FEDERATION COUNCIL

APPENDIX A
BOREE CREEK

FEDERATION VILLAGES FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

MARCH 2022

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Project **Federation Villages Floodplain Risk Management Study and Plan**	**Project Number** **118048**
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BOREE CREEK

TABLE OF CONTENTS

PAGE

LIST OF APPENDICES TO THE MAIN REPORT

LIST OF ATTACHMENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF DIAGRAMS

1. BACKGROUND

1.1. Study Area

The township of Boree Creek is located adjacent to Boree Creek at the boundary of the Federation Council LGA, approximately 50 km south of Narrandera and 82 km west of regional centre Wagga Wagga. The region, including the town itself and surrounds, has a total population of 298 (2016 Census), and 121 private dwellings. The Study Area is shown on Figure A1.

Boree Creek drains a catchment area of approximately 141 km^2 to the town and flows in a south-westerly direction along the southern edge of the township. The creek continues southwest to Lake Cullivel and is joined by Brookong Creek before flowing into Urangeline Creek which discharges into Lake Urana. The catchment is predominantly cleared rural land and is used for grazing and agriculture. The land directly north of the township is densely vegetated and the banks of the creek are predominantly River Red Gum.

1.2. Land Use

Land use zoning in Boree Creek is defined in the Urana Local Environmental Plan (LEP) 2011, shown on Figure A2. Majority of the town itself is zoned as “RU5 Village” with a small area to the northeast zoned as “R5 Large Lot”. The Lockhart-Boree Creek Road which connects Boree Creek to neighbouring towns is located to the southeast of the town and zoned as “SP2 Infrastructure”. The entire region is otherwise zoned as “RU1 Primary Production”. Boree Creek itself is zoned as a “Major River”.

The major facilities in town include Boree Creek Public School, Soldiers Memorial Hall, Boree Creek Post Office, grain silos and Boree Creek Hotel. Boree Creek is the last operating section of the (mostly closed) railway between The Rock and Oaklands. The siding has been closed to passenger services since 1975, however seasonal freight trains service the grain silos. The railway line runs on a raised embankment (siting between 0.5m and 1.5m above the natural surface) across Boree Creek and through the middle of town. The line terminates to the west of town.

1.3. Demographic Overview

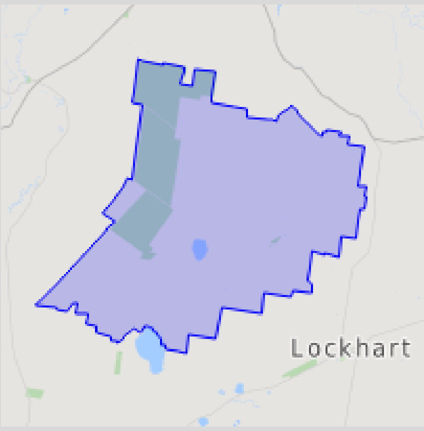
Understanding the social characteristics of the Study Area can help ensure appropriate risk management practices are adopted and shape the methods used for community engagement. Census data regarding house tenure and age distribution can also provide an indication of the community’s lived experience with recent flood events, and hence an indication of their flood awareness. According to The 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 low adult: child ratios making evacuation difficult;
- **Those lacking access to a motor vehicle** may need additional assistance to evacuate;
- **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**, requiring early evacuation, or if evacuation orders are ignored, may need medical evacuation resupply of essential items, or emergency rescue.

The following information has been extracted from the 2016 Census for the town of Boree Creek (and surrounds) and is relevant to the above considerations.

Boree Creek Demographic Overview



Population: 199 (298 including surrounds)
No. of Private Dwellings: 121
No. of lone person households: 16
Property Tenure:

- 77% owned (either outright or with a mortgage)
- 13.5% rented

Language

- 93.5% of people speak only English at home

No. persons over the age of 75: 11
Elderly people are often frailer and may be unable to respond as quickly to flood emergencies without requiring some assistance.
No. single-parent families: 8
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/SSC10512?opendocument#internet

Table A 1: Characteristics of Boree Creek (Australian Bureau of Statistics, 2016)

	Boree Creek	NSW
Population Age:		
0 – 14 years	20.7%	18.5%
15 - 64 years	59.2%	65.1%
> 65 years	20.1%	16.2%
Average people per dwelling	2.4	2.6
Own/mortgage property	77%	64.5%
Rent property	13.5%	31.8%
No cars at dwelling	6.4%	9.2%
Speak only English at home	9.5%	68.5%

The above statistics can help inform appropriate community engagement and flood related communication strategies. For example, with a high proportion of the population speaking English at home, communication materials in English are considered appropriate for use in this study. The high proportion of children and adults over 65 (20.7% and 20.1% compared to 18.5% and 16.2% in NSW, respectively) should also be considered as the low adult-to-child ratio and older individuals can make evacuation more difficult or time consuming. It is noted however that with small communities often comes a high degree of connectedness between residents, which can significantly reduce the effect of these challenges.

1.4. Local Environment

Boree Creek has a large catchment (141 km^2), which is bounded by the Murrumbidgee River catchment to the north, the Colombo Creek catchment to the west, the Brookong Creek catchment to the south and the Bullenbung Creek catchment to the east. Boree Creek runs south-southeast for approximately 20 km (as the crow flies), towards Lake Cullivel where it deepens into a broad expanse of inland water. Buckingbong State Forest, located approximately 13 km east of the town, indicates the type of vegetation (pine and gum forests) that would have previously dominated the area, which has since been cleared for agricultural purposes. In the Boree Creek area, the main crops grown include wheat, canola and barley, with lupins (pulses) and peas also grown on some farms. The land is also used for cattle and sheep grazing. Boree Creek is home to many areas of cultural significance. The name 'Boree' comes from the Aboriginal word 'corroboree', which describes gatherings in which local Aboriginal people would come together in large groups to celebrate events including births, deaths, marriages and initiation ceremonies (Reference 9).

The creek's banks are lined with large River Red Gum, and the bed is described by residents as being clogged by growth (both native and noxious species). Additionally, road and rail crossings are considered to cause an obstruction to flow. In-bank vegetation density and other obstructions will be investigated further later in this study.

Boree Creek does not have a reticulated sewerage system, rather, on-site sewage management systems (OSSMS) are used for each property. OSSMS, such as septic tanks, are miniature sewage treatment plants. If poorly designed and maintained, OSSMS will cause problematic effects including public health risks, water pollution of local creeks/rivers, agricultural land degradation and local amenity issues, effects which would be exacerbated during a flood event.

Dwellings situated on smaller lots may have insufficient space for appropriate subsoil 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. OSSMS, however, can be less susceptible to flood damage than formal reticulated systems, which can back up with floodwater and cause widespread issues with plumbing throughout towns.

2. PREVIOUS STUDIES

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

The Flood Study Report for Boree Creek (Reference 4), completed for Council in 2017 by Jacobs, provided an estimation of mainstream and local overland flow design flooding information for the town. The local catchment that drains to the village of Boree Creek covers an area of approximately 141 km^2, characterised by cleared rural land used for grazing and dryland cropping.

The study utilised a hydrologic model (XP-RAFTS (2013 version)) and hydraulic (TUFLOW) model. Due to the lack of streamflow gauging stations on Boree Creek, the RAFTS model and the TUFLOW hydraulic model were calibrated to recorded flood levels for both 2012 and 2010 events. 27 surveyed flood levels were available for the 2012 event. The comparison of the modelled flood levels for the 2012 event with 27 recorded flood levels across the town revealed differences ranging from -0.28 to +0.25 m. The modelled 2012 flood level revealed that the houses located on Namoi Street are shown to be flood free, as was observed during the flood. The modelled flood levels for the 2012 event were underestimated by up to 0.09 m on Darling Street, up to 0.28 m at the western side of Richmond Street, and up to 0.14 m on Hume Street. However, the modelled flood level was up to 0.25 m higher than was observed at a property in vicinity of the Richmond Street intersection with Aston Street and up to 0.18 m higher than observed levels at a property at the intersection of Murray Street and Namoi Street.

For the 2010 event, there is only one recorded flood level located at the ‘Emro’ property that was surveyed for this study. For the 2010 event, calibration was undertaken by adjusting parameters in the hydrologic and hydraulic models for only one recorded flood level located at the ‘Emro’ property. The difference in recorded flood level at this location found the TUFLOW model produced results approximately 0.04 m lower. These calibration results are reasonable considering the uncertainty in the range of data used.

The calibrated and validated hydrologic and hydraulic models were used to investigate flood behaviour for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design events (using ARR 1987 methodologies), and the PMF. An initial loss of 15 mm was adopted for both events up to and including the 10% AEP event, and an initial loss of 10 mm was adopted for events between 5% and 0.2% AEP. An initial loss of 0 mm was adopted for the PMP event. A continuing loss of 2.5 mm/hr was adopted for all design events up to and including the 0.2% AEP event and a continuing loss of 1 mm/hr was adopted for the PMP event. Initial rainfall losses adopted in this study are based on the same losses adopted in the Lockhart Flood Study Report (WMAwater, 2014). The key findings from the report on Boree Creek are summarised below:

- Overbank flooding occurs in events as frequent as the 20% AEP event and sections of Boree Creek Road located east of the Orara Street intersection are subject to flooding. The railway culvert constricts the floodplain and the ‘Emro’ property is surrounded by floodwater;
- Two railway culverts located east of the town reported as the major hydraulic controls, causing floodwaters to back up through the developed areas of Boree Creek;

- The railway culvert is a major hydraulic control in the 5% AEP event and causes extensive shallow flooding within the village and all access roads are subject to shallow flooding;
- Extensive flooding occurs in the village in the 1% AEP event and the majority of the roads within the village are inundated;
- In the PMF, the entire village is subject to inundation of depths greater than 1 m and the railway is overtopped.

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 11)

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, Greater 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, depths and levels 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 collected information was used in the first instance to prepare and update SES's flood intelligence systems, especially its Local Flood Plans and Flood Intelligence Cards. The key findings from the report on Boree Creek are summarised below:

- The report collected information for the flood events of March 2012, February 2011 and October 2010 at Boree Creek;
- The report compiled a history of flooding at Boree Creek based on a thorough search of historical newspapers from the National Library of Australia's online database;
- Major flooding occurred at Boree Creek in 1890, 1931, 1934, two floods in 1936, 1939, 2010 and 2012;
- During the March 2012 flood event, at least 24 houses and 10 businesses flooded over the floor;
- 135 mm of rain was recorded at a private gauge on the 4th of March 2012 (however the period over which it was recorded was not specified);
- The flood event of 2010 was about 0.3 m below the March 2012 flood peak at 'Emro' homestead; and
- The February 2011 event was lower than the October 2010 flood event and was noted as having fewer impacts on Boree Creek.

2.3. Lockhart Flood Study, Final Report, WMAwater, 2014 (Reference 10)

The town of Lockhart is located approximately 25 km southeast of Boree Creek in the Lockhart Shire Council Local Government Area. The township of Lockhart experiences regular flooding from the Brookong Creek and also from major overland flow.

The Lockhart Flood Study was completed in 2014 by WMAwater for Lockhart Shire Council (Reference 10). The scope of this study included defining the flood behaviour in the township of Lockhart under existing conditions (5-year ARI, 10%, 5%, 1%, 0.5% AEP events and the Probable Maximum Flood (PMF)). Brookong Creek at Lockhart has been subjected to numerous flood events in 1934, 1931, 1974 and 1939 (presented in order to magnitude). However, the 2012 and 2010 floods surpassed all previous flood events in terms of magnitude and damage. Therefore, the study used information from March 2012 and October 2010 events to ensure the hydraulic model could reproduce observed flood behaviour in the town. The 1% AEP design flood resulted in a near identical flood to the March 2012 event where approximately 70 residential and 28 businesses suffered from over floor inundation.

