FEDERATION COUNCIL

APPENDIX B
MORUNDAH

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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MORUNDAH

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1. BACKGROUND

1.1. Study Area

Morundah is the northern-most village located within the Federation Council Local Government Area (LGA), approximately 31 km southwest of Narrandera and 44 km north of Urana. It is a small town in the Riverina region of New South Wales with a total regional population of 69 (2016 Census), and 53 private dwellings. The town is located on the left bank (east) of Colombo Creek, an effluent of Yanco Creek, as shown on Figure B1. Yanco Creek receives inflows from the Murrumbidgee River, regulated by the Yanco Weir, located approximately 15 km downstream (west) of Narrandera (as the crow flies). Further south, the interaction of Colombo and Yanco Creeks is regulated by the Tarabah Weir, located approximately 6 km north of the Morundah Village. Exchange of water between the Colombo and Yanco Creeks also naturally occurs along the floodplain.

An earthen levee approximately 3.2 km in length is situated between the Morundah township and Colombo Creek, though its level of protection is not formally known. The levee was initially constructed sometime between 1959 and 1974, with repairs and upgrades undertaken during and following the flood events in 1974 and 2012. Local runoff from the local catchment to the east and north of the town, in addition to breakouts from the Murrumbidgee River can also cause overland flooding in town. Both these flow mechanisms contribute to Morundah's flood risk, particularly if the overland flow cannot drain through existing levee pipes in a timely manner. In the March 2012 event, for example, heavy rain over the local catchment caused local overland flows initially, while Colombo Creek peaked approximately one week later, reportedly overtopping the levee at nine locations and seeping into the racecourse area.

1.2. Land Use

The land use zoning is defined by the Urana Local Environment Plan (LEP) 2011 as shown on Figure B2. Majority of the built-up area is zoned as 'RU5 Village', and the Newell Highway situated along the southern boundary of the village zoned as 'SP2 Infrastructure'. The remainder of the region is zoned as "RU1 Primary Production", while Yanco Creek and Colombo Creek are zoned as "Major Rivers".

The major facilities in town include the Morundah Hotel and performing arts centre "Morundah Opera House", also known as the Paradise Palladium Theatre, located next door to the Morundah Hotel on Browley Street. The theatre regularly hosts concerts and a range of community events, workshops, and market days. Other key facilities in Morundah include a small self-contained water filtration treatment plant operated by Riverina Water, which supplies potable water to Morundah from Colombo Creek. A railway line runs parallel to the Newell Highway past the township, and a grain storage facility is situated in Morundah on the eastern side of Browley Street. The railway is primarily used seasonally for transport of grain and other goods.

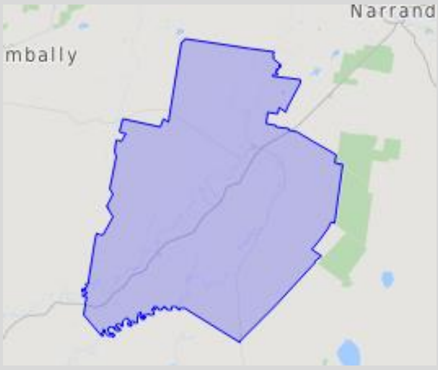
1.3. Demographic Overview

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 Bureau of Meteorology Flood Preparedness Manual (Reference 7), 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 Morundah (and surrounds) and is relevant to the above considerations.

Morundah Demographic Overview*



Population: 69

No. of Private Dwellings: 53

No. of lone person households: 36

Median Population Age: 53 years

Average people per dwelling: 2.3

Average number of cars at dwelling: 2.5

Statistics from:
http://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/SSC12733?opendocument

* Due to the small population in this area, limited information is available from the ABS for confidentiality concerns.

The characteristics noted above are considered in the community engagement strategy and when evaluating response modification options, such as flood education, warning or evacuation systems. Risk factors for any community may include a high proportion of elderly residents (who require assistance to evacuate), lone person households (which can result in reduced awareness of flood warnings/evacuation orders). 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. Information from Morundah's residents during the community consultation indicated that residents tended to 'look out for each other' when it came to issuing flood warnings, preparing for evacuation and recovering following a flood event.

1.4. Local Environment

Morundah has geographic and hydrologic characteristics typical of the district. Soils in the Riverina district tend to be sandy along river channels, with clay soils found on the perimeter of the floodplain. Morundah consists of a small village and is surrounded by land primarily used for agriculture.

