.6	1440	TP10: 4148	467
2% AEP	120	TP6: 3936	15.6	1440	TP4: 4105	582
1% AEP	120	TP6: 3936	18.6	1440	TP4: 4105	751
0.5% AEP	120	TP6: 3936	21.5	2880	TP9: 4197	796
0.2% AEP	120	TP6: 3936	25.8	2880	TP3: 2466	1061
PMF	60	NA	236.8	1080	NA	13182

6. DESIGN FLOOD MODELLING RESULTS

6.1. Design Flood Behaviour

The hydrologic and hydraulic models described in Section 4 and the design flood inputs discussed in Section 5 have been used to estimate design flood behaviour for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP events and the PMF. Results have been mapped for all investigated events, presented as an envelope of mainstream and overland flow flood mechanisms. The flood behaviour across the full range of design events is described below, and shown on Figure D8 to Figure D15 respectively.

6.2. Local Overland Flow

The local topography around Rand slopes *away* from Billabong Creek, rather than towards it. This is somewhat different to the overland flow behaviour observed in Morundah and Urana for example, where the local catchment drains towards the main watercourse. As such, runoff generated by local rainfall drains away from the village of Rand to the north east and does not collect behind the informal levee separating Billabong Creek from the township.

Overland flow affectation occurs in two main regions: to the west of Railway Parade, where sheet flow remains at depths of less than 0.15 m in events from the 20% AEP up to the 0.2% AEP, only exceeding this depth in the PMF. Sheet flow travels to the north and is not constrained by topographic features. The other key region is on the eastern side of Railway Parade, where runoff accumulates behind the former Rand-Henty railway embankment, filling a minor stock dam (possibly the former steam train water supply) and ponding to depths of up to 0.5 m in the 1% AEP event. It is noted however that both of these areas are located north of the developed area of Rand, and do not directly affect property in events more frequent than the PMF.

6.3. Mainstream Flood Behaviour

Running along the south-western edge of the town, Billabong Creek is the main source of mainstream flood risk in Rand. However, despite having multiple breakouts both upstream and downstream of town, the creek itself is relatively confined as it passes through town, owing to naturally high ground on the banks either side of the creek, as well as the informal levee on the right (eastern) bank. As a result, the developed parts of Rand are free from mainstream flood risk in events equivalent to and more frequent than the 0.2% AEP event. The PMF extent encroaches on the town, but, again, due to the rising topography (which crests around Kindra Street/ Urana Road), the PMF extends only around 50 m from the creek's right (eastern) bank.

While the majority of buildings in Rand are not directly inundated by flooding from Billabong Creek, breakouts upstream and downstream of town can affect access to Rand via Urana Road, Four Corners Road and Mahonga Road, in events as frequent as a 20% AEP event (particularly affecting Urana Road to the east of town (towards Walbundrie). Section 7 investigates a range of options to address the flood immunity of Urana Road in this direction.

6.3.1. Comparison to Flood Study

A comparison between the 1% AEP peak flood levels is provided on Figure D16, indicating the overall difference in design results following the model revisions (described in Section 4) and update to ARR 2019 methodologies (Section 5). Despite the ARR 2019 methodologies producing a higher peak flow at Walbundrie Gauge (751 m^3/s compared to 663 m^3/s derived using ARR 1987), by the time the flows arrive at Rand (routed through the MIKE11 model), the peak flows are comparable to those developed in the Flood Study (Reference 4). As such, the modelled peak flood levels are not materially influenced, with revised results within +/- 0.1 m of the Flood Study results.

Table D 8:Comparison of Peak flows at the upstream TUFLOW boundary

Design Event	FRMS&P (ARR 2019)	Flood Study (ARR 1987) (Reference 4)
20% AEP	-	230.9
0.2EY	200	-
10% AEP	259	257
5% AEP	319	314
2% AEP	371	382
1% AEP	423	409
0.5% AEP	472	482
0.2% AEP	597	590
PMF	6004	6000

6.4. Hydraulic Hazard Classification

Hazard classification plays an important role in informing floodplain risk management in an area as it reflects the likely impact of flooding on development and people. In the Floodplain Development Manual (Reference 3) hazard classifications are essentially binary – either Low or High Hazard as described on Figure L2 of that document. However, in recent years there has been a number of developments in the classification of hazard especially in *Managing the floodplain: a guide to best practice in flood risk management in Australia (Third Edition)* (Reference 7). The Flood Study (Reference 4) presents hazard categorisation mapping based on the Floodplain Development Manual, while this study presents revised mapping based on the methodology outlined in Reference 7. The classification is divided into 6 categories (H1-H6), listed in Table D 9, which indicate constraints of hazard on people, buildings and vehicles appropriate to apply in each zone. The criteria and threshold values for each of the hazard categories are presented in Diagram D 4.

Table D 9: Hazard Categories

Category	Constraint to people/vehicles	Building Constraints
H1	Generally safe for people, vehicles and buildings	*No constraints*
H2	Unsafe for small vehicles	*No constraints*
H3	Unsafe for vehicles, children and the elderly	*No constraints*
H4	Unsafe for vehicles and people	*No constraints*
H5	Unsafe for vehicles and people	All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people	All building types considered vulnerable to failure

Diagram D 4: Hazard Classifications

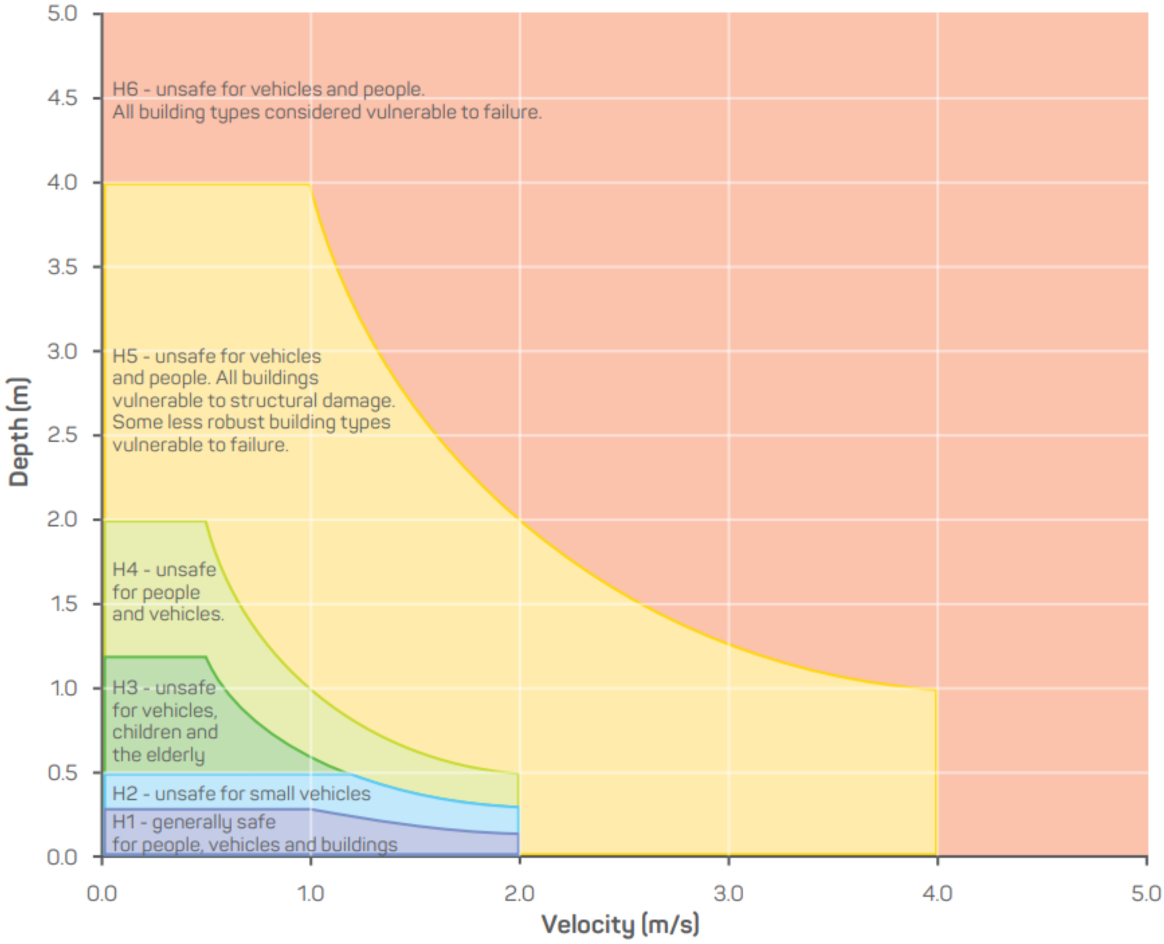


Figure D17 to Figure D19 present the hazard classifications based on the H1-H6 delineations for the 5% and 1% AEP events, as well as the PMF event, respectively. These maps show high hazard areas located along Billabong Creek and no high hazard areas within Rand.