Information contained in the report regarding regional flooding information, historic flooding, hydrologic and hydraulic model parameters, setup and calibration are all useful to understand the catchment conditions and flood behaviour around Lockhart, which is not far from Boree Creek (25 km southeast). In particular, the study undertook a calibration (March 2012 event)/ validation (October 2010 event) events to determine the losses and adopted the initial loss of 15 mm for events up to and including the 10% AEP event and an initial loss of 10 mm for events between 5% and 0.2% AEP events. An initial loss of 0 mm adopted for the PMF event. A continuing loss of 2.5 mm/hr adopted for all design events and a continuing loss of 1 mm/hr adopted for the PMF event. These losses were adopted in the Boree Creek Flood Study (Jacobs, Reference 4).

3. AVAILABLE DATA

3.1. Site Visit

A site inspection was carried out by WMAwater staff accompanied by Council staff on the 9th of August 2018 to gain an overall appreciation of the study area, and to identify areas of Boree Creek that either contributed to flood risk (e.g. obstructions in the creek and its various crossings) or that were subject to the greatest flood risk. Figure A3 contains 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. 1m resolution LiDAR data for Boree Creek used in Jacobs (2017) (Reference 4) and the present study, was provided by DPIE which was originally captured and processed by LPI in February 2014. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of highly varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ±0.15 m for clear terrain. The horizontal accuracy of the data is 0.8 m at 95% confidence interval (CI), while the vertical accuracy is 0.3 m at 95% CI. A digital elevation model was produced by sampling the LiDAR data to produce a 4 m × 4 m grid. This cell size provides an adequate level of precision for the representation of flood behaviour in the study area while managing model run times. The terrain topography is shown on Figure A4 based on the model grid used in the Flood Study.

3.3. Aerial Photography

Aerial photography was provided by Council. Boree Creek is covered by the 'Lockhart' tile, captured in 2008. 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, were obtained from the Flood Study (Reference 4). Detailed structure survey undertaken by TJ Hinchcliffe and Associates in 2015 as part of the Flood Study provided the following:

- Details including dimensions, shape, invert level, top of road level for 9 culverts (ID No. 22 to No. 31). Culvert details are presented in Table A 1A2 and shown on Figure A7. Note: culvert IDs are taken from the original structure survey provided in Appendix A of the Flood Study; and
- Zero marks of two flood depth indicators at Culvert No. 28 and Culvert No. 31 were reduced to AHD.

Note: the major railway culvert (large box culverts, dimensions 6 cells, each 3.36 m high x 3.40 m wide, with a total span of approximately 20.4 m) was modelled as a bridge in the Flood Study due to its clearance above ground level and span, as this allowed it to be retained in the 2D model.

Table A 2: Key hydraulic structures in Boree Creek

ID	Location	Type	Width / Diameter (m)	Height (m)	Length (m)	No. barrels/ cells
22	Eades Street	Circular Pipe	0.375	NA	5.95	2
23	Railway embankment on the western side of the study area	Box Culvert	0.62	0.9	4.2	3
24	Boree Creek Road	Box Culvert	1.87	1.23	9.5	1
25	Boree Creek Road	Circular Pipe	0.6	NA	35.8	1
26	Located on the south-west side of the Boree Creek Road and Drummond Street intersection	Circular Pipe	0.6	NA	4.55	1
27	Railway embankment on the south-east side of the study area	Box Culvert*	3.40	3.36	20.4	6
28	Lockhart Boree Creek Road near Drummond Street	Box Culvert	1.85	1.25	9.3	4
29	Railway embankment on the south-east side of the study area	Circular Pipe	1.2	NA	9.0	3
30	Lockhart-Boree Creek Road, immediately downstream of culvert ID 29	Box Culvert	1.85	1.23	10.0	4
31	Boree Creek - Kywong Road	Box Culvert	2.42	0.9	7.9	3

* Modelled as bridge

3.5. Pit and Pipe Network

Local stormwater drainage is conveyed towards Boree Creek via a series of roadside table drains and culverts beneath driveways, shown on Figure A5, with a limited number of culverts beneath roads. The kerb and gutter system is incomplete and allows water to drain directly from roads into the adjacent table drains. Boree Creek 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);
- An 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 database 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 floor level estimates is provided in Table A 3 below.

Table A 3: Floor Level Database – Boree Creek

Property Type	No. Included in Damages Assessment
Residential	54
Non-Residential	13
Total	67

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 (ARR) 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 Floodplain Rick Management Study and Plan. 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 Boree Creek (Jacobs, 2017 Reference 4) was completed for Federation Council (Council) in accordance with the NSW Government's Flood Prone Land Policy. The Flood Study aimed to determine design flood behaviour in the area based on ARR 1987 methodologies and used an XP-RAFTS hydrologic model and a TUFLOW hydraulic model, with extents shown on Figure A6. The models were reviewed by WMAwater to determine the suitability for application in the Floodplain Risk Management Study and Plan (FRMS&P). The review found that the models were largely fit for use in the FRMS&P with only minor revisions, as described below, as well as an update to ARR 2019 methodologies (See Section 5.2).

4.1. Hydrologic Model Review

The Boree Creek catchment draining to Boree Creek village (including local overland runoff from the village itself) 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 4.2.6.1).

4.1.1. Model Extent

The Flood Study (Reference 4) developed an XP-RAFTS hydrologic model that covered the entirety of the Boree Creek catchment to the limit of the hydraulic model just downstream of town with an area of approximately 154 km^2, shown on Figure A6. The Boree Creek catchment boundary is located beyond the extent of available LiDAR data. In its place, the Flood Study (Reference 4) used Shuttle Radar Topographic Mission (SRTM) collected by NASA in February 2000, processed to produce a 1 arc second (30 m) digital surface model covering most of the earth's landmass. This data was provided by NSW DPIE (then OEH) and used to delineate the catchment and sub-catchment boundaries lying beyond the extent of the available LiDAR data, shown on Figure A6. The catchment boundary was reviewed in conjunction with the available topographic data confirming the boundary was appropriately represented.

4.1.2. Model Configuration

4.1.2.1. Sub-catchment Delineation

Both mainstream and overland flows are represented within the XP-RAFTS model, with a slight refinement of the sub-catchments within the village compared to the broader catchment. The sub-catchment delineation was reviewed and deemed appropriate for use in the FRMS&P. The sub-catchments in the village centre are relatively large for an urban area (at approx. 1.2 km^2), however this has not hampered assessment of flood mitigation options in the village as the majority of the flood risk is driven by mainstream flooding generated by the broader upstream catchment rather than overland flow. This flood behaviour is described further in the subsequent sections of this report.

4.1.2.2. Sub-catchment Slope

The Flood Study used the aforementioned LiDAR and SRTM data to estimate the vectored slope of each sub-catchment. Review of the slope calculations indicated that the slopes were generally assigned appropriately, with the exception of sub-catchments No. 1 and 2 which were assigned slightly higher slopes than calculated by WMAwater. The sensitivity of peak flood levels to the changes in slopes within the hydrologic model were found to not be significant enough to warrant changing the hydrologic model. The calculated slopes are considered to be conservative and were adopted for use in the FRMS&P.

4.1.2.3. Roughness

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. A Manning's 'n' value of 0.04 was assigned for channel areas and cleared agricultural land, while a roughness of 0.08 was assigned to areas with heavier vegetation, e.g. in sub-catchment No. 18, which covers the wooded area in town to the east of Sandigo Road. The assigned parameters, listed in Table A 4are within the acceptable range typically used for these surface types. While 0.04 is considered on the higher side for cleared land, in this case it is considered appropriate to account for crops, long grasses, and variable tilling practices associated with agricultural activities. The Flood Study assigned a nominal impervious fraction of 5% across the catchment. While this may underestimate the proportion of paved surfaces in the village centre, the nominal impervious fractions is considered appropriate given the limited size of the village and associated proportion of hard surfaces compared to the greater catchment.

Table A 4: XP-RAFTS Parameters

Sub-catchment No.	Area (ha)	Slope (%)	Impervious fraction (%)	Hydraulic Roughness (Manning's 'n' value)
1	1771.5	2.5	5	0.045
2	1179.3	2.7	5	0.040
3	1279.6	0.7	5	0.040
4	1240.8	0.7	5	0.040
5	627.0	0.7	5	0.040
6	138.2	0.3	5	0.040
7	1237.1	0.6	5	0.040
8	812.0	0.8	5	0.040
9	353.6	0.9	5	0.040
10	547.7	0.7	5	0.040
11	1130.5	0.8	5	0.040
12	305.0	0.6	5	0.040
13	876.9	0.6	5	0.040
14	1268.4	0.8	5	0.040
15	230.2	1.0	5	0.040
16	239.7	0.6	5	0.040
17	188.1	1.2	5	0.050

Sub-catchment No.	Area (ha)	Slope (%)	Impervious fraction (%)	Hydraulic Roughness (Manning's 'n' value)
18	89.3	0.4	5	0.080
19	710.5	0.7	5	0.040
20	42.6	0.2	5	0.060
21	125.1	0.8	5	0.040
22	124.2	1.5	5	0.040
23	153.1	0.2	5	0.070
24	148.7	1.1	5	0.040
25	615.6	0.5	5	0.040

4.1.3. Losses

The hydrologic model uses 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.

The Flood Study (Reference 4) applied an initial loss of 15 mm for design flood estimation of events up to and including the 10% AEP event, and an initial loss of 10 mm was applied for events between 5% and 0.2% AEP. An initial loss of 0 mm was adopted for the PMP event. A continuing loss of 2.5 mm/hr was adopted for all design events up to and including the 0.2% AEP event, and a continuing loss of 1 mm/hr was adopted for the PMP event. These losses were based on the same losses adopted in the Lockhart Flood Study Report (Reference 10).

While these losses were applied in accordance with guidance available at the time, the design losses applied in the FRMS&P are based on guidance from ARR 2019. These are discussed further in Section 5.5.

4.2. Hydraulic Model (TUFLOW) Review

A combined 1D-2D TUFLOW model was developed by Jacobs (Reference 4) for Boree Creek representing both mainstream and overland flooding. 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).

4.2.1. Hydraulic Model Extent

Boree Creek 1D/2D TUFLOW model domain covers an area of 12.4 km^2, centred on Boree Creek village and extending approximately 2 km northeast (upstream) and 2 km southwest (downstream), capturing approximately 7 km of Boree Creek itself. The hydraulic model boundary is sufficiently broad to allow for the full width of the PMF.

4.2.2. 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 4 m grid (See Section 3.2). The grid size was selected to appropriately represent the flood behaviour whilst balancing model run times.

4.2.3. Bridges and Culverts

Culverts were modelled as 1D elements with details obtained from the topographic survey by TJ Hinchcliffe and Associates in 2015 (refer to Section 3.4). Blockage factors were applied to pipes that were partially buried at the time of the survey. Bridge structures were modelled using a 2D layered flow constriction. 2D layered flow constriction elements will allow the different layers of the bridge (below deck, deck, railings and above railings) to be modelled so that the losses associated with different flow conditions can be more accurately simulated. It is noted that the limited underground stormwater network in Boree Creek (along Eades Street) has not been included in the model, rather only cross-drainage structures pertinent to flooding have been included. This is a common approach, particularly as stormwater pipe capacities are generally exceeded in events greater than the 20% AEP event, and details about stormwater pit and pipe networks are often unavailable. The hydraulic structure modelling approach has been maintained for the FRMS&P.

4.2.4. Buildings

In the Flood Study, buildings were 'nulled out' or removed 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. Following review against current aerial imagery, the same building layer used in the Flood Study was utilised in this FRMS&P.

4.2.5. Roughness Parameters

The Flood Study (Reference 4) used aerial photography to identify various land use areas and assign an appropriate Manning's 'n' value based on industry guidelines. The selected parameters are listed in Table A 5. The adopted roughness parameters are also shown on Figure A7. The Manning's 'n' values assigned to open rural area and 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.