On-site sewage management systems (OSSMS) are used in Morundah where there is no reticulated sewerage system. OSSMS are miniature sewage treatment plants. If poorly designed and maintained, OSSMS can cause problematic effects including public health risk, water pollution of local creeks/rivers, agricultural land degradation and local amenity issues. 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. Morundah's potable drinking water is supplied by the Colombo Creek, thus environmental protection of the creek and town itself are a high priority. Council recently adopted an OSSMS strategy in November 2018 providing a management framework, allowing effective regulation of the system as well as the protection of the environment and public health associated with the system.

2. PREVIOUS STUDIES

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

The Flood Study Report for Morundah, completed for Council in 2017 by Jacobs (Reference 4), provided an estimation of mainstream flooding and local catchment overland flow affectation in the town. The hydrologic and hydraulic models established in the Flood Study have been reviewed (and updated) as part of this FRMS&P, and as such, are described in detail in Section 4 of this report.

The key findings from the Flood Study report on Morundah are summarised below:

- Yamma Road Bridge on Colombo Creek is a significant hydraulic control in Morundah;
- Properties in the township are subject to flooding due to rainfall runoff generated from the local catchment to the north and east, which drain towards Colombo Creek through the town;
- Properties located along the eastern side of Milvain Drive are subject to up to 0.5 m depth of flooding in the 20% AEP event due to the local catchment runoff and Milvain Drive (and the remaining developed area) is generally flood free;
- Sections of Milvain Drive and a number of properties located along north-west of Goree Street and Yamma Street are subject to shallow flooding in the 5% AEP event;
- The majority of the developed areas in Morundah are subject to shallow flooding in the 1% AEP event;
- The majority of the developed areas in Morundah are subject to up to 0.5 m flood depth in the 0.2% AEP event;
- The entire town is subject to more than 1 m depth of flooding in the PMF event;
- The entire town is located below 1% AEP flood level plus 0.5 m freeboard (provisional flood planning level);
- The Morundah levee (2015 survey) overtopped in the PMF event only, however the report notes that the TUFLOW model may underestimate flood behaviour and the levee could be overtopped in more frequent events.

2.2. Sturt Highway Upgrade West of Narrandera, Flood Study Review and Impact Assessment of Highway Upgrade Options, Lyalls and Associates, May 2015 (Reference 5)

This report, undertaken by Lyall & Associates for the NSW Roads and Maritime Services, investigated the flood impacts of the proposed upgrade of a 30 km section of the Sturt Highway, west of Narrandera. The study was undertaken in two phases including the flood study review and update (Phase 1) and flood impact assessment of highway upgrade options (Phase 2). Two hydraulic models were developed for a 140 km reach of the Murrumbidgee River between Wagga Wagga and downstream of Narrandera using TUFLOW GPU and TUFLOW Classic modelling systems.

The hydraulic models were calibrated against the flood events of September 1974, December 2010 and March 2012 and the study updated design flood estimates for the Murrumbidgee River at Narrandera gauge (GS 410005) for the full range of flood events between 20% AEP and extreme floods. Modelled discharge hydrographs breaking out from the Murrumbidgee River into the Yanco Creek system in the vicinity of Narrandera for the modelled flood events were available to Jacobs for use in the Morundah Flood Study (Reference 4). A peak flow of 3107 m^3/s and peak flood level of 146.67 m AHD was reported for the 1% AEP event at the Murrumbidgee River at Narrandera Gauge (GS 410005).

2.3. 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 6)

This report was completed for the NSW State Emergency Service (SES) in 2013 to develop an understanding of flood behaviour and impacts that occurred in the Riverina in March 2012. 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 key findings from the report on the village of Morundah are summarised as:

- The March 2012 flood (gauge height 2.975 m) is most likely the third highest on record at the Colombo Creek gauge at Morundah (GS 410014) following the June 1931 (gauge height 2.997 m) and July 1952 (gauge height 2.997 m) floods;
- The data for Colombo Creek suggests a small flood height range, with five historic floods ranging from 2.9 to 3.0 m. This may be due to the very wide floodplain;
- The lowest height of the levee (at the time of the March 2012 flood) protecting Morundah is estimated to correspond to a gauge height of 2.93 m. [Note: the Morundah levee was since upgraded – refer to Section 3.5].

Detailed information regarding the March 2012 flood event is presented in Reference 4 including timings throughout the flood event, photographs and observations about the flood behaviour.

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

Bewsher Consulting was engaged by the NSW Department of Land and Water Conservation in 1999 to undertake a Floodplain Management Plan for Billabong Creek in two phases (with the town of Morundah included in the Study Area). The available data and the flood behaviour were reviewed in the first phase and a report entitled “Phase A: Data Review and Flood Behaviour, Main Report” were produced. The scope of Phase A included community consultation; review of planning and environmental aspects; review of flood hydrology including review of rainfall records, streamflow records and flood extents; undertaking flood frequency analysis and formulation, calibration and verification of a MIKE11 hydraulic computer model using data from the 1974 and 1983 design floods and the 1931 extreme flood event. The highest flood on record is the 1952 flood with a peak flow of 5,680 ML/day (65.7 m^3/s) in Colombo Creek at Morundah.