6.5. Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the Floodplain Risk Management process to assist in the assessment of the suitability of future types of land use and development, and the formulation of floodplain risk management plans. The Floodplain Development Manual (Reference 3) defines land inundated in a particular event as falling into one of the three hydraulic categories listed in Table D 10.

Table D 10: Hydraulic Categorisation Definitions (*Floodplain Development Manual* (Reference 3))

Category	Definition
Floodway	• Those areas where a significant volume of water flows during floods; • Often aligned with obvious natural channels; • Areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which my adversely affect other areas; and • Often, but not necessarily, areas with deeper flow or areas where higher velocities occur.
Flood Storage	• Parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood; • If the capacity of a flood storage area is substantially reduced, for example by the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased; and • Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.
Flood Fringe	• Remaining area of land affected by flooding after floodway and flood storage areas have been defined; • Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

To define the floodway, the Howells et al. (Reference 9) methodology was applied, which differentiates the floodway from other hydraulic categories by selecting a velocity-depth product criteria that exceeds a specific threshold. These parameters were confirmed iteratively through encroachment analysis using the criteria determined in the Flood Study (Reference 4) as a starting point.

The encroachment analysis involved totally excluding all areas not defined as 'floodway' from the modelling domain, re-running the 1% AEP event and examining the subsequent impact on flood levels. If the reduction in conveyance area resulted in an increase in greater than 0.1 m to existing flood levels, the floodway area was increased. This approach is informed by Section L4 of the Floodplain Development Manual (Reference 3), which defines Flood Storage areas as *"those areas outside floodways which, if completely filled with solid material, would cause peak flood levels to increase anywhere by more than 0.1 m and/or would cause the peak discharge anywhere downstream to increase by more than 10%."*

The resulting parameters are provided in Table D 11. Following application of these criteria, the resulting floodway areas were examined to ensure continuity of flowpaths, and to remove any isolated grid cells inappropriately classified as floodway (for example as an artefact of the modelling).

Table D 11: Hydraulic Category Definition Parameters

Category	Floodway Definition Parameters
Floodway	$V \times D > 0.25$ m^2/s and $V > 0.25$ m/s, or $V > 1.0$ m/s and $D > 0.0$ m
Flood Storage	Areas outside floodway where $D > 0.5$ m
Flood Fringe	Areas outside floodway where $D < 0.5$ m

Hydraulic Categorisation for the 5% AEP, 1% AEP and PMF events are shown on Figure D20 to Figure D22, respectively. The analysis indicates that in the 5% and 1% AEP events, the floodway is generally contained within the Billabong Creek channel, and a breakout to the south (away from Rand). In the PMF, out of bank flow across the southern bank (west of Rand) is classified as floodway, while out-of-bank flow on the northern side of the creek is broadly classified as flood storage. In the PMF, a flowpath develops from the former railway/stock dam, heading downhill to the north. This flowpath is classified as floodway.

7. FLOOD RISK MANAGEMENT MEASURES

The FRMS process aims to identify and assess risk management measures which could be put in place to mitigate areas of unacceptable flood risk. The following section discusses the options considered specific to Rand, whilst the main report considers LGA-wide options.

The 2005 NSW Government's Floodplain Development Manual (Reference 3) separates risk management measures into three broad categories, outlined below:

Property modification measures modify existing properties, and land use and development controls for future new development or redevelopment. This is generally accomplished through such means as flood proofing, house raising or sealing entrances, strategic planning such as land use zoning, building regulations such as flood-related development controls, or voluntary purchase/voluntary house raising.

Response modification measures modify the response of the community to flood hazard by educating flood affected property owners about the nature of flooding so that they can make better informed decisions. Examples of such measures include provision of flood warning, emergency services, and improved awareness and education of the community.

Flood Modification Measures modify the physical behaviour of a flood including depth, velocity and redirection of flow paths. Typical measures include flood mitigation dams, retarding basins, channel improvements, levees or defined floodways. Pit and pipe improvement and even pumps may be considered where practical.

The Federation Villages Floodplain Risk Management Study assessed a range of potential options for the management of flooding. A range of options are considered separately and discussed in the following sections.

7.1. Flood Modification Measures

Flood modification measures aim to change the behaviour of a flood (e.g. reducing flood levels or velocities or excluding water from particular areas). These measures usually involve structural works (often permanent, though temporary structures can also be assessed) which are generally installed to modify flood behaviour on a wider scale, and in general, to be effective in the 1% AEP event.

Flood modification measures were identified by Council, Emergency Services or by members of the community (as part of the community consultation process) and through the examination of available flood modelling and identified hotspots; as having the potential to reduce flood risk at Rand. An initial hydraulic impact assessment has been undertaken for each identified option to determine its effectiveness in reducing flood risk, and to facilitate a general assessment of the option. Those which were identified as being potentially viable then underwent a more detailed assessment, from which the Floodplain Risk Management Plan recommendations are then derived.

Types of flood modification measures can include, retarding basins, bypass floodways, major channel or structure modifications, levees and diversion embankments, road raising and local drainage upgrades.

Table D 12 provides a summary of the flood modifications options considered for Rand.

Table D 12: Flood modification options considered for Rand

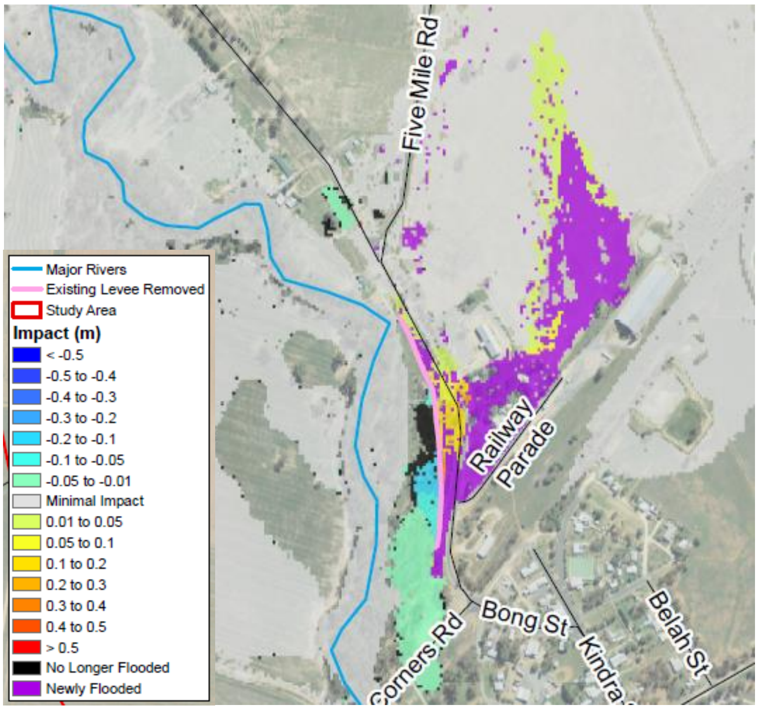
ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMR-01: Levee investigations	An informal earth levee (which has an approximate level of protection of the 1% AEP + 0.5m) runs along the right bank (eastern side) of Billabong Creek through Rand. This option considered either extension of the existing levee and an assessment to understand the benefits provided by the existing levee.	Refer to Figure D23. The existing informal levee is thought to provide some protection to a limited area of Rand; however, it is unclear the exact extent or level of protection provided. Formalisation and extension of the levee is not recommended due to the high costs and limited risk reduction. However, further investigation is required to confirm.	**Yes,** further investigation into the benefits of the existing levee. (Discussed in Section 7.1.1) Further investigation of a levee upgrade is not recommended.
FMR-02: Urana Road upgrade	Raising 900m of Urana Road where road closure due to ponding is known to occur. Tested for road raising of 0.5m, 1m or 1.7m to achieve various immunity levels.	Refer to Figure D24. In each scenario, the raised road obstructs breakouts from Billabong Creek moving from southwest to northeast, with varying degrees of effectiveness.	No, does not materially change flood risk, high construction costs

ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMR-03: Urana Road culvert upgrade	Doubling the existing box culvert crossing Urana Road in vicinity of the intersection of Urana Road and Western Road.	Refer to Figure D25. No material impact on flood behaviour as the increased capacity is exceeded in the 20% AEP event, causing Urana Road to still be overtopped by a depth of 0.5 m in the 20% AEP event, and 0.8 m in the 1% AEP event.	No, does not materially change flood risk, high construction costs

7.1.1. FMR-01: Levee Investigations

An informal earth levee runs along the right bank (eastern side) of Billabong Creek through Rand. A scenario was assessed where the existing levee was removed from the terrain in order to understand the flood risk benefits it provides (Diagram D 5). This confirmed the parts of the floodplain to which the levee provides protection and that no residential properties are protected. The existing levee provides flood protection to the Rand Hotel and the adjacent rural fire shed. As an informal system there is currently no data on the built form or condition, nor its intended purpose and level of protection provided. Although the current analysis indicates that the majority of the levee sits at a level of approximately the 1% AEP flood level plus 0.5m (Figure D23).

Diagram D 5: Impacts of Levee Removal – 1% AEP Event



Options were considered as part of this study, including extending the levee at its current level, formalising and extending the levee system and considering realignment and/or upgrade, as well as a ‘do nothing’ scenario (Figure D23).

Upgrading and extending the levee would involve substantial costs, with limited flood risk benefit provided, and are therefore not considered to be economically viable. Options regarding the levee were discussed with the FMC and it was agreed that the 'do nothing' scenario was the appropriate recommendation including maintaining the levee at its current level of protection. However, further investigation is required to ensure there are no unintended consequences in this. These detailed investigations should look to identify the beneficiaries of the current system, understand the condition of the levee, ownership of the land and negotiating easements.

7.1.1.1. Recommendation

FMR-01: Levee Investigation (Maintenance)	
☑	Further investigate the informal Rand levee to identify the beneficiaries of the current system, understand the condition of the levee and land ownership.

7.2. Response Modification Measures

7.2.1. RMR-01: Automated Road Closure Warning System

During community consultation, residents of Rand noted that Urana Road is overtopped by floodwaters breaking out from Billabong Creek during frequent events, and that ponding can remain for several days. This not only results in an inconvenience to motorists, it also requires Council staff to travel to Rand to put up and take down road closure signs, placing a further demand on Council staff. As the closure signs are only implemented once Council is notified, there is a risk of motorists crossing floodwaters prior to the roads closure. Residents also noted that if 'Road Closed' signs remained in place after floodwaters had subsided, residents would ignore signs and be more likely to ignore similar signs in the future.

A number of structural options were assessed to modify the road in this location to prevent inundation and ponding (Figure D24 and D25). However, none were found to be viable and an alternative automated road closure warning system has been investigated. Such systems can include automated warning signs, boom gates, self-deploying flood gates, depth markers and/or warning lights.

Approximately 800 m to one km of Urana Road is cut during a 1% AEP event, including the crossroads with Western Road. Any automated system would require the installation and calibration of a gauge on Billabong Creek, and a telecommunication system. A broader flood warning system has been recommended in the main report. The costs involved depend on the system employed and the particular site characteristics, but generally vary from $5,000 for simple depth markers, to $60,000 for a gauged and gated system. It is therefore recommended that further investigation is undertaken into the potential for a warning system in this location and identifying the most appropriate configuration considering aspect of the broader system.

7.2.1.1. Recommendation

RMR-01: Automated road closure warning system	
☑	Investigate the feasibility of an automated warning system for closing Urana Road in Rand during flood events.

7.3. Property Modification Measures

7.3.1. PMR-01: Voluntary House Raising or Purchase

Voluntary house raising (VHR) seeks to reduce the frequency of exposure to flood damage of the house and its contents by raising the house above the Flood Planning Level (FPL), whilst Voluntary Purchase (VP) schemes are a long-term option to permanently remove residential properties from areas of high flood hazard where there is a real risk to life during flood events. Both schemes can be eligible for state government funding if undertaken in accordance with the published guidelines, which includes criteria for identifying properties.

The property spreadsheet developed as part of this FRMS was used to initially identify any potential properties which meet the criteria provided in state guidelines (Reference 14 and 15). For VHR this is properties locate outside of the floodway and within low to moderate hazard areas only (H1 to H3) that are inundated over floor in events up to and including the 1% AEP event under current conditions. For VP this is properties located within a floodway, or highly hazardous flood conditions (H4 to H6).

Based on current estimates, all dwellings in Rand have their lowest floor level above the 0.5% AEP level and are more commonly not flooded until the PMF event, if at all. As such, a VHR scheme is not recommended. Most properties are located outside the 1% AEP flood extent or within the shallow fringe areas, and therefore well away from the floodway which is confined to Billabong Creek. As such, a VP scheme is not recommended.

7.3.1.1. Recommendation

PMR-01: Voluntary House Raising or Purchase	
☒	A VP/VHR scheme is not recommended for Rand.

7.4. Summary of Recommended Options

The following management options specific to Rand are recommended.

Reference	Name	Type
FMR-01	**Levee Investigation (Maintenance)**	Flood modification
RMR-01	**Automated road closure warning system**	Response modification

These will be further assessed in the overarching FRMS and in turn prioritised for implementation as part of the FRMP.

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February 2020

Attachment 1

1. ARR 2019 Data Hub Metadata

The metadata provided in this section has been downloaded directly (or calculated as required) from http://data.arr-software.org/, originally accessed in April 2019.

1.1. Local Catchment Model

1.1.1. IFD Data

Average design rainfall depths (mm) at the Rand local catchment centroid (-35.5875 , 146.5875)

Duration	AEP							
(min)	20%	0.2EY	10%	5%	2%	1%	0.5%	0.2%
15	15.4	15.7	18.4	21.3	25.2	28.2	31.5	36.2
30	20.4	20.8	24.3	28.2	33.3	37.3	41.7	48.1
45	23.4	23.9	27.8	32.2	38.1	42.5	47.5	54.9
60	25.5	26.0	30.3	35.1	41.4	46.2	51.7	59.7
90	28.6	29.1	33.9	39.2	46.1	51.4	57.5	66.5
120	30.8	31.4	36.5	42.2	49.6	55.4	61.9	71.5
180	34.2	34.9	40.5	46.7	55.0	61.3	68.6	79.1
270	38.0	38.8	44.9	51.8	61.0	68.2	76.2	87.7
360	41.0	41.8	48.5	55.9	65.9	73.8	82.4	94.8
540	45.6	46.5	54.0	62.4	73.8	82.9	92.5	106
720	49.3	50.2	58.4	67.6	80.3	90.4	101	116
1080	54.8	55.9	65.2	75.9	90.5	102	114	131
1440	59.1	60.3	70.5	82.4	98.6	112	125	144
1800	62.5	63.7	74.7	87.6	105	119	134	155
2160	65.3	66.6	78.3	92.0	111	126	141	164
2880	69.7	71.1	83.8	98.8	119	136	153	178
4320	75.6	77.1	91.1	108	130	148	168	196
5760	79.5	81.1	95.7	113	136	155	176	207
7200	82.2	83.9	98.6	116	139	159	181	213
8640	84.3	86.0	100	117	141	161	184	215
10080	85.9	87.6	102	118	141	161	184	216