Table A 5: TUFLOW model hydraulic roughness values

Land use type	Manning's 'n' value
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
Creek	0.045

4.2.6. Boundary Conditions

4.2.6.1. Model Inflows

The TUFLOW model simulated both mainstream and overland flood behaviour within the study area. Total catchment flows draining to the upstream of the TUFLOW model were applied at the upstream boundary. Runoff generated from local catchments within the TUFLOW model extent were applied directly to the main creek or applied over the sub-catchment where areas of overland flow are of concern. The inflow boundaries are shown on Figure A5.

4.2.6.2. Downstream Boundary

The TUFLOW model downstream boundary is located approximately 2 km downstream of Boree Creek village, to eliminate the potential influence of the boundary conditions on flood behaviour in the study area. The hydraulic model boundary conditions were adopted without modification in this FRMS&P.

5. DESIGN FLOOD MODELLING

5.1. Overview

The hydrologic and hydraulic models developed as part of the Flood Study (Reference 4) have been adopted for use in design flood modelling with minor amendments and version updates as described in Section 4. Key parameters such as topography, slope and Manning's "n" remain unchanged from the Flood Study (Reference 4). All other parameters, data and assumptions that form the basis of the design flood modelling are based on inputs from ARR 2019 and are detailed below.

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.

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 IFD values for the catchment centroid are presented in Table A 6 and the Data Hub metadata is presented in Attachment 1.

Table A 6: Average design rainfall depths (mm) (selected durations) at the centroid of Boree Creek catchment (Longitude 146.688, Latitude -35.063)

Duration (min)	AEP							
	20%	0.2EY	10%	5%	2%	1%	0.5%	0.2%
60	25.5	26	30.5	35.6	42.5	48	53.8	61.5
90	28.8	29.4	34.5	40.1	47.9	54	60.5	69.1
120	31.3	31.9	37.4	43.5	51.8	58.3	65.4	74.7
180	35	35.7	41.7	48.4	57.5	64.7	72.6	83
270	39	39.8	46.4	53.7	63.7	71.6	80.4	91.9
360	42	42.9	50	57.8	68.5	76.9	86.4	98.8
540	46.7	47.7	55.4	64.1	75.9	85.1	95.7	109

5.3.1. ARR 2019 Spatially Varied IFDs

ARR 2019 (Reference 2) recommends the application of a non-uniform spatial pattern for catchments greater than 20 km^2 to account for the spatial variability of rainfall across the catchment area. While the Boree Creek catchment covers an area of approximately 154 km^2, analysis of the 1% AEP critical duration IFD (6 hours, determined through analysis described in Section 5.5) indicated that the variability of the IFDs across the catchment was limited – ranging from 75.2 mm at the western part of the catchment to 79.5 mm to the east, with depths over 60% of the catchment within 76.5 mm to 77.5 mm. This low variability indicates that the total rainfall depth is appropriately represented by the IFD depth at the catchment centroid (76.9 mm in the 1% AEP, 6 hour storm duration, consistent with the area-weighted catchment average of 76.8 mm), and as such spatially varying IFDs have not been applied.

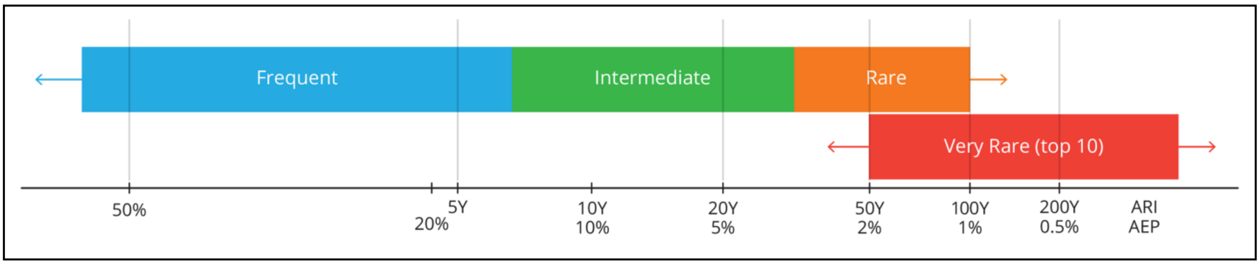
5.4. ARR 2019 Temporal Patterns

Temporal patterns describe how rain falls over time and form a component of storm hydrograph estimation. Previously, with the 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 are 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 ARR guidelines have adopted a regionally specific ensemble of ten different temporal patterns for a particular design rainfall event. Given the rainfall-runoff response is 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 2016 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 Boree Creek 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 A1 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. At the time of the model update, the "very rare" bin had been unavailable and was not used in this flood study; instead, temporal patterns from the "rare" bin were applied for the 0.5% and 0.2% AEP events. There are ten temporal patterns for each AEP/duration in ARR 2019 that have been utilised in this study for the 20% AEP event to 0.2% AEP events.

Diagram A1: 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 centroid is presented in Attachment 1. The method employed to estimate the PMP utilises a single temporal pattern (Reference 6), as is consistent with ARR 2019.

5.4.1. ARR 2019 Areal Temporal Patterns

ARR 2019 recommends that areal temporal patterns (ATP) should be considered in catchments larger than 75 km^2 to account for the spatial smoothing of rainfall that occurs over larger catchments. Boree Creek catchment covers an area of approximately 154 km^2, putting it above the threshold at which ATPs should be considered. ATPs are available for storm durations including and greater than 12 hours, however the hydrologic assessment found that the critical durations for design flood events in Boree Creek were 9 hours or less (refer to Section 5.5) leading to the adoption of standard temporal patterns for design flood estimation rather than ATPs (as they are not available for sub 12 hour durations).

5.5. Critical Duration Assessment

To determine the critical duration (the duration of rainfall over the catchment that will result in the greatest depth of flooding), ARR 2019 recommends than 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 4.5 hour, 6 hour and 9 hour durations found to result in the highest mean peak flows across the floodplain. Using the TUFLOW results, a representative temporal pattern is 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) at the Boree Creek village. Further description of the assessment method and box plots for each AEP duration are presented in Attachment 1. The results of the critical duration assessment are provided in Table A 7.

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

Event	Critical Duration (min)	Adopted Temporal Pattern	IFD (mm)	ARF	Initial Loss (mm)	Continuing Loss (mm/hr)	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet
20% AEP	540	TP3: 4069	47.7	0.9645	13.9	0.16	137
10% AEP	540	TP6: 4063	55.4	0.9611	13.1	0.16	191
5% AEP	540	TP6: 4063	64.1	0.9666	13.4	0.16	233
2% AEP	360	TP7: 4025	68.5	0.9403	10.2	0.16	306
1% AEP	360	TP7: 4025	76.9	0.9350	6.7	0.16	353
0.5% AEP	360	TP7: 4025	86.4	0.9297	6.7	0.16	408
0.2% AEP	360	TP7: 4025	98.8	0.9226	6.7	0.16	481
PMF*	120	Not applicable			0.0	1.0	4026

*The probable maximum precipitation (PMP) uses a single temporal pattern (Reference 6). For this event, peak flows at each of the key sub-catchments were analysed to determine the critical duration (duration which produces the highest peak flow at the outlet). At all the locations of interest, the 120 minute (2 hour) storm was the critical and was adopted for the PMF design flood event. This is consistent with the Flood Study (Reference 4).

5.6. Rainfall Losses

Design rainfall losses were obtained from the ARR 2019 data hub (http://data.arr-software.org/). Based on the recent guideline developed by NSW DPIE (Reference 12), 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 Boree Creek catchment, the continuing loss is therefore taken as: 0.4 x 0.4 mm/hr = 0.16 mm/hr, and used in conjunction with probability neutral burst initial loss values (presented in Table A 8). It is noted that the values applied in the 1% AEP event were also used for rarer events (0.5% AEP and 0.2% AEP). Note that XP-RAFTS uses linear interpolation to estimate the probability neutral burst initial loss of durations other than the presented ones in Table A 8.

Table A 8: Probability Neutral Burst Initial Loss at the Catchment Centroid (mm)

Duration	AEP				
(min)	20%	10%	5%	2%	1%
60	9.4	8.8	9.3	9.1	7.6
90	9.6	9.0	9.3	8.7	7.9
120	10.4	9.6	10.0	9.3	8.4
180	10.7	9.8	10.7	9.8	7.2
360	12.9	12.0	12.5	10.2	6.7
720	14.9	14.2	14.3	12.3	8.8

5.7. 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 is extracted via the ARR Data Hub (Reference 2), and applied to each sub-catchment. An ARF of 0.935 is applied for the 1% AEP event (6 hour duration). The full suite of ARFs across all design events and durations are taken directly from the Data Hub.

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 these events in Figure A8 to Figure A15, and are described below.

6.1.1. Design Peak Flows

The peak flows at the catchment outlet for the full suite of design events are provided in Table A 9. The location of the outlet is shown on Figure A5, approximately 1.6 k m west (downstream) of Lawrence Street. The critical duration that corresponds to each event is provided in brackets. For comparison, the peak flow derived from the Flood Study (Reference 4), based on ARR 1987, are provided in the final column.

Table A 9: Design peak discharges at downstream model boundary (m^3/s)

Design Event	FRMS&P (ARR 2019) (Critical duration)	Flood Study (Reference 4) (ARR 1987) (Critical duration)
20% AEP	137 (9 hr)	71 (20% AEP 72 hr)
10% AEP	191 (9 hr)	96 (72 hr)
5% AEP	233 (9 hr)	155 (36 hr)
2% AEP	306 (6 hr)	212 (6 hr)
1% AEP	353 (6 hr)	272 (6 hr)
0.5% AEP	408 (6 hr)	346 (6 hr)
0.2% AEP	481 (6 hr)	474 (6 hr)
PMF	4026 (2 hr)	4178 (2 hr)

For events larger than the 2% AEP, the critical duration remains consistent between the two methodologies; while there is a significant shift for events smaller than this. At Boree Creek, for the more frequent, longer duration rainfall events, the IFD showed a greater reduction from that applied in the ARR 1987 method and this would impact on determining the critical duration for these events.

6.1.2. Peak Flood Depths and Levels

Out-of-bank flooding occurs in the Boree Creek village in events as frequent as the 20% AEP event (Figure A8), with flow breaking out of the creek upstream of the railway and flowing westwards along Richmond Street re-joining the main channel downstream of town. In the 10% and 5% AEP events, the overbank floodplain widens significantly, with the majority of Boree Creek village and surrounding roads subject to inundation. It is noted that parts of the railway embankment are overtopped in the 5% AEP event, particularly in areas adjacent to the main creek crossing.

The majority of developed areas in Boree Creek between Eades Street and Namoi Street are subject to significant inundation (greater than 1 m depths) in the 1% AEP event and rarer. In these events all access roads to Boree Creek are subject to flooding, and the railway embankment is overtopped by approximately 1.4 m. Table A 10 provides peak flood levels at key road crossings in the Boree Creek Study Area, shown on Figure A7. Levels shown in red indicate the road is overtopped in that event.

Table A 10: Modelled peak flood levels at major waterway crossings

Location (Structure ID)*	Waterway Crossing	Soffit Level (m AHD)	Deck Level (m AHD)	Peak Flood Level (m AHD)				
				20% AEP	5%AEP	1%AEP	0.5%AEP	PMF
31	**Boree Creek – Kywong Road**	147.31	147.68	148.65	149.36	149.55	149.75	151.28
27	**Railway Bridge**	147.56	148.27	146.27	147.37	147.58	147.89	149.66
29	**Railway Culvert (3 pipes)**	147.04	148.56	147.63	148.14	148.32	148.61	149.95
28	**Drummond Road**	145.00	145.30	146.24	147.21	147.37	147.68	149.62
25	**Urana-Boree Creek Road**	143.85	148.95	145.23	146.19	146.35	146.60	148.13

*Structure IDs taken from TJ Hinchcliffe & Associates survey, Appendix B of Reference 4. Red text indicates the road/railway is overtopped.