The station has been gauged on 509 occasions, the largest being in August 1934 where a peak flow rate of 3,132 ML/day was recorded. The rating table was considered good and the highest annual flows from 1913 to 1998 were used to generate the flood frequency analysis. The Flood Frequency Analysis resulted in a peak flow of 6,700 ML/day (78 m^3/s) for 1% AEP event at Morundah.

3. AVAILABLE DATA

3.1. Site Visit

A site inspection was carried out by WMAwater staff accompanied by Council staff on the 9th August 2018 to gain an overall appreciation of the study area, and to identify areas of Morundah subject to the greatest flood risk. In Morundah, dwellings on the north-eastern side of Browley Street have been known to be affected by overland flow coming from the north-east, while properties on the Yamma Road side of town, including the Morundah Hotel, are subject to mainstream flooding from Colombo Creek. A subsequent site visit was undertaken on the 17th October 2018 following the community consultation session to visit locations where issues had been raised by residents, including several culverts that had been noted to be of insufficient capacity. Figure B3 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. LiDAR data for Morundah used in the Flood Study (Reference 4) was originally captured and processed by LPI between 10 February and 11 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 steeply 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.

The Flood Study (Reference 4) produced a digital elevation model by sampling the 1 m LiDAR data to produce an 8 m × 8 m grid. Due to the reasonably large grid size (8 m grid) the model was locally refined to show sub-grid elements such as road crests crossing the floodplain and smaller channels. The road crests and small channels were included in the model with break lines using elevations obtained from the 1 m LiDAR data. Due to the presence of standing water in some sections of the Colombo Creek when the LiDAR data was captured, the depth of the creek was assumed to be 1 m deep. Details of the Morundah levee, which had been raised following the 2012 event, was incorporated into the model based on the survey of the levee undertaken in 2015 (Reference 4). The ground levels are shown on Figure B4 based on the model grid used in the Flood Study.

3.3. Aerial Photography

Aerial photography was provided by Council. Morundah is covered by the ‘Yanco’ 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, shown on Figure B5, were obtained from the Flood Study (Reference 4). A topographic survey undertaken as part of the Flood Study by T Hinchcliffe & Associates provided the following:

- Details of eight bridge structures including deck and soffit levels, length, width, railing height, location and width of piers and photographs;
- Details of three culvert structures (two under Yamma Road and one under Yarrabee Street). Details included location and invert levels of inlets and outlets, length, number of cells, blockage and photographs;
- Details of Tarabah and Yanco Weirs (including gate locations, invert levels, top levels, gate size, number of gates and photographs);
- Details of gauging station at Tarabah Weir, Yanco Weir and on Yanco Creek at Morundah (gauge zero referenced to Australian Height Datum (AHD) and photographs); and
- Details of Spiller's Regulator on Back Creek just downstream from Yanco Creek, and Molly's Regulator (including gate locations, invert levels, top levels, gate sizes, number and type of gates and photographs).

3.5. Levee Survey

A survey of the Morundah levee crest was undertaken by NSW Public Works, completed in February 2015, capturing crest levels following significant raising of the levee following the 2012 flood event. The AutoCAD files for the survey were provided including the horizontal and vertical alignment of the levee, features such as tracks and culverts crossing the levee, and thirteen cross sections (see Appendix A of Reference 4). During the Flood Study, Council also provided a survey of the levee undertaken in 2012, however, it was not georeferenced. Following manual processing of the 2012 survey, a comparison of levels between the two levee alignments and crest levels found that the raised levee (2015) is approximately 0.8-1.0 m higher than the levee surveyed in 2012.

3.6. Pit and Pipe Network

Local stormwater drainage is conveyed towards Colombo Creek via a series of roadside table drains and culverts beneath driveways, with a limited number of culverts beneath roads. The kerb and gutter system are intermittent and allows water to drain directly from roads into the adjacent table drains. Morundah does not have a sub-surface stormwater drainage network, and as such, no pit and pipe details were provided. There are 3 pipes through the levee (Figure B5) designed to allow local overland flow to be drained to Colombo Creek. The pipes are modelled as unidirectional (i.e. with one-way flap valves on the creek side) and have diameters varying between 200 mm and 450 mm.

3.7. 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 B1 below.