1.1.2. Areal Reduction Factors

Areal Reduction Factors for the Design Storm Events (Local Catchment)

Duration	AEP						
(min)	20%	10%	5%	2%	1%	0.5%	0.2%
60	0.9730	0.9708	0.9687	0.9658	0.9637	0.9615	0.9587
90	0.9773	0.9747	0.9722	0.9689	0.9663	0.9638	0.9604
120	0.9797	0.9769	0.9740	0.9702	0.9674	0.9645	0.9607
180	0.9827	0.9796	0.9764	0.9722	0.9690	0.9659	0.9617
360	0.9892	0.9876	0.9859	0.9838	0.9821	0.9805	0.9783
720	0.9933	0.9924	0.9915	0.9903	0.9894	0.9885	0.9873
1080	0.9947	0.9940	0.9934	0.9925	0.9918	0.9912	0.9903
1440	0.9961	0.9956	0.9952	0.9947	0.9943	0.9939	0.9933
2160	0.9969	0.9965	0.9961	0.9955	0.9951	0.9947	0.9941
2880	0.9974	0.9970	0.9966	0.9960	0.9956	0.9951	0.9946
4320	0.9980	0.9976	0.9971	0.9965	0.9961	0.9957	0.9951

1.1.3. Initial Losses

Probability Neutral Burst Initial Loss at the Centroid of the Study Area (mm)

Duration	AEP				
(min)	20%	10%	5%	2%	1%
60	8.3	8.1	8.5	8.7	6.6
90	9.2	8.5	8.6	8.3	7.7
120	10.1	9.0	8.9	8.2	6.7
180	10.1	9.0	9.3	9.1	7.6
360	12.9	11.5	11.4	9.8	6.7
720	14.8	14.3	15.1	12.5	8.8
1080	16.3	15.6	16.2	13.9	9.4
1440	17.3	16.2	16.0	15.2	11.0
2160	18.8	19.0	20.2	18.6	14.4
2880	18.8	19.0	20.7	19.5	14.7
4320	20.1	21.7	23.3	22.0	17.4

1.2. Billabong Creek Mainstream Model

1.2.1. IFD Data

Design rainfall depths (mm) at the Billabong Creek to Walbundrie catchment centroid (-35.686113, 147.226796)

Duration	AEP							
(min)	20%	0.2EY	10%	5%	2%	1%	0.5%	0.2%
15	16.0	16.3	19.0	22.0	26.2	29.5	32.2	36.1
30	21.2	21.6	25.2	29.3	34.8	39.1	42.8	48.1
45	24.4	24.9	29.0	33.6	39.9	44.8	49.0	55.2
60	26.7	27.2	31.7	36.7	43.5	48.8	53.4	60.1
90	30.1	30.7	35.7	41.2	48.7	54.5	59.7	67.2
120	32.7	33.4	38.7	44.6	52.6	58.8	64.3	72.3
180	36.7	37.4	43.3	49.8	58.5	65.3	71.3	80.1
270	41.2	42.0	48.4	55.6	65.2	72.6	79.0	88.7
360	44.8	45.7	52.5	60.2	70.4	78.4	85.2	95.6
540	50.4	51.4	59.0	67.5	78.8	87.8	95.2	107
720	54.8	55.9	64.1	73.2	85.5	95.2	103	116
1080	61.6	62.8	71.9	82.1	96.0	107	116	131
1440	66.7	68	77.9	88.9	104	116	127	142
1800	70.8	72.2	82.7	94.4	111	123	138	157
2160	74.2	75.7	86.6	98.9	116	129	146	168
2880	79.4	81.0	92.8	106	124	139	157	180
4320	86.5	88.2	101	115	135	150	168	191
5760	91.0	92.8	106	120	141	157	172	194
7200	94.2	96.1	109	124	144	160	175	197
8640	96.6	98.5	112	126	145	162	176	198
10080	98.5	100	113	127	145	162	176	200

1.2.2. Areal Reduction Factors

Areal Reduction Factors for the Design Storm Events at the Wallbundrie catchment centroid

Duration	AEP						
(min)	0.2EY	10%	5%	2%	1%	0.5%	0.2%
60	0.4917	0.4740	0.4532	0.4259	0.4051	0.3844	0.3570
90	0.5557	0.5348	0.5104	0.4782	0.4538	0.4295	0.3973
120	0.5942	0.5706	0.5432	0.5069	0.4795	0.4520	0.4157
180	0.6429	0.6168	0.5864	0.5462	0.5158	0.4854	0.4452
360	0.7375	0.7237	0.7077	0.6865	0.6704	0.6543	0.6331
720	0.8039	0.7961	0.7869	0.7748	0.7656	0.7564	0.7443
1080	0.8388	0.8335	0.8274	0.8192	0.8130	0.8068	0.7987
1440	0.8738	0.8710	0.8678	0.8636	0.8604	0.8573	0.8530
2160	0.8890	0.8861	0.8827	0.8782	0.8748	0.8714	0.8670
2880	0.8985	0.8955	0.8920	0.8873	0.8838	0.8802	0.8756
4320	0.9105	0.9073	0.9035	0.8985	0.8948	0.8910	0.8861

1.2.3. Initial Losses

Probability Neutral Burst Initial Loss at the Wallbundrie catchment centroid (mm)

Duration	AEP				
(min)	20%	10%	5%	2%	1%
60	10.4	9.7	10.4	10.5	9.3
90	10.7	9.6	10.0	10.1	9.3
120	10.5	9.7	10.1	9.8	8.5
180	12.1	10.8	11.1	10.4	8.7
360	13.0	12.1	12.8	10.8	7.1
720	16.0	14.6	14.6	12.5	8.3
1080	17.7	16.9	16.9	14.6	9.6
1440	19.2	18.6	19.0	17.1	12.1
2160	21.4	21.0	21.4	19.4	14.7
2880	22.1	22.3	23.1	21.1	14.7
4320	22.8	23.6	24.3	22.5	17.8

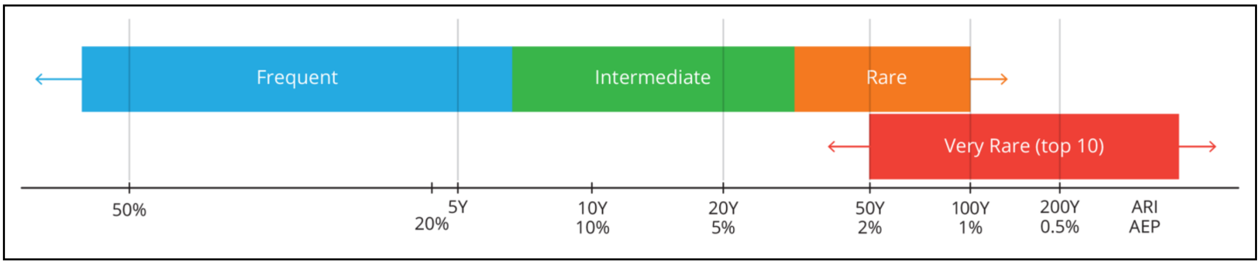
2. Critical Duration Assessment

This section provides supporting material relating to the critical duration assessment undertaken for the local runoff through Rand, as well as the mainstream Billabong Creek model (with its outlet at Walbundrie). The mechanisms are assessed separately, as described in Section 5.7 of Appendix F.