6.1.3. Comparison to Flood Study

A comparison between the 1% AEP peak flood levels is provided on Figure A16. In general, with the various model updates discussed in Section 4 and application of ARR 2019 guidelines, the 1% AEP peak flood levels are on average 0.2 m higher than the results from the Flood Study (Reference 4), which used ARR 1987 methodologies. The main reason for the difference in levels is that, even though the prescribed rainfall depths from ARR 2019 are *lower* than in ARR 1987, the initial and continuing losses are significantly lower than those from ARR 1987, meaning that less rainfall is assumed to infiltrate into the ground, and a greater proportion of the design rainfall is converted into runoff.

6.2. 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 A 11, 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 A2.

Table A 11: 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 A2: Hazard Classifications

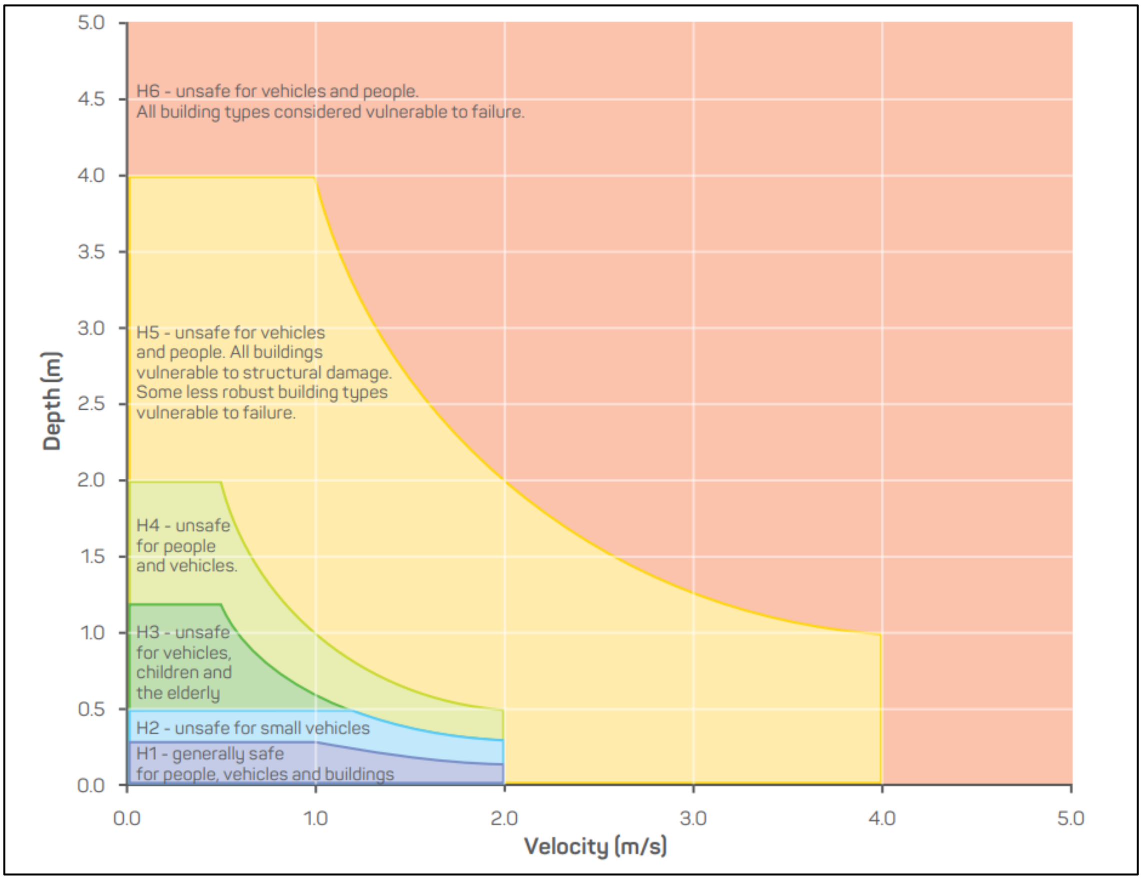


Figure A17 to Figure A19 present the hazard classifications based on the H1-H6 delineations for the 5% AEP, 1% AEP and PMF events respectively. In the 5% AEP event, most areas within the developed area of Boree Creek are classified as H1 “generally safe for people, vehicles and buildings” due to the shallow depth of flooding, while areas of higher hazard generally align with the main channel. Richmond Street becomes dangerous in the 5% AEP event, with peak velocities of over 1.2 m/s occurring at the western end of the road around Eades Street, resulting in a classification of H4.

In the 1% AEP event, areas located on both sides of the Richmond Street up to Clarence Street are categorised as H3, indicating the flood behaviour makes them unsafe for vehicles, children and the elderly. Richmond Street becomes classified as H5 in the 1% AEP owing to even higher velocities and depths, resulting in it becoming unsafe for vehicles and people.

Significant flood depths in the PMF event lead to the majority of Boree Creek township being categorised as H5 (Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure). Richmond Street becomes classified as H6 in the PMF event.

6.3. 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 A 12.

Table A 12: 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.

Draft hydraulic categories were defined in the Flood Study (Reference 4) and reviewed for suitability under current conditions, acknowledging the change in design flood behaviour occurring as a result of the update to ARR 2019 methodologies. The definition of the floodway was reviewed using the Howells et al. (Reference 8) methodology, starting with the depth and velocity criteria adopted by Jacobs.

These parameters were confirmed iteratively through encroachment analysis, in which areas defined as 'flood storage' were given a high Manning's 'n' (to simulate a loss of conveyance capacity), and the subsequent impact on flood levels examined. 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 adopted for this FRMS&P are provided in Table A 13. 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 (for example as an artefact of the modelling).

Table A 13: Hydraulic Category Definition Parameters

Category	FRMS&P Hydraulic Categorisation Parameters
Floodway	$V \times D$ > 0.2 m^2/s and V > 0.2 m/s, or V > 1.0 m/s and D > 0 m
Flood Storage	Areas outside floodway where D > 0.5 m (Consistent with Flood Study)
Flood Fringe	Areas outside floodway where D < 0.5 m (Consistent with Flood Study)

The resulting hydraulic categorisation for the 5% AEP, 1% AEP and PMF events are shown on Figure A20 to Figure A22, respectively. The Richmond Street flow path is clearly shown as floodway in the 5% and 1% AEP event (though are indistinguishable in the PMF, in which the majority of the floodplain is classified as floodway when using the above parameters, which were based on the 1% AEP event). The results also clearly indicate the obstruction caused by the railway embankment, which splits the floodway between the two hydraulic structures to the east of the main channel.

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 the Boree Creek catchment, 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 Boree Creek. 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.

Retarding basins and levees were found to not be appropriate for Boree Creek, other types of measures were considered and are discussed in the following sections. Table A 14 provides a summary of the flood modifications options considered for Boree Creek.

Table A 14: Flood modification options considered for Boree Creek

ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMBC-01: Railway and Drummond Street Culvert Upgrades	Doubling capacity of the two existing culverts on the eastern bank of Boree Creek	Refer to Figure A23 (5% AEP) and Figure A24 (1% AEP). The increased culvert capacity allows for greater conveyance in smaller events, resulting in only marginal reductions in peak floods level (less than 0.05m in both events) over a broad area upstream. Results in localised increase in flood levels downstream of Drummond Street.	No, does not materially change flood risk, high construction costs
FMBC-02: Western Culvert Upgrades	Doubling capacity of the five existing culverts	Refer to Figure A25 (5% AEP) and Figure A26 (1% AEP) Whilst the results show that the option does not reduce peak flood levels in either event, as the scale of mainstream flooding in Boree Creek far exceeds the culvert capacities, the increased capacity did assist in draining the shallow overland flow caused by local rainfall over the town. Consideration should also be given to the installation of flap gate to prevent backflow.	**Yes,** as a measure to manage local drainage only (Section 7.1.1)
FMBC-03: Boree Creek - Kywong Road Upgrade	Doubling culvert capacity in the Boree Creek - Kywong Road embankment	Refer to Figure A27 (5% AEP) and Figure A28 (1% AEP). Only a marginal reduction in peak levels of up to <0.05m in both modelled events, however may assist in local drainage.	**Yes,** as a measure to manage local drainage and potential evacuation only (Section 7.1.2)
FMBC-04: Major channel augmentation and railway bridge expansion	Expanding the railway bridge, and major channel modification works on Boree Creek.	Refer to Figure A29 (5% AEP) and Figure A30 (1% AEP). This option was to test the hydraulic benefits of bridge and channel augmentation. Upstream of the railway line, would be no longer flooded during the 5% AEP event, and peak flood levels in surrounding areas reduced by up to 0.4 m. In the 1% AEP event, reduce flood levels in the Boree Creek township by up to 0.3 m, both events result in peak flood levels downstream of the railway increase by up to 0.2 m, impacting on properties south of Urana-Boree Creek Road, particularly on Lawrence Street.	**Yes,** to be assessed further if modification or removal of the railway line is considered in the future (Section 7.1.3)
FMBC-05: Relocation of railway terminus east of Boree Creek	Relocating the grain silos to the eastern side of Boree Creek, near the intersection of Lockhart-Boree Creek Road	Refer to Figure A31(5% AEP) and Figure A32 (1% AEP). In both events, widespread reductions in flood levels on the upstream (northern) side of the embankment, and peak flood level increases downstream. In a 1% AEP event, peak flood levels are reduced by approximately 0.2 m, while in the 5% AEP, parts of town north of Clarence Street and Namoi Street would be no longer flooded.	
FMBC-06: Remove disused part of railway infrastructure	Remove part of railway infrastructure and create a drainage path to Boree Creek	Refer to Figure A33 (5% AEP) and Figure A34(1% AEP). Localised benefits, though one property no longer flooded in 5% AEP and two in the 1% AEP. Newly flooded area downstream through sporting facilities. This option demonstrates that broader works are required to the railway line to achieve significant benefit.	

ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMBC-07: Vegetation management	Manning's 'n' values modified by +/- 20% to represent changing vegetation cover	Refer to Figure A34 (1% AEP). Limited impacts on flood behaviour, therefore not recommended as flood management measure. However, ongoing Council works for environmental / weed management should be maintained.	No, does not materially reduce flood risk. There are opportunities through other Council programs (such as environmental/weed management) to maintain vegetation levels.
FMBC-08: Downstream levee bank augmentation	A levee bank located along the southern bank of Boree Creek has the potential to constrain flows downstream of town.	Observed flood behaviour has identified this levee as a potential constraint to flows passing through Boree Creek. The levee is currently overtopped in a 0.2EY event. Depths in excess of 0.5m flow over the levee during the 10% AEP event. It is concluded that the levee is unlikely to significantly influence flood behaviour at the 1% AEP event but may be holding back flood water and impacting parts of Boree Creek in less frequent events.	No, not as a floodplain management option but may warrant further investigation at a local scale to improve flood behaviour in frequent events.

7.1.1. FMBC-02: Boree Creek Western Culvert Upgrades

7.1.1.1. Option Description

This option investigates the impact of increasing the capacity of the five culverts (ID 22, 23, 24, 25 and 26) at the western end of Richmond Street, with a view to improve the conveyance of flood waters through the railway and road embankments and alleviate flooding within town. Option FM02 was modelled by doubling the number of culverts (ID 22, 23, 24, 25 and 26) summarised in Table A 15 and shown in Figure A7.

Table A 15: Option FMBC-02 Summary of the original and the tested culvert arrangement

Culvert ID	Type	Original Configuration	Tested Configuration
22 (Eades St)	Circular	2 x ϕ0.375 m	4 x ϕ0.375 m
23 (Railway)	Box	3 cells × 0.62 m (W) × 0.9 m (H)	6 cells × 0.62 m (W) × 0.9 m (H)
24 Boree Ck Rd	Box	1 cell x 1.87 m (W) x 1.23 m (H)	2 cell x 1.87 m (W) x 1.23 m (H)
25 Boree Ck Rd	Circular	1 x ϕ0.6 m	2 x ϕ0.6 m
26 Boree Ck Rd	Circular	1 x ϕ0.6 m	2 x ϕ0.6 m

An additional option was considered combining FMBC-01 and FMBC-02 to determine the cumulative benefit of these options. It was determined that FMBC-02 benefits the local drainage system, while the benefits being sought with FMBC-01 are better achieved by more significant works as described for FMBC-04, FMBC-05 and FMBC-06.

7.1.1.2. Option Assessment

Modelled Flood Behaviour

The change in peak flood levels in the 5% and 1% AEP events are shown on Figure A25 and Figure A26. The results show that the option does not reduce peak flood levels in either event, as the scale of mainstream flooding in Boree Creek far exceeds the culvert capacities, even when doubled. Further analysis was undertaken to investigate if the option is effective in a more frequent event (20% AEP). The increased culvert capacity did assist in draining the shallow overland flow caused by local rainfall over the town, however once the mainstream flow exceeds the capacity of the Boree Creek channel, the flow (even in a 20% AEP event) exceeds the culvert capacity.

Costs and economic viability

Costs for upgrading culverts stem from excavation of a section of Urana Boree Creek road, installation of the culverts, resurfacing of the sections and ongoing maintenance. These are likely to be far greater than the reduction in flood damages (considering the economic benefits of the works), and therefore the option is unlikely to be economically viable from a flood risk management perspective.

Social and environmental impacts

There would be short-term disruption during the construction period, and standard sediment and erosion control measures would be required during construction, however no ongoing social or environmental impacts are anticipated.

Financial viability

The option is unlikely to be eligible for grant funding due the negligible impacts on flood behaviour. However, there may be benefit in upgrading these culverts (ID 22, 23, 24, 25 and 26) for the purpose of local stormwater drainage. Further investigation outside of this FRMS&P would be needed to ascertain the value of this to residents of Boree Creek or motorists passing through, to determine if the capital costs would be justified, and if so, further analysis would be required to optimise the proposed pipe size and configuration depending on the design requirements of the pipes. This is particularly relevant if other options relating to the railway embankment are considered further. Council should consider other funding opportunities for this work.

7.1.1.3. Recommendation

FMBC-02: Boree Creek Western Culvert Upgrades	
☒	Option FMBC-02 is not recommended as a flood risk management measure due to the negligible impacts on mainstream flood behaviour
☑	The option may provide benefits to local stormwater drainage management and should be considered if other funding opportunities were to become available.

7.1.2. FMBC-03: Boree Creek – Kywong Road Culvert Upgrade

7.1.2.1. Option Description

Richmond Street becomes Boree Creek - Kywong Road leaving town to the northeast. The road has been identified as a potential alternate evacuation route during flood events, as not all residents choose to access the primary route, Lockhart Road, in the south.

The road embankment (~ 1 m height) has been identified in the Flood Study as causing an obstruction to flow, causing flood waters to back up on the northern (upstream) side of the road embankment and eventually overtop the road, currently limiting its use as an evacuation road. The conveyance though the embankment is currently controlled by one culvert structure (ID 31): 3 box culverts (7.9 m × 2.42 × 0.9 m). This option investigates increasing the capacity of the existing box culverts (ID 31) (specifically doubling the capacity in the results presented below), with the aim to increase conveyance through the crossing, reducing the extent of water ponding upstream and assist in reducing over-road inundation.

7.1.2.2. Option Assessment

Modelled Flood Behaviour

The change in peak flood levels in the 5% and 1% AEP events are shown on Figure A27 and Figure A28, and indicate that in either event, flood levels are not changed by more than 0.01 m across the study area. It is noted that, as shown in Table A 10, at this location the road would be overtopped by 1.0 m in the 20% AEP event.

Costs and economic viability

Costs for upgrading culverts stem from excavation of a section of road, installation of the culverts, resurfacing of the sections and ongoing maintenance. Economic benefits of the works shown to be negligible (a reduction in AAD of $100), and therefore the option is not considered to be economically viable from a mainstream flood risk management perspective (noting, however, that damages assessment does not consider benefits from improved evacuation, as it largely focuses on tangible property damages).

Social and environmental impacts

There would be short-term disruption during the construction period, and standard sediment and erosion control measures would be required during construction, however no ongoing negative social or environmental impacts are anticipated. The upgrades would provide some minor benefits to the ability to evacuate, but only for the minor frequent events.

Financial viability

The current modelled option is unlikely to be eligible for grant funding due the negligible impacts on flood behaviour. However, a feasibility study considering the entire length of road, which includes a number of creek crossings outside of the Boree Creek catchment, may be warranted to understand the potential of formalising the road as an alternate evacuation route. Council should consider other funding opportunities for this subsequent work.

7.1.2.3. Recommendation

FMBC-03: Boree Creek – Kywong Road Culvert Upgrades

☒	Option FMBC-03 is not recommended as a flood risk management measure due to the negligible impacts on flood behaviour.
☑	Undertake a feasibility study of formalising the Boree Creek – Kywong Road as an evacuation route for the entire length of road. This would include modifications of all existing creek crossings, as well as the Boree Creek crossing.
☑	In the absence of road upgrades, consideration of additional signage to improve driver safety (see Section 7.5.1 of the main report)

7.1.3. FMBC-04 / 05 / 06: Railway Line Augmentation

7.1.3.1. Option Description

The railway line has been identified as a significant obstruction to floodwaters moving through the township of Boree Creek. To assess the possible benefits that could be derived from changes to this obstruction, a number of options were assessed involving augmentation of the railway line. These included complete removal of the line and associated infrastructure, significant creek and channel works and partial removal of the line. The three options presented in detail below aim to identify the influence of the railway line on flood behaviour within Boree Creek and to identify the scale of works required to provide improved benefits to flood risk.

FMBC-04 expands the existing bridge section from approximately 20 m wide to 80 m wide, and undertaking major earthworks in the Boree Creek channel, reducing the bed level by approximately 2 m, and expanding the bed width to 50 m. The channel works were modelled for a length of ~500 m, 300 m upstream of the railway, and a further 200 m downstream, tying into the natural ground levels, with a total excavation in the order of 48,000 m^3. FMBC-05 considers relocating the grain silos to the eastern side of Boree Creek, near the intersection of Lockhart-Boree Creek Road, such that the railway need not cross the creek (if it no longer travels further west). This option includes the removal of a 600m stretch of the railway embankment, centred around the creek crossing and assumes that the remainder of the embankment (to the west) remains in place. FMBC-06 removes part of railway infrastructure and creates a drainage path to Boree Creek.

7.1.3.2. Option Assessment

Modelled Impacts

FMBC-04

The effect of this option on peak flood levels is shown on Figure A29 and Figure A30 for the 5% AEP and 1% AEP events, respectively. Upstream of the railway line, the area northwest of Boree Creek township (particularly properties located on both sides of Namoi Street) would be no longer flooded (12 properties) during the 5% AEP event, and peak flood levels in surrounding areas reduced by up to 0.4 m. With the significant increase to channel capacity and expanded bridge span, peak flood levels downstream of the railway increase by up to 0.2 m in a 5% AEP event, impacting on properties south of Urana-Boree Creek Road, particularly on Lawrence Street. Figure A30 shows that in the 1% AEP event, Option FMBC-04 would reduce flood levels in the Boree Creek township by up to 0.3 m, with 10 properties no longer flooded in this event. As in the 5% AEP event, peak flood levels downstream (south) of the railway are increased by up to 0.2 m, exacerbating flood risk to properties south of Urana-Boree Creek Road and Lawrence Street.

FMBC-05

The effect of this option on peak flood levels is shown on Figure A31 and Figure A32 for the 5% AEP event and 1% AEP event, respectively. In both events, removal of the embankment where it crosses the creek significantly affects flood behaviour, with widespread reductions in flood levels on the upstream (northern) side of the embankment, and peak flood level increases downstream as the conveyance capacity is increased across the former obstruction. This option represents less significant works than FMBC-04 and while still positive the benefits are slightly less than with FMBC-04. In a 1% AEP event, peak flood levels are reduced by approximately 0.2 m, and four properties no longer flooded in this event while in the 5% AEP, parts of town north of Clarence Street and Namoi Street would be no longer flooded. In the 1% AEP event however, peak flood level increases downstream of the embankment extend to the downstream boundary of the model. Further analysis would be needed to determine the change in peak flows and flood behaviour downstream of Boree Creek.

FMBC-06

The effect of this option on peak flood levels is shown on Figure A33 and Figure A34 for the 5% AEP event and 1% AEP event respectively. In both events, removal of a portion of the embankment locally affects flood behaviour, with reductions in flood levels on the immediate upstream (northern) side of the embankment, and peak flood level increases downstream as the conveyance capacity is increased across the former obstruction. In a 5% AEP event, peak flood levels are locally reduced by approximately 0.1 m, while in the 1% AEP, there is sightly lesser reduction across a larger area extending to the east. In the 1% AEP event however, peak flood level increases and inundation of areas previously not flooded in this event occur downstream of the embankment. One property no longer flooded in the 5% AEP and two in the 1% AEP.

Other Options Considered

A number of other scenarios were preliminarily assessed including complete removal of the line and associated infrastructure. This option was found to result in similar benefits and impacts to that shown for FMBC-05 and when considering the additional costs has not been considered further. Other options considered and discounted include a range of railway bridge sizes, combinations of bridge sizes, creek widening and embankment removal scenarios coupled with various culvert upgrades. It was determined that the likely most effective way forward is for a portion of the railway embankment to be removed, similar to FMBC-05.

Costs and economic viability

- ***FMBC-04*** Unlikely that such a large-scale excavation would be feasible, either in terms of costs or environmental impacts – but has been modelled to indicate the scale of works that may be required to achieve a reduction in flood risk.
- ***FMBC-05*** Optimisation of extent of earthworks to balance flood mitigation benefits with costs of the works; potential savings on bridge and rail maintenance with removal of the existing structures (minimal). Cost would also stem from the relocation of the grain facility and associated trackwork. This option was shown to reduce AAD by 40%.

- ***FMBC-06*** Of the three options considered the relative costs would be lower, however the smaller scale of works are not shown to provide the same level of reduced flood risk as the larger scale options.

Social and environmental impacts

- ***FMBC-04*** The works require the removal of a number of trees (potentially affecting habitats) and riparian vegetation critical for bank stability. Removal of this vegetation would mean the newly formed creek banks would either require engineered reinforcement, or batters flat enough to resist slumping. Residents adversely affected by this option (i.e. on the downstream side of the railway) would need to be compensated, potentially through acquisition of their property (similar to a voluntary purchase scheme), as it is unlikely that house raising will be suitable given the floodway categorisation and high hazard at these sites. Voluntary purchase for such properties is discussed below.
- ***FMBC-05*** Identification of current silo site landholders, and owners of potential silo relocation sites; Identification of key stakeholders, affected organisations and approving agencies would be needed (Graincorp, John Holland (responsible for the railway line) silo users and local residents); Potential impact on cultural and heritage values; Current and projected usage of railway between Lockhart and Boree Creek, and Boree Creek and Urana; Removal of the silos would create open space that could be used for other purposes (e.g. with recreational, environmental or heritage value).
- ***FMBC-06*** The smaller scale of works proposed means that the impacts raised above would be lessened, this includes downstream landholders as the majority of impacted areas are open space.

Financial viability

The scale of work required to reduce flooding is likely to be significant with significant associated costs, a number of stakeholders may be responsible for different aspects of the overall work. Some aspects may be eligible for grant funding. A feasibility study is required to determine the exact scale of works required to achieve the most cost effective and acceptable outcome. The average annual damages under existing conditions is just under $725,000, a works combination reducing damages by 40% (as is the case for FMBC-05) at a cost of say $2M would achieve a benefit cost ratio of 1.4.