2.1.1. Local Catchment Critical Duration Assessment

To determine the critical duration (the duration of rainfall over the catchment that would result in the greatest depth of flooding) in Rand, ARR 2019 recommends than an ensemble approach is used, where 10 temporal patterns are analysed for each storm duration in the TUFLOW hydraulic model. Given the computational demands of this number of model runs, the number of storm durations to be tested was shortlisted based on results from the hydrologic model. This attachment provides further details of this process (which was undertaken for an event in each bin (see Diagram F1 , using the 1% AEP event as an example.

Diagram F1: Temporal Pattern Bins



Three key sub-catchment outlet locations were chosen to assess the peak flows generated by rainfall over the Rand catchment using the XP-RAFTS model. The chosen sub-catchments are listed below and are shown on Figure E5:

- No. 1 – Urban Area east of former railway;
- No. 3 – area northwest of former railway;
- No. 4– area southwest of Kindra Street (draining to Billabong Creek); and
- No. 5 – area between Mahonga Road and the Rand Levee.

A range of storm durations (from 15 minutes to 72 hours) and the full ensemble of temporal patterns were run in XP-RAFTS, and the results were analysed at each of these locations. A box plot of 1% AEP flows for each of these locations can be seen in Diagram F2 to Diagram F5.

The box and whiskers for each duration indicate the spread of results obtained from the ensemble of temporal patterns. The box defines the first quartile to the third quartile of the results and the bottom and top line (also called ‘whiskers’) represent the maximum and minimum values. The hollow circles beyond these lines are statistical outliers. The red horizontal line within the box represents the median value. The red circle is the mean (average) value.

Diagram F2: Box plot of peak local flow at sub-catchment No.1 of different durations for 1% AEP event

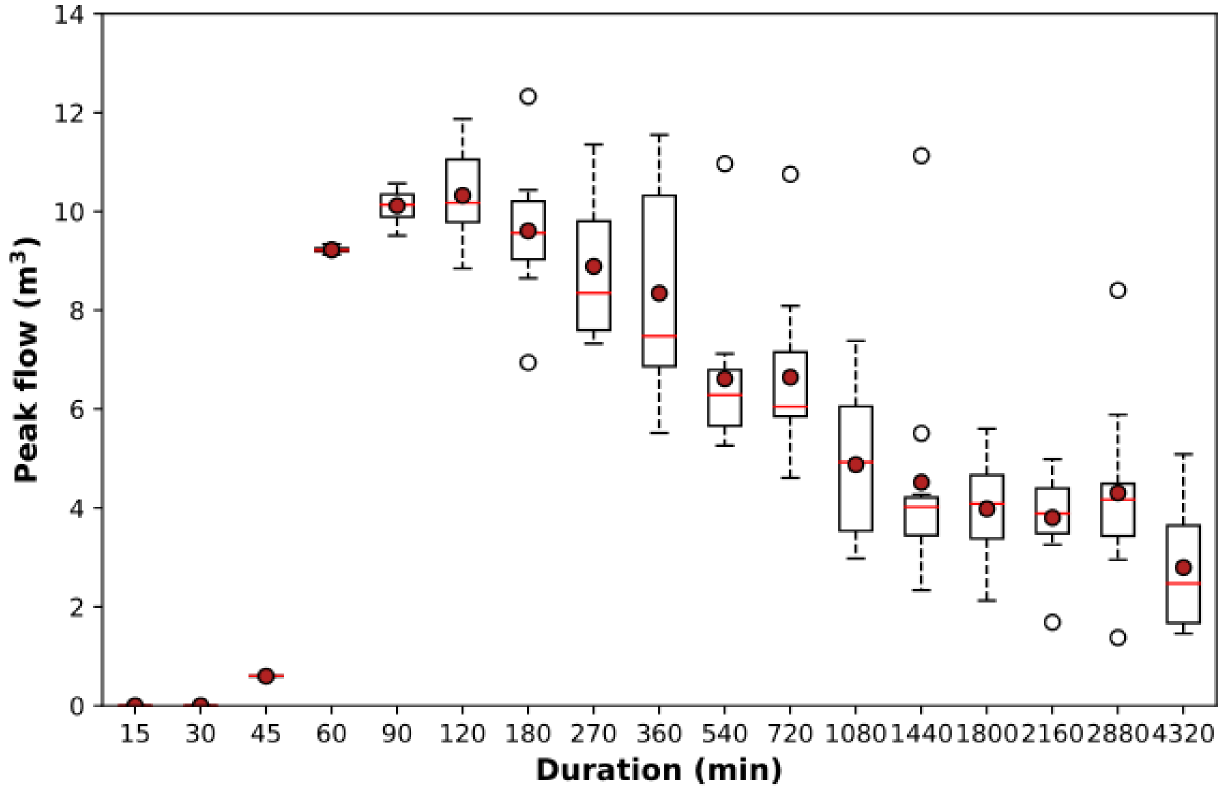


Diagram F3: Box plot of peak local flow at sub-catchment No.3 of different durations for 1% AEP event

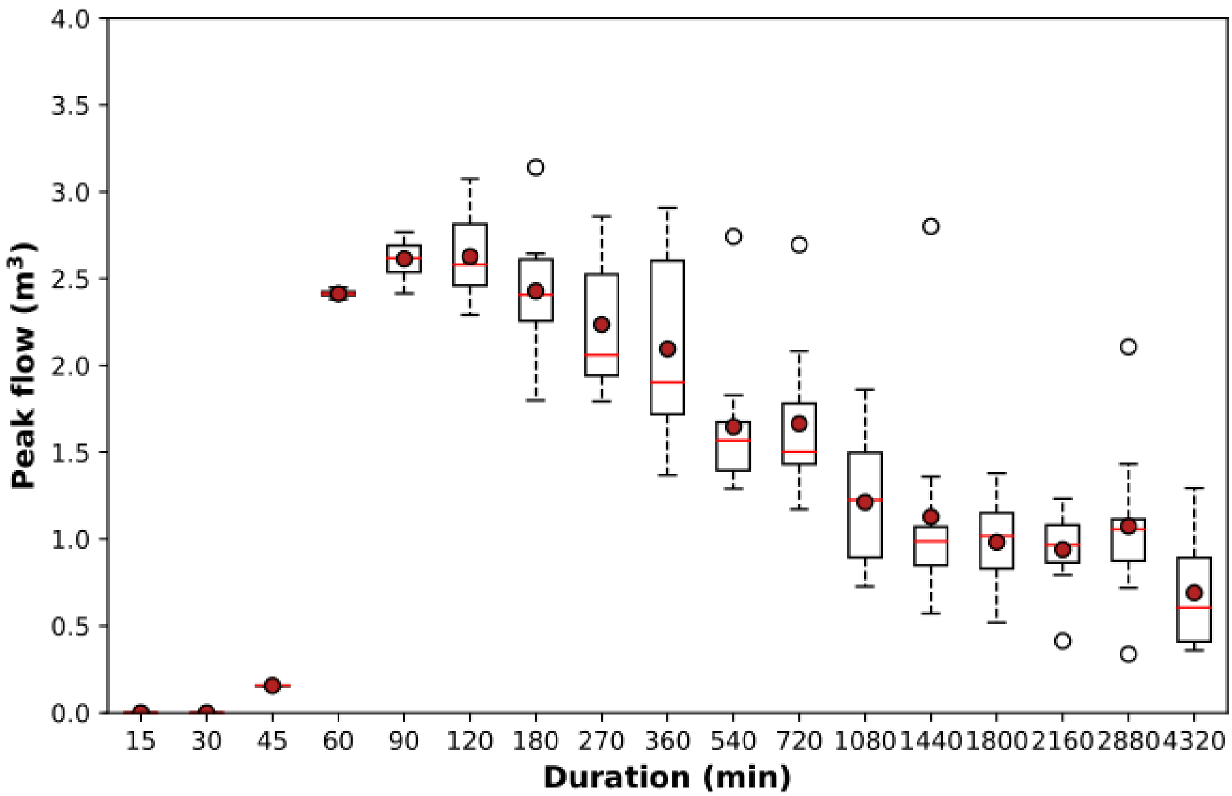


Diagram F4: Box plot of local flow at sub-catchment No.4 of different durations for 1% AEP event