7.1.3.3. Recommendation

FMBC-04/05/06: Railway line augmentation	
☒	Option FMBC-04/05/06 is not recommended as a flood risk management measure due to the negligible impacts on flood behaviour.
☑	Further optioneering and feasibility assessment should be undertaken in the future, including engagement with the line owners and operators to determine if significant changes, or complete decommissioning of the line, is foreseen or there is an appetite for changes to the line.

7.2. Response Modification Measures

7.2.1. RMBC-01: Formal Evacuation Location

Currently, there is no formal location for sheltering following evacuation due to flooding for residents of Boree Creek. In previous flood events the primary location has been the school however, relocation to an alternative site was required during the March 2012 event. As part of the FRMS&P it was agreed to identify potential locations outside of the PMF extent which could be used to site a formal evacuation shelter. The floodplain of Boree Creek is broad, generally extending over 1 km either side of the main channel alignment. A review of the key road routes available from Darling Street to beyond the PMF extent was undertaken, which showed the route travelling along Orara Street, north towards Sandigo Road (to the point shown with a green arrow below) provides the shortest route to flood free land, along a route with the highest flood immunity. It should be noted that this route is not flood-free, being inundated in events starting from the 10% AEP event. Parts of the road are also inundated by more than 300 mm (generally considered to be the maximum depth to be safely traversed by cars) for over 7 hours in a 1% AEP event and more than 14 hours in the PMF.

The option to use this location as a formal evacuation centre should be discussed with the local community. This process would need to consider the land tenure, whether a permanent structure is required, and if so, the maximum capacity required and the likely maximum time evacuees would be sheltered. It should also be identified whether the shelter would be used to accommodate pets and livestock. It will be necessary to understand the constraints of the evacuation route, and consider how and when triggers would be provided to the community to ensure their safe evacuation prior to the road being cut. Elements of an early warning trigger systems are recommended to be considered as part of a broader wholistic system for the catchment and are discussed in the main report.

7.2.1.1. Recommendation

RMBC-01: Formal evacuation shelter

☑ Engage with the local community regarding the formalisation of a shelter and further assess the feasibility.

7.3. Property Modification Measures

7.3.1. PMU-01: Voluntary House Raising

7.3.1.1. Option Assessment

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). This results in a reduction in the frequency of household disruption and associated trauma and anxiety, however other external flood risks remain, such as the need to evacuate prior to properties being isolated by floodwaters.

VHR schemes are eligible for state government funding based on criteria set out in the *Guidelines for Voluntary House Raising Schemes* (Reference 13). In accordance with these guidelines, VHR is generally excluded for properties located within floodways; is limited to low hazard areas; and applies only to houses constructed before 1986. House raising is most suitable for non-brick single storey buildings on piers, and is typically not feasible for slab-on-ground constructions. However, advances in construction techniques and other alternatives may make house raising a viable option for slab-on-ground properties, and therefore individual assessments are required. Repurposing the ground floor for non-habitable use and constructing a second story (above the FPL) for habitable uses may also be a possibility. The VHR guideline states that "*VHR can be an effective strategy for existing properties in low flood hazard areas where mitigation works to reduce flood risk to properties are impractical or uneconomical*".

Outputs from the flood damages assessment and classification of the floodplain into hydraulic categories and hazard classifications have been used to identify residential dwellings that are located outside of the floodway and within low to moderate hazard areas only (H1 to H3) and are inundated over floor in events up to and including the 1% AEP event under current conditions. Six properties in Boree Creek met this criteria.

Costs of house raising is typically in the order of $60,000 although is highly variable and dependant on the specific property and building characteristics. An economic assessment of the option was undertaken and presented below, using a 70-year effective life of the house raising assuming the properties are raised to the 1% plus 500mm level, and allowing for a 20% contingency factor. The option was tested for both 4%, 7% and 10% discount rates. Raising of individual properties was also assessed using a 7% discount rate only. Results are shown in Table A 16.

Table A 16: VHR economic assessment for Boree Creek

Option	NPV Costs	Change in AAD	NPV Benefits	Discount rate	BCR
Raising all properties	**$432,000**	**$23,300**	**$353,033**	**7%**	**0.82**
			$566,896	4%	1.31
			$255,975	10%	0.59
Raising individual properties					
Prop A015	$72,000	$5,775	$87,501	7%	1.22
Prop A023	$72,000	$2,827	$42,834	7%	0.59
Prop A030	$72,000	$2,641	$40,015	7%	0.56
Prop A041	$72,000	$3,090	$46,818	7%	0.65
Prop A045	$72,000	$5,984	$90,667	7%	1.26
Prop A064	$72,000	$2,982	$45,182	7%	0.63

This shows that a voluntary house raising scheme may be economically viable, with two properties shown to have BCRs greater than one, and raising all properties resulting in a BCR near one. However, it will depend on the actual costs involved in raising and therefore further investigation is recommended.

7.3.1.2. Recommendation

PMBC-01: Voluntary House Raising

☑ Undertake a feasibility investigation (including to confirm structural compatibility of the identified buildings and a more accurate cost estimate of raising to at least the 1% AEP + 0.5m flood level), and if found viable, prepare the documentation for funding applications.

7.3.2. PMBC-02: Voluntary Purchase

Voluntary Purchase (VP) schemes are a long-term option to remove residential properties from areas of high flood hazard. VP is recognised as an effective floodplain risk management measure for existing properties in areas where:

- There are highly hazardous flood conditions and the principal objective is to remove people living in these properties and reduce the risk to life of residents and potential rescuers;
- A property is located within a floodway and its removal may contribute to a floodway clearance program that aims to reduce significant impacts of flood behaviour elsewhere in the floodplain by improving the conveyance of the floodway; or
- Purchase of a property enables other flood mitigation works to be implemented (e.g. channel improvements of levee construction).

In the NSW Government *Guidelines for Voluntary Purchase Schemes* (Reference 14), the eligibility criteria notes that VP will be considered only where no other feasible flood risk management options are available to address the risk to life at the property, and that subsidised funding is generally only available for residential properties. Once a dwelling is purchased it would be demolished, and a restriction placed upon the lot to prevent future residential or commercial development. The Guideline further sets out the way in which a VP scheme should be undertaken and how properties should be valued.

To understand the suitability of Voluntary Purchase in Boree Creek, a first-pass assessment was undertaken to identify the locations of dwellings in relation to the floodway. Dwellings situated inside the 1% AEP floodway extent may be eligible for voluntary purchase, as their removal would reduce the number of occupants in highly hazardous areas, as well as reduce obstruction to flow caused by the dwelling itself. This process identified 13 potential properties for a voluntary purchase scheme.

Median house prices for residential properties in Boree Creek was not available (realestate.com.au as of 26 February 2021), so the median value from Urana has been used ($114,000). An economic assessment of the option was undertaken and presented below, using a 100-year effective life. The option was tested for both 4%, 7% and 10% discount rates for all purchasing all properties, and 7% for the individual property analysis. The damages were derived based on existing flood behaviour (that is, no change in flow behaviour as a result of the buildings removal is accounted for in the damages).

Table A 17: VP economic assessment for Boree Creek

Option	Costs	Change in AAD	NPV Benefits	Discount rate	BCR
Purchasing all properties	**$1.482m**	**$246,517**	**$3,763,841**	**7%**	**2.54**
			$6,282,527	4%	4.24
			$2,771,487	10%	1.83
Purchasing individual properties					
Prop A020	$114,000	$26,213	$400,229	7%	3.51
Prop A034*	$114,000	$12,351	$188,569	7%	1.65
Prop A035*	$114,000	$13,870	$211,767	7%	1.86
Prop A040	$114,000	$13,030	$198,946	7%	1.75
Prop A044	$114,000	$12,033	$183,725	7%	1.61
Prop A047*	$114,000	$14,155	$216,127	7%	1.90
Prop A048*	$114,000	$7,367	$112,478	7%	0.99
Prop A049*	$114,000	$12,897	$196,916	7%	1.73
Prop A053	$114,000	$29,364	$448,330	7%	3.93
Prop A055	$114,000	$29,325	$447,742	7%	3.93
Prop A056	$114,000	$29,255	$446,672	7%	3.92
Prop A057	$114,000	$32,933	$502,823	7%	4.41
Prop A059	$114,000	$13,717	$209,437	7%	1.84

* Assuming the implementation of option FMBC-05, these properties would no longer be located in the floodway and may not be eligible for voluntary purchase. The removal of these properties reduces the capital cost to $912,000 (with a net present value of $2,177,979). Under this option the flood behaviour at the other properties listed above would also be improved, subsequently the cost of damage would be reduced and results in a BCR of 2.39 for the overall scheme. This BCR indicates that the scheme would still be considered financially viable and beneficial in reducing flood damages for Boree Creek, even with the implementation of FMBC-05 (or similar).

The results show that a voluntary purchase scheme is likely to be economically viable, depending on the agreed purchase price. Further investigation is required, including testing the community's appetite for such a scheme, the progression of other mitigation strategies and to determine how best the purchase land could be integrated with the community. During Public Exhibition of the Draft FRMS&P, a resident from Boree Creek who owns a dwelling which has been inundated a number of times over the last 10 years indicated support for further investigation of a voluntary purchase scheme in Boree Creek. Given the size of the committee in Boree Creek, special consideration of the impacts of a VP/VHR scheme to the social fabric will require consideration.

7.3.2.1. Recommendation

PMBC-02: Voluntary Purchase

☑ Undertake a VP feasibility study to determine viability of a scheme, including consultation with the identified properties, and if appropriate, prepare the documentation for funding applications. This should be undertaken following engagement with the owners of the railway line as per FMBC-04/05/06.

7.4. Summary of Recommended Options

The following management options specific for the Boree Creek catchment are recommended.

Reference	Name	Type
FMBC02	Boree Creek Western Culvert Upgrades	Flood modification
FMBC03	Boree Creek – Kywong Road Culvert Upgrade	Flood modification
FMBC04/05/06	Railway line augmentation	Flood modification
RMBC01	Evacuation Assembly and Shelter Location	Response modification
PMBC01	Voluntary House Raising scheme	Property modification
PMBC02	Voluntary Purchase scheme	Property modification

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

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Attachment 1

Boree Creek Critical Duration Assessment – Supporting Material

To determine the critical duration (the duration of rainfall over the catchment that will result in the greatest depth of flooding) in Boree Creek, ARR 2019 recommends than an ensemble approach is used, where 10 temporal patterns (see Section 5.4 of the main report) 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.

Three key sub-catchment outlet locations were chosen to assess the peak flows generated by rainfall over the Boree Creek catchment using the XP-RAFTS model. The chosen sub-catchments are listed below and are shown on Figure C6:

- No. 13 – Upstream of urban areas on Boree Creek;
- No. 16 – Upstream of urban areas on Aston Street, capturing runoff from south of town;
- No. 23 – Urban Catchment draining to William Street/ Eades Street.

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 C1 to Diagram C3.

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 C1: Box plot of peak total flows at sub-catchment No.13: 1% AEP event

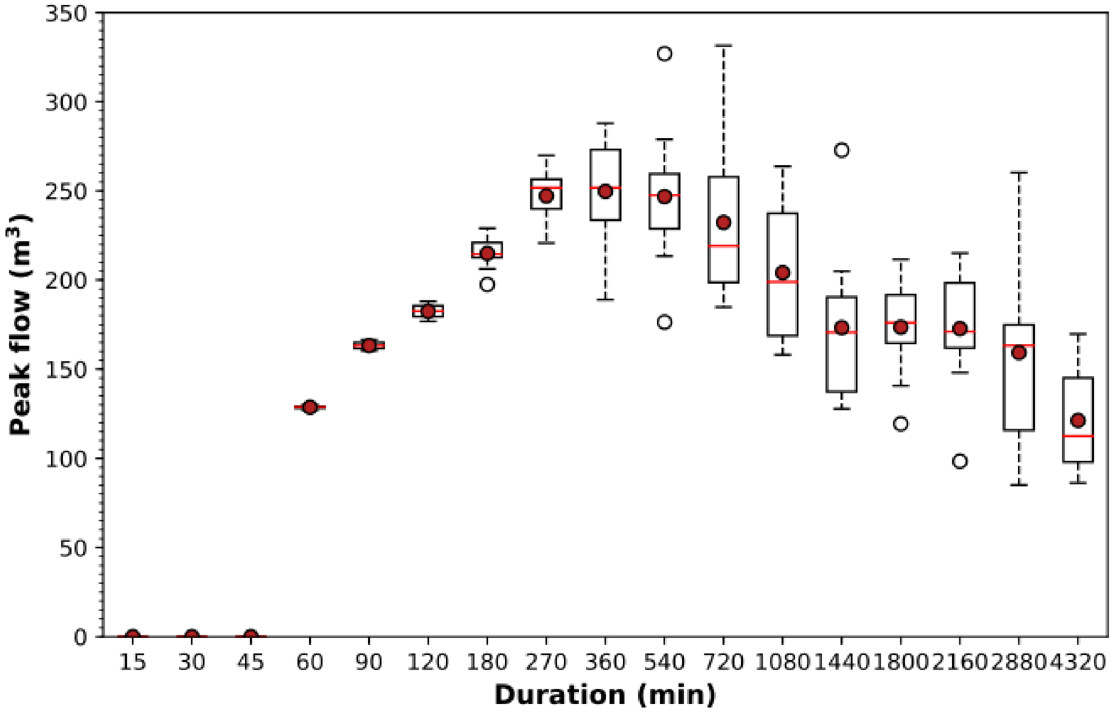


Diagram C2: Box plot of peak total flows at sub-catchment No.16: 1% AEP event

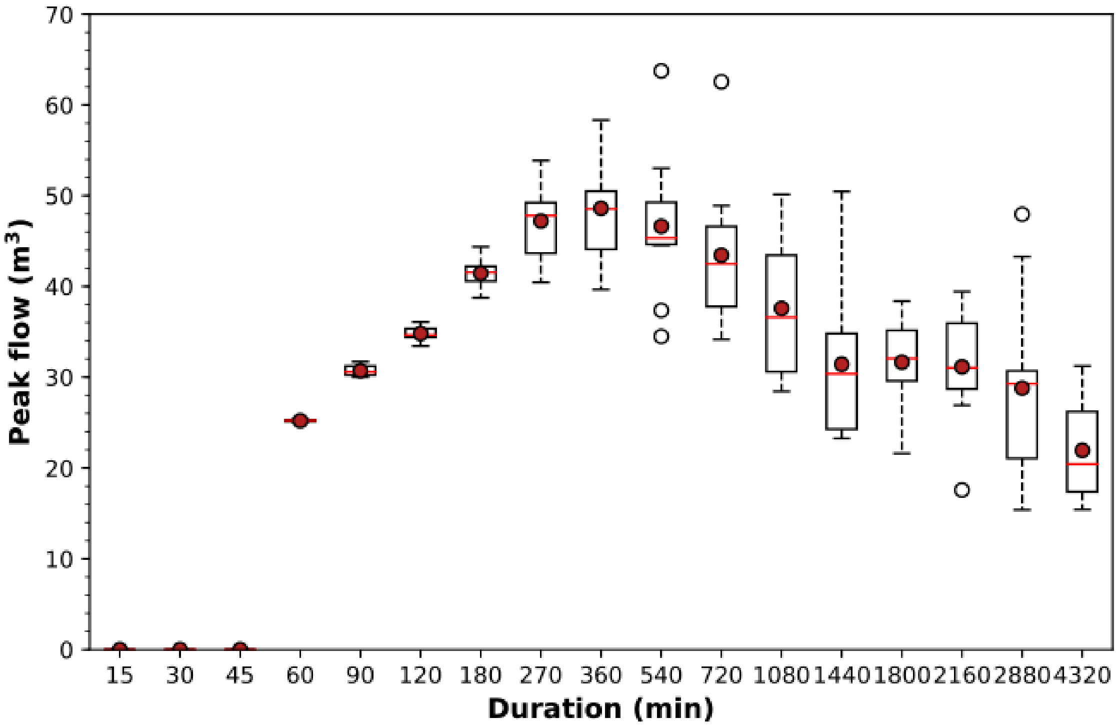
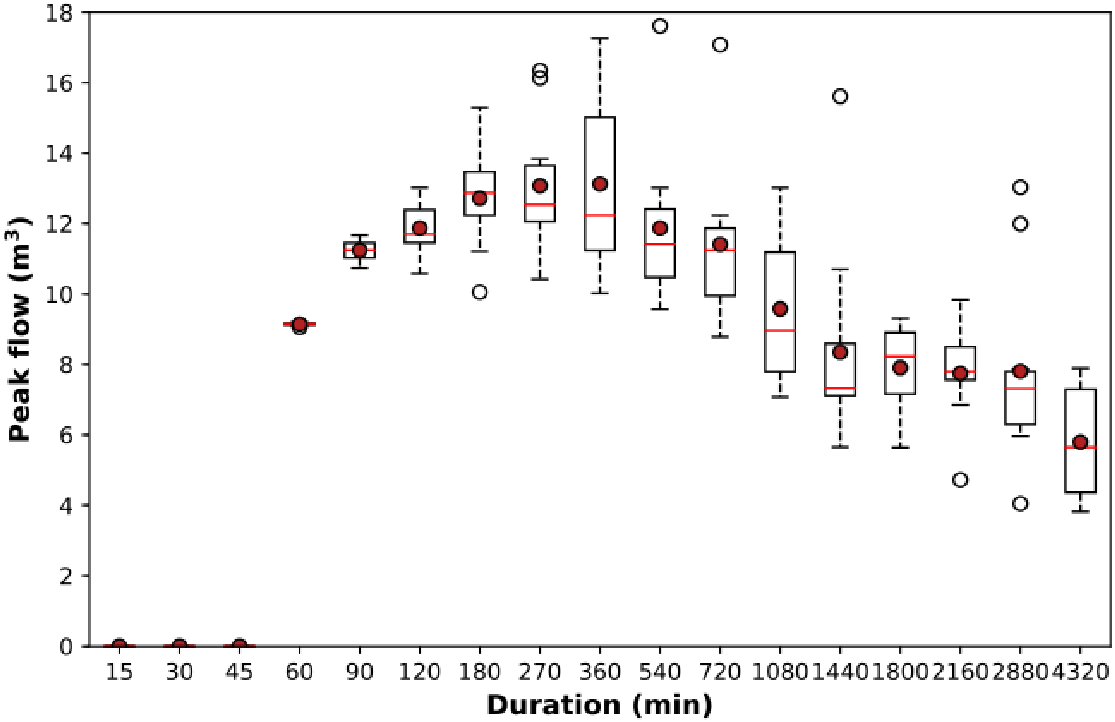
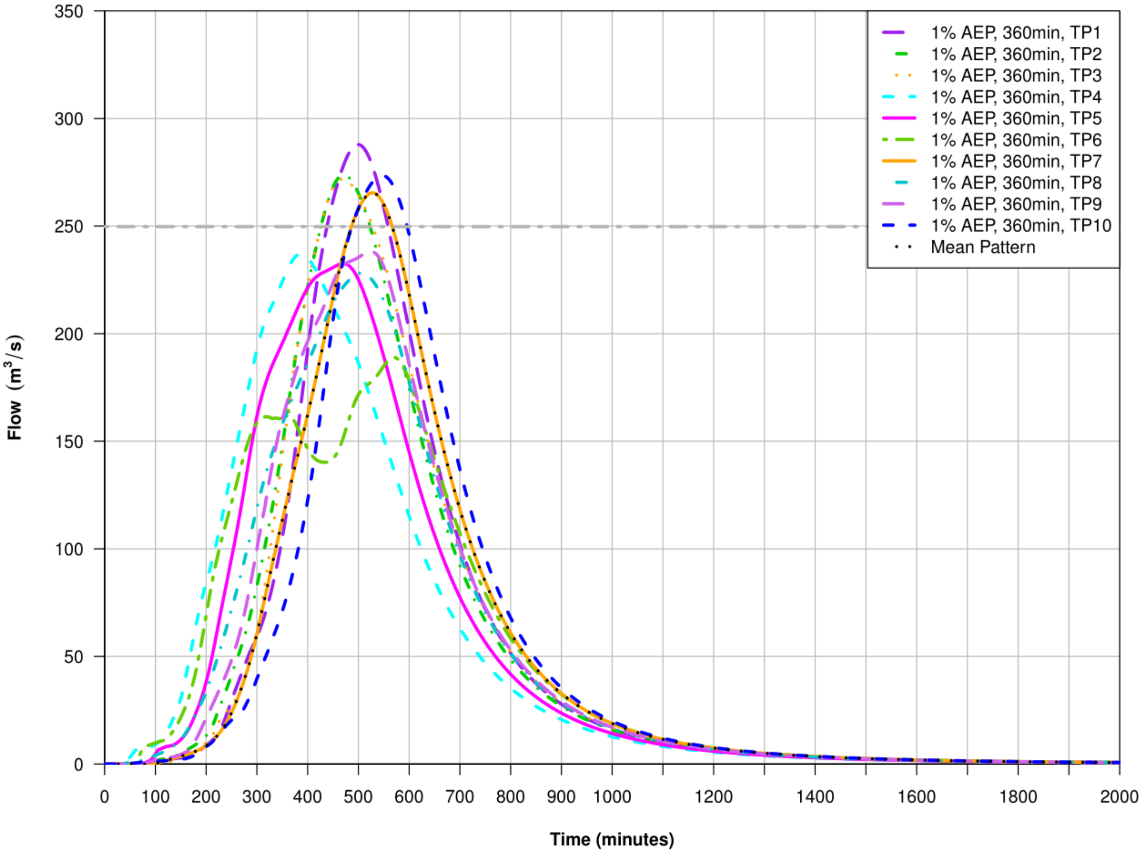


Diagram C3: Box plot of peak total flows at sub-catchment No.23: 1% AEP event



For the 1% AEP event, similar mean peak flows occurred for a range of durations from 270 minutes to 540 minutes. Diagram C1 to Diagram C3 indicate that the 360 minute (6 hour) storm is critical at sub-catchments No.13, 16 and 23, producing the highest mean flows from the ensemble of temporal patterns. The box plots also indicate that the 4.5 hr and 9 hr storms produce comparable mean peak flows, and that further analysis is needed to confirm the critical duration, and subsequently, temporal pattern. The distribution of the hydrographs produced by the ten temporal patterns at sub-catchment No. 13 (total flow), within the 360 minute storm duration for the 1% AEP event is shown in Diagram C4.

Diagram C4: 360 minute 1% AEP total flow hydrographs for sub-catchment No.13 (horizontal dot-dashed line represents the mean flow line).



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 model was run for the 4.5 hour, 6 hour and 9 hour 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 C5), and the 'winning' storm duration and temporal pattern were applied to the smaller events within each bin. The resulting critical durations and representative temporal patterns selected for each design event are listed in Table C1.