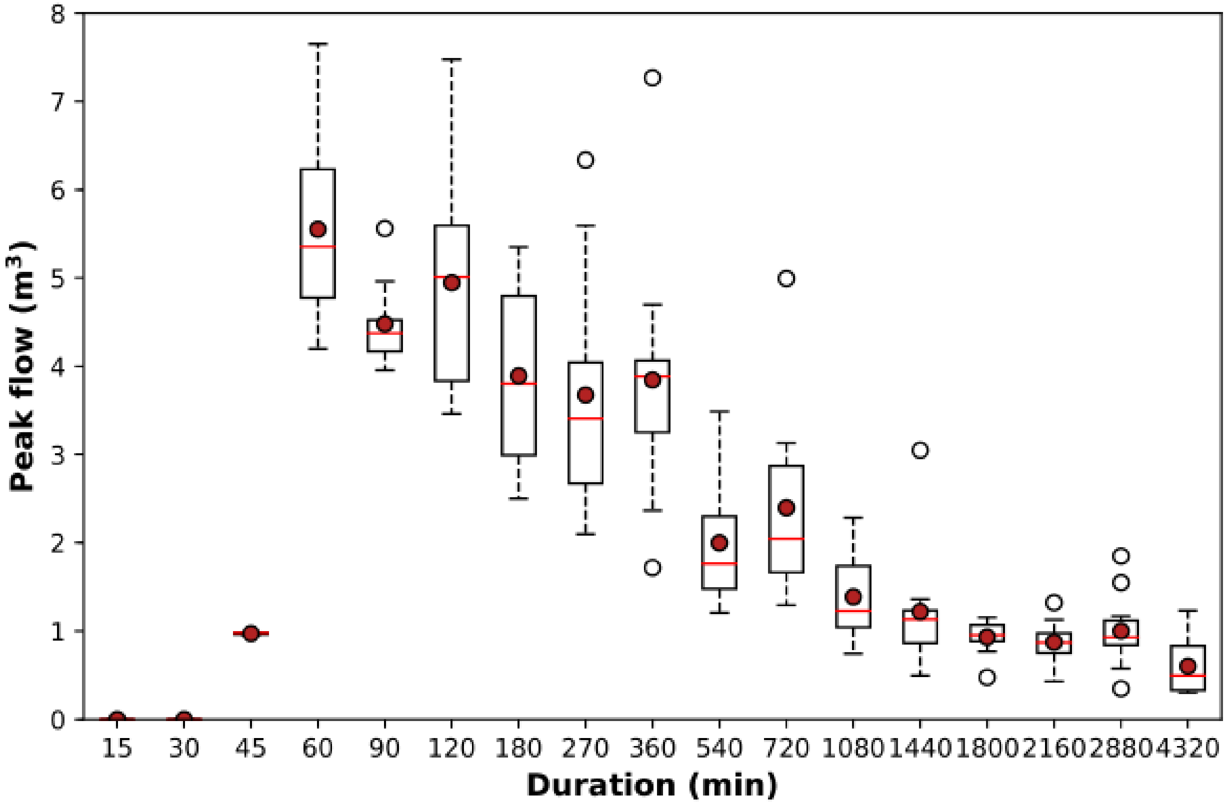
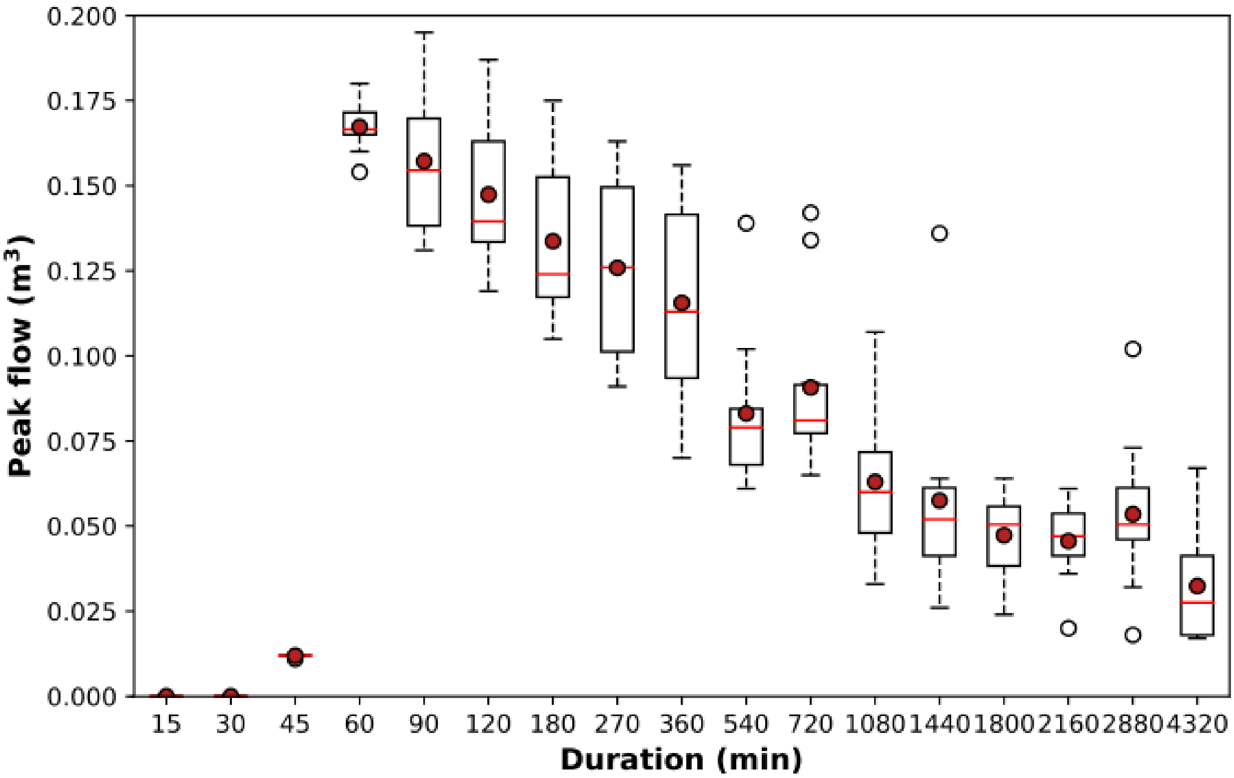


Diagram F5: Box plot of peak local flow at sub-catchment No.5 of different durations for 1% AEP event



The above box plots indicate that, across the local catchment, the highest mean flow is produced by storm durations of 60 to 180 minutes.

The final selection of critical duration and temporal pattern was conducted based on peak flood levels produced by TUFLOW. For the 1% AEP event as an example, the TUFLOW hydraulic model was run for the 60 minute, 120 minute and 180 minute durations and the ensemble of 10 temporal patterns. The representative temporal pattern was selected by producing a 'mean grid', averaging the 10 peak flood level grids (each produced by a different temporal pattern). The peak flood level results of each temporal pattern were then compared to the mean grid to assess the differences. The temporal pattern that produced results as close to and just above the mean grid was selected as the 'adopted temporal pattern' for each duration. The combination of duration and representative temporal pattern that produced the highest peak flood levels was adopted as the basis for design flood estimation.