Diagram C5: Temporal Pattern Bins

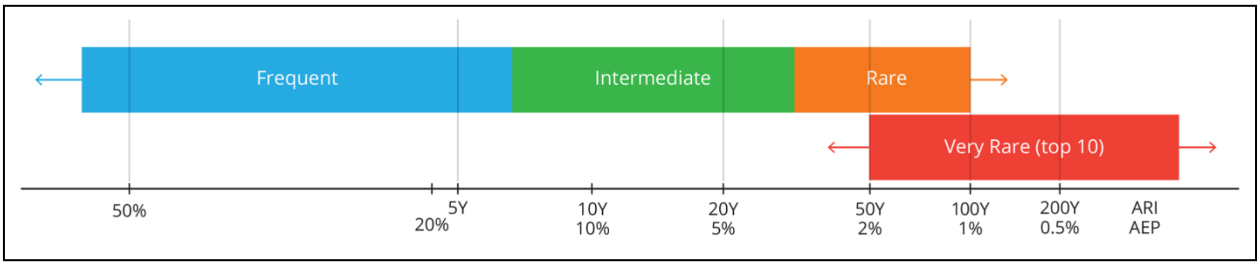


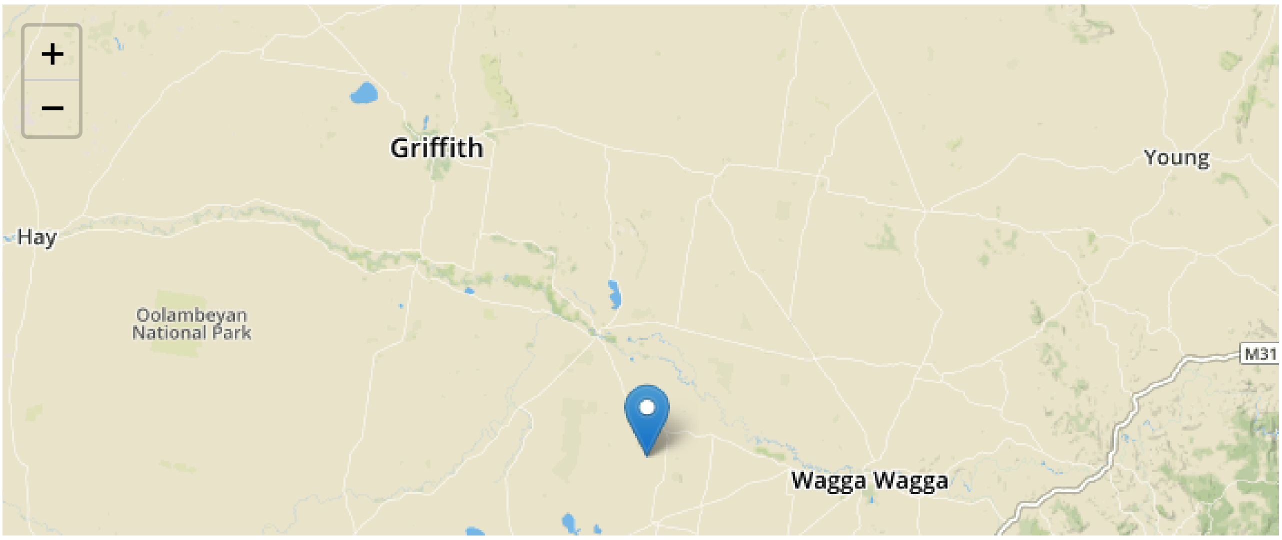
Table C1: Adopted durations and temporal patterns for design flood events

Event	Critical Duration (min)	Adopted Temporal Pattern	IFD (mm)	ARF	Initial Loss (mm)	Continuing Loss (mm/hr)	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet
0.2EY	540	TP3: 4069	47.7	0.9645	13.9	0.16	137
10% AEP	540	TP6: 4063	55.4	0.9611	13.1	0.16	191
5% AEP	540	TP6: 4063	64.1	0.9666	13.4	0.16	233
2% AEP	360	TP7: 4025	68.5	0.9403	10.2	0.16	306
1% AEP	360	TP7: 4025	76.9	0.9350	6.7	0.16	353
0.5% AEP	360	TP7: 4025	86.4	0.9297	6.7	0.16	408
0.2% AEP	360	TP7: 4025	98.8	0.9226	6.7	0.16	481
PMF*	120	Not applicable			0.0	1.0	4026

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	146.688
Latitude	-35.063
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
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 03:52PM
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

Time Accessed	14 February 2019 03:52PM
Version	2016_v1

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	25860.0
Storm Initial Losses (mm)	27.0
Storm Continuing Losses (mm/h)	0.4

Layer Info

Time Accessed	14 February 2019 03:52PM
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 03:52PM
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 03:52PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-35.0625&longitude=146.6875&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	14 February 2019 03:52PM

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)	3.0 (0.163)	2.1 (0.084)	1.6 (0.052)	1.1 (0.030)	0.9 (0.021)	0.8 (0.016)
90 (1.5)	3.8 (0.183)	2.6 (0.089)	1.7 (0.050)	1.0 (0.024)	0.7 (0.014)	0.4 (0.008)
120 (2.0)	2.3 (0.102)	1.7 (0.055)	1.3 (0.036)	1.0 (0.022)	0.5 (0.010)	0.2 (0.003)
180 (3.0)	2.6 (0.104)	2.7 (0.077)	2.7 (0.065)	2.8 (0.057)	1.3 (0.022)	0.2 (0.003)
360 (6.0)	1.4 (0.044)	1.2 (0.028)	1.1 (0.021)	1.0 (0.016)	1.2 (0.017)	1.4 (0.018)
720 (12.0)	0.0 (0.000)	0.5 (0.009)	0.8 (0.013)	1.1 (0.015)	1.5 (0.018)	1.8 (0.020)
1080 (18.0)	0.0 (0.000)	0.3 (0.005)	0.4 (0.007)	0.6 (0.008)	1.4 (0.016)	2.0 (0.020)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.4 (0.004)	0.7 (0.006)
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 03:52PM

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 03:52PM
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)	0.1 (0.008)	0.1 (0.003)	0.0 (0.001)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.1 (0.003)	0.0 (0.001)	0.0 (0.001)	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 03:52PM
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)	13.7 (0.753)	13.9 (0.546)	14.0 (0.459)	14.1 (0.396)	14.4 (0.339)	14.6 (0.305)
90 (1.5)	15.5 (0.752)	16.0 (0.555)	16.3 (0.472)	16.6 (0.413)	14.0 (0.293)	12.1 (0.224)
120 (2.0)	11.5 (0.509)	13.5 (0.432)	14.8 (0.397)	16.1 (0.371)	12.5 (0.241)	9.8 (0.167)
180 (3.0)	13.6 (0.539)	14.4 (0.412)	14.9 (0.358)	15.4 (0.318)	14.7 (0.256)	14.2 (0.220)
360 (6.0)	8.5 (0.277)	10.3 (0.245)	11.5 (0.229)	12.6 (0.218)	16.9 (0.247)	20.2 (0.262)
720 (12.0)	3.7 (0.098)	6.2 (0.124)	8.0 (0.133)	9.6 (0.139)	14.2 (0.173)	17.6 (0.192)
1080 (18.0)	0.7 (0.016)	3.9 (0.070)	6.0 (0.091)	8.1 (0.106)	11.5 (0.127)	14.1 (0.139)
1440 (24.0)	0.0 (0.000)	3.0 (0.050)	4.9 (0.069)	6.8 (0.083)	8.2 (0.084)	9.3 (0.085)
2160 (36.0)	0.0 (0.000)	0.7 (0.010)	1.1 (0.014)	1.5 (0.017)	2.9 (0.027)	3.9 (0.032)
2880 (48.0)	0.0 (0.000)	0.1 (0.001)	0.1 (0.002)	0.2 (0.002)	0.8 (0.007)	1.2 (0.009)
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 03:52PM
Version	2018_v1
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)	29.2 (1.600)	28.2 (1.109)	27.6 (0.904)	27.0 (0.757)	26.1 (0.613)	25.4 (0.529)
90 (1.5)	29.3 (1.418)	31.3 (1.087)	32.6 (0.946)	33.9 (0.843)	30.0 (0.626)	27.1 (0.501)
120 (2.0)	28.6 (1.272)	30.9 (0.989)	32.4 (0.867)	33.9 (0.779)	32.5 (0.628)	31.5 (0.540)
180 (3.0)	24.7 (0.978)	28.7 (0.822)	31.4 (0.753)	33.9 (0.701)	30.9 (0.537)	28.7 (0.443)
360 (6.0)	20.4 (0.665)	23.9 (0.568)	26.1 (0.523)	28.3 (0.490)	39.1 (0.571)	47.2 (0.614)
720 (12.0)	14.0 (0.377)	19.6 (0.389)	23.3 (0.391)	26.9 (0.390)	29.5 (0.361)	31.4 (0.343)
1080 (18.0)	8.5 (0.206)	13.6 (0.244)	16.9 (0.257)	20.2 (0.264)	24.2 (0.268)	27.3 (0.268)
1440 (24.0)	5.9 (0.134)	13.4 (0.224)	18.4 (0.260)	23.2 (0.282)	22.7 (0.234)	22.4 (0.205)
2160 (36.0)	1.6 (0.034)	7.5 (0.114)	11.4 (0.146)	15.1 (0.167)	13.8 (0.129)	12.8 (0.107)
2880 (48.0)	0.6 (0.012)	6.9 (0.098)	11.0 (0.133)	15.0 (0.156)	18.9 (0.166)	21.9 (0.170)
4320 (72.0)	0.0 (0.000)	0.9 (0.012)	1.5 (0.016)	2.0 (0.019)	12.3 (0.099)	20.0 (0.143)

Layer Info

Time Accessed	14 February 2019 03:52PM
Version	2018_v1
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%)**

Layer Info

Time Accessed	14 February 2019 03:52PM
Version	2019_v1
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)	15.5	9.4	8.8	9.3	9.1	7.6
90 (1.5)	15.0	9.6	9.0	9.3	8.7	7.9
120 (2.0)	15.7	10.4	9.6	10.0	9.3	8.4
180 (3.0)	15.6	10.7	9.8	10.7	9.8	7.2
360 (6.0)	17.2	12.9	12.0	12.5	10.2	6.7
720 (12.0)	19.4	14.9	14.2	14.3	12.3	8.8
1080 (18.0)	21.1	16.7	15.9	16.4	13.4	8.9
1440 (24.0)	21.9	17.4	16.9	17.0	15.2	10.7
2160 (36.0)	23.0	19.0	18.8	20.1	18.4	13.9
2880 (48.0)	23.4	19.1	19.3	20.7	19.1	13.0
4320 (72.0)	23.9	20.4	21.6	23.0	20.8	14.5

Layer Info

Time Accessed	14 February 2019 03:52PM
Version	2018_v1
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	0
Area (km2)	1084.669184
Catchment Number	10724
Volume Factor	0.091664
Peak Factor	0.032319

Layer Info

Time Accessed	14 February 2019 03:52PM
Version	2016_v1

Download TXT (downloads/e313ab51-ab8a-4c67-bdd4-aae306f44130.txt)

Download JSON (downloads/6a633a38-284f-48ab-9c44-71539c9431c9.json)

Download PDF (downloads/0c8e592d-bf17-452c-b346-8209853d6a24.pdf)

Table B. 1: Areal Reduction Factors for the Design Storm Events

Duration (min)	AEP						
	20%	10%	5%	2%	1%	0.5%	0.2%
60	0.9019	0.8949	0.8879	0.8787	0.8717	0.8647	0.8555
90	0.9167	0.9085	0.9002	0.8894	0.8811	0.8729	0.8621
120	0.9252	0.9159	0.9067	0.8944	0.8851	0.8759	0.8636
180	0.9358	0.9255	0.9152	0.9016	0.8913	0.8810	0.8674
360	0.9581	0.9527	0.9474	0.9403	0.9350	0.9297	0.9226
720	0.9725	0.9695	0.9666	0.9627	0.9597	0.9568	0.9528
1080	0.9779	0.9757	0.9735	0.9706	0.9684	0.9662	0.9633
1440	0.9832	0.9818	0.9804	0.9785	0.9771	0.9757	0.9738
2160	0.9864	0.9849	0.9835	0.9816	0.9801	0.9787	0.9768
2880	0.9882	0.9868	0.9853	0.9834	0.9819	0.9804	0.9785
4320	0.9905	0.9889	0.9874	0.9854	0.9839	0.9824	0.9804