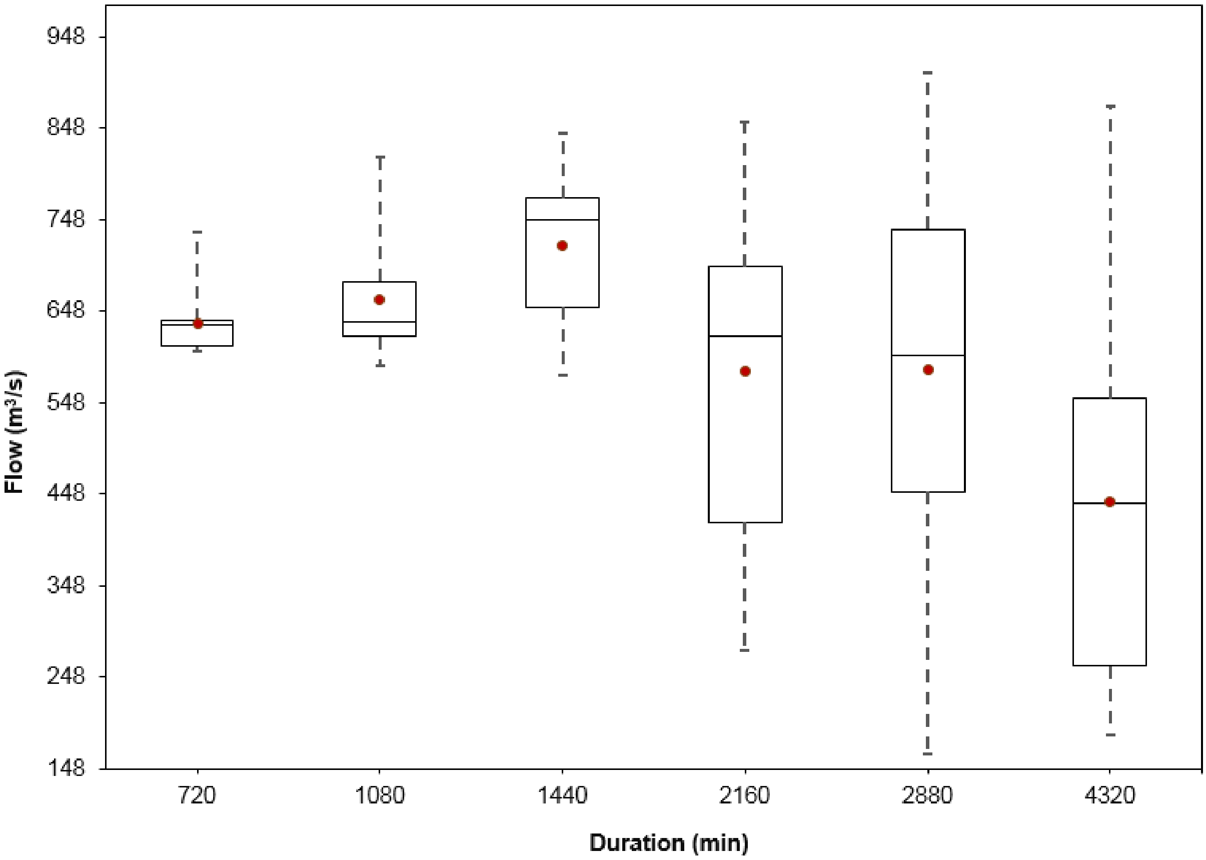
This selection process was repeated for the largest event within each bin (see Diagram F1), and the 'winning' storm duration and temporal pattern were applied to the smaller events within each bin. Table F1 presents a summary of the critical duration and adopted temporal pattern for each design flood event.

The probable maximum precipitation (PMP) uses a single temporal pattern. In this case, the peak flows at each of the key sub-catchments were analysed to determine the critical duration (duration which produces the peak flows). At all the locations of interest, the 60 minutes (1 hour) storm was the critical duration and was adopted for the PMF design flood event.

2.1.2. Billabong Creek Critical Duration Assessment

The critical duration assessment for the Billabong Creek catchment to Walbundrie was based on determining the duration and representative temporal pattern producing the highest mean flow at the Walbundrie gauge. The 24 hr duration (1440 minute) was identified as the critical duration. The box plots demonstrating the distribution of peak flows across various storm durations (from 720 minute to 4320 minute) are shown in Diagram F6.

Diagram F6 Box plot of peak flow at Walbundrie catchment of different durations for 1% AEP event



2.1.3. Critical Duration Assessment Results

Table F1 presents a summary of the critical duration and adopted temporal pattern for each design flood event.

Table F1: Adopted durations and temporal patterns for design flood events (local catchment)

	Local Catchment (XP-RAFTS)			Billabong Creek Catchment (RORB)		
Event	**Critical Duration (min)**	**Adopted Temporal Pattern**	**Peak flood discharge (m^3/s) at the catchment outlet**	**Critical Duration (min)**	**Adopted Temporal Pattern**	**Peak flood discharge (m^3/s) at the catchment outlet**
0.2EY	180	TP4: 3983	8.5	1440	TP8: 4157	201
10% AEP	120	TP6: 3944	9.2	1440	TP10: 4148	340
5% AEP	120	TP6: 3944	11.6	1440	TP10: 4148	467
2% AEP	120	TP6: 3936	15.6	1440	TP4: 4105	582
1% AEP	120	TP6: 3936	18.6	1440	TP4: 4105	751
0.5% AEP	120	TP6: 3936	21.5	2880	TP9: 4197	796
0.2% AEP	120	TP6: 3936	25.8	2880	TP3: 2466	1061
PMF	60	NA	236.8	1080	NA	13182

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	146.588
Latitude	-35.587
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
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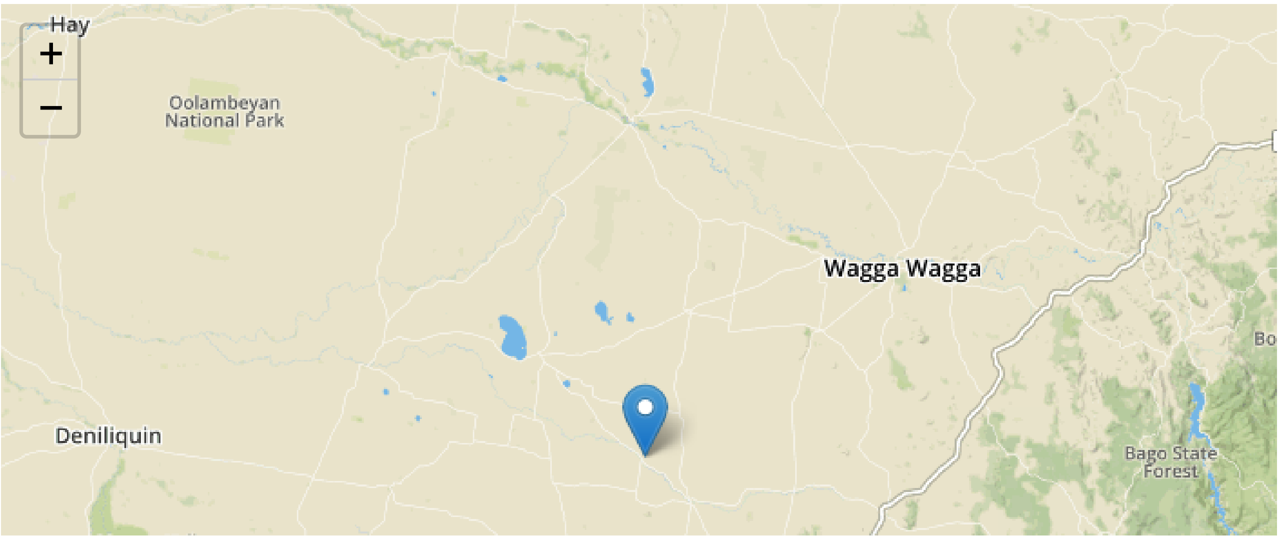
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show
Baseflow Factors	show



Data

River Region

Division	Murray-Darling Basin
River Number	11
River Name	Billabong-Yanco Creeks

Layer Info

Time Accessed	14 February 2019 03:56PM
Version	2016_v1

ARF Parameters

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

Zone	a	b	c	d	e	f	g	h	i
Southern Semi-arid	0.254	0.247	0.403	0.351	0.0013	0.302	0.058	0.0	0.0

Short Duration ARF

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

Layer Info

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Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR DIRECT USE** in urban areas

Note: As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. The continuing storm loss information from the ARR Datahub provided below should only be used where relevant under the loss hierarchy (level 5) and where used is to be multiplied by the factor of 0.4.

ID	31050.0
Storm Initial Losses (mm)	23.0
Storm Continuing Losses (mm/h)	3.4

Layer Info

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Version	2016_v1

Temporal Patterns | Download (.zip) (http://192.168.70.224/static/temporal_patterns/TP/MB.zip)

code	MB
Label	Murray Basin

Layer Info

Time Accessed	14 February 2019 03:56PM
Version	2016_v2

Areal Temporal Patterns | Download (.zip) (http://192.168.70.224/./static/temporal_patterns/Areal/Areal_MB.zip)

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	14 February 2019 03:56PM
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BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-35.5875&longitude=146.5875&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

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Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	4.5 (0.244)	3.1 (0.122)	2.2 (0.072)	1.3 (0.037)	1.3 (0.032)	1.3 (0.029)
90 (1.5)	4.2 (0.205)	2.8 (0.098)	1.8 (0.054)	0.9 (0.023)	0.7 (0.014)	0.5 (0.009)
120 (2.0)	3.0 (0.133)	2.1 (0.068)	1.5 (0.042)	1.0 (0.023)	0.6 (0.012)	0.3 (0.006)
180 (3.0)	3.3 (0.132)	3.3 (0.097)	3.3 (0.082)	3.3 (0.071)	1.5 (0.028)	0.2 (0.003)
360 (6.0)	1.2 (0.040)	2.4 (0.059)	3.2 (0.067)	4.0 (0.072)	2.6 (0.039)	1.5 (0.020)
720 (12.0)	0.0 (0.000)	0.4 (0.007)	0.6 (0.010)	0.8 (0.012)	1.2 (0.015)	1.5 (0.017)
1080 (18.0)	0.0 (0.000)	0.1 (0.002)	0.2 (0.003)	0.2 (0.003)	1.1 (0.012)	1.7 (0.017)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.5 (0.005)	0.8 (0.007)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	14 February 2019 03:56PM

Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	14 February 2019 03:56PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

25% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.2 (0.009)	0.1 (0.004)	0.0 (0.001)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.002)	0.0 (0.001)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

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Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

75% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	17.4 (0.942)	16.6 (0.650)	16.1 (0.529)	15.6 (0.443)	15.5 (0.374)	15.4 (0.334)
90 (1.5)	15.1 (0.727)	16.1 (0.565)	16.8 (0.497)	17.5 (0.447)	14.2 (0.309)	11.8 (0.229)
120 (2.0)	11.2 (0.497)	15.0 (0.488)	17.6 (0.481)	20.0 (0.475)	16.5 (0.332)	13.8 (0.249)
180 (3.0)	15.2 (0.607)	16.1 (0.469)	16.6 (0.411)	17.2 (0.368)	14.5 (0.265)	12.6 (0.205)
360 (6.0)	6.1 (0.203)	10.5 (0.256)	13.4 (0.277)	16.2 (0.290)	17.6 (0.266)	18.6 (0.252)
720 (12.0)	4.0 (0.111)	5.0 (0.102)	5.7 (0.098)	6.3 (0.094)	13.4 (0.167)	18.6 (0.206)
1080 (18.0)	0.9 (0.021)	3.5 (0.064)	5.2 (0.080)	6.9 (0.091)	9.7 (0.107)	11.7 (0.115)
1440 (24.0)	0.0 (0.000)	3.6 (0.061)	6.0 (0.084)	8.2 (0.100)	8.8 (0.089)	9.2 (0.083)
2160 (36.0)	0.0 (0.000)	0.8 (0.013)	1.4 (0.017)	1.9 (0.020)	2.8 (0.026)	3.6 (0.028)
2880 (48.0)	0.0 (0.000)	0.2 (0.002)	0.3 (0.003)	0.4 (0.004)	0.5 (0.005)	0.7 (0.005)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

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Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

90% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	37.9 (2.053)	33.0 (1.294)	29.8 (0.982)	26.7 (0.761)	28.0 (0.676)	28.9 (0.626)
90 (1.5)	29.8 (1.436)	33.2 (1.162)	35.4 (1.045)	37.6 (0.960)	29.3 (0.636)	23.1 (0.449)
120 (2.0)	25.2 (1.124)	30.5 (0.991)	34.1 (0.932)	37.4 (0.888)	37.5 (0.756)	37.6 (0.679)
180 (3.0)	24.5 (0.978)	32.0 (0.936)	37.0 (0.914)	41.8 (0.895)	31.6 (0.575)	23.9 (0.390)
360 (6.0)	15.5 (0.514)	20.1 (0.491)	23.2 (0.478)	26.1 (0.467)	31.8 (0.483)	36.1 (0.490)
720 (12.0)	14.8 (0.408)	17.7 (0.359)	19.6 (0.336)	21.4 (0.317)	26.8 (0.334)	30.8 (0.341)
1080 (18.0)	9.6 (0.237)	15.5 (0.283)	19.4 (0.298)	23.2 (0.305)	24.9 (0.275)	26.1 (0.256)
1440 (24.0)	3.2 (0.074)	14.2 (0.240)	21.5 (0.305)	28.5 (0.346)	24.3 (0.247)	21.2 (0.190)
2160 (36.0)	0.5 (0.010)	6.2 (0.095)	10.0 (0.128)	13.7 (0.149)	13.6 (0.123)	13.6 (0.108)
2880 (48.0)	1.9 (0.038)	8.2 (0.117)	12.3 (0.147)	16.2 (0.164)	16.2 (0.136)	16.2 (0.119)
4320 (72.0)	0.0 (0.000)	1.4 (0.018)	2.3 (0.025)	3.1 (0.029)	5.8 (0.044)	7.8 (0.052)

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Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.816 (4.1%)**	0.726 (3.6%)	**0.934 (4.7%)**
2040	**1.046 (5.2%)**	1.015 (5.1%)	**1.305 (6.6%)**
2050	**1.260 (6.3%)**	1.277 (6.4%)	**1.737 (8.8%)**
2060	**1.450 (7.3%)**	1.520 (7.7%)	**2.214 (11.4%)**
2070	**1.609 (8.2%)**	1.753 (8.9%)	**2.722 (14.2%)**
2080	**1.728 (8.8%)**	1.985 (10.2%)	**3.246 (17.2%)**
2090	**1.798 (9.2%)**	2.226 (11.5%)	**3.772 (20.2%)**

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Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	**50**	**20**	**10**	**5**	**2**	**1**
60 (1.0)	14.0	8.3	8.1	8.5	8.7	6.6
90 (1.5)	14.7	9.2	8.5	8.6	8.3	7.7
120 (2.0)	15.6	10.1	9.0	8.9	8.2	6.7
180 (3.0)	15.0	10.1	9.0	9.3	9.1	7.6
360 (6.0)	18.0	12.9	11.5	11.4	9.8	6.7
720 (12.0)	19.0	14.8	14.3	15.1	12.5	8.8
1080 (18.0)	20.5	16.3	15.6	16.2	13.9	9.4
1440 (24.0)	21.7	17.3	16.2	16.0	15.2	11.0
2160 (36.0)	22.8	18.8	19.0	20.2	18.6	14.4
2880 (48.0)	22.7	18.8	19.0	20.7	19.5	14.7
4320 (72.0)	23.4	20.1	21.7	23.3	22.0	17.4

Layer Info

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Note	As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. Probability neutral burst initial loss values for NSW are to be used in place of the standard initial loss and pre-burst as per the losses hierarchy.

Baseflow Factors

Downstream	10814
Area (km2)	4477.94911775
Catchment Number	10844
Volume Factor	0.288732
Peak Factor	0.046337

Layer Info

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