Table B1: Floor Level Database – Morundah

Property Type	No. Included in Damages Assessment
Residential	35
Non-Residential	5
Total	**40**

3.8. 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 Study. ARR 2019 IFD information was obtained from the Bureau of Meteorology (BoM) via the ARR 2019 Data Hub, with IFDs and all other metadata provided in Attachment 1. Section 5 describes the processes used to update the hydrologic and hydraulic models to implement ARR 2019 methodologies.

4. FLOOD MODELLING REVISIONS AND UPDATES

The Flood Study (Reference 4) aimed to determine design flood behaviour in the area using the below approach:

- Derivation of **design hydrographs** for flows breaking out from the Murrumbidgee River into Yanco Creek at the Yanco Creek Offtake (Yanco Weir) (See Section 4.2.1.3)
- A **MIKE11** hydraulic model was established to route flows from the Yanco Offtake, southwards to the upstream boundary of the Morundah study area, where the resulting hydrographs were used as inflows into the Morundah TUFLOW model (See Section 4.2.1);
- An **XP-RAFTS** hydrologic model was established to convert rainfall to runoff within the local catchment of Morundah itself (using ARR 1987 methodologies, see Section 4.1); and
- A **TUFLOW** hydraulic model was developed to estimate design flood behaviour using mainstream inflows for Colombo and Yanco Creeks from the MIKE11 hydraulic model, and local inflows from the XP-RAFTS hydrologic model (see Section 4.2.2).

Details of the above models are provided in the subsequent sections. The models were reviewed by WMAwater to determine the suitability for application in the Floodplain Risk Management Study. 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 updates to ARR 2019 methodologies where appropriate (See Section 5). The model review is split into two sections:

- **Hydrologic Model Review** (i.e. XP-RAFTS model for the local Morundah catchment), and
- **Hydraulic Model Review** (pertaining to both the MIKE11 model and its inflows, as well as the TUFLOW model of Morundah itself).

4.1. Hydrologic Model Review (Local Catchment Only)

The local catchment draining to Morundah village was modelled using XP-RAFTS (2013 version). A comprehensive review of the model has been undertaken to confirm the model is suitable for use in this FRMS&P, prior to being updated to the 2018 version and re-run using ARR 2019 methodologies (see Section 5). The sections below describe the review of the local overland flow hydrologic model and document any modifications made prior to use of these models in this FRMS&P.

4.1.1. Model Extent

The XP-RAFTS model developed in the Flood Study (Reference 4) covers the local catchment area to the north and north east of Morundah. The catchment extends approximately 6 km north-northwest of the town and is bounded by the Newell Highway to the east, and Colombo Creek to the southwest of town. Review of the XP-RAFTS hydrologic model, and discussions with Council, identified that there could be additional catchment to the east of the original model boundary in two locations, described as follows:

- The area immediately west of the railway line, north of the catchment boundary identified in the Flood Study (Reference 4).

WMAwater established a coarse HPC rainfall-on-grid TUFLOW model to determine where runoff would be likely to flow and to identify any flow paths that may convey additional runoff towards Morundah (as the flat terrain makes it difficult to determine catchment boundaries based on topographic data alone). This exercise led to the extension of the Morundah XP-RAFTS model to include an area of 473.8 ha. The extension involved delineating one additional sub-catchment (sub-catchment No.7, shown on Figure B6), and the application of model parameters consistent with the adjacent existing sub-catchment (No.1);

- The area south east of the Newell Highway and north of Federation Way appeared to be excluded from the XP-RAFTS hydrologic model. However, the review found that there would be little value in extending the model in this area as it was not considered likely to impact flood behaviour in Morundah itself or affect the approach to mitigation options in this FRMS&P. A detailed memo describing the review was provided to Council in November 2018.

The extended XP-RAFTS model covering Morundah's catchments is approximately 17.4 km^2 and is shown on Figure B5 and Figure B6.

4.1.2. Model Parameters

The parameters used in the Flood Study for the XP-RAFTS hydrologic model simulation were assessed for suitability in the FRMS&P. The XP-RAFTS model parameters have been adopted without modification from the Flood Study (Reference 4) and are presented in Table B2. Parameters from Sub-catchment 1 were applied to the newly added Sub-catchment 7.

Table B2: XP-RAFTS model sub-catchment data for Morundah's local catchment

Sub-catchment No.	Area (ha)	Slope (%)	Impervious fraction (%)	Hydraulic Roughness (Manning's 'n' value)
1	1103.7	1.0	5	0.045
2	61.9	0.1	8	0.050
3	18.4	0.3	20	0.040
4	32.9	1.0	5	0.050
5	28.1	0.1	5	0.045
6	24.6	0.1	5	0.045
7*	473.8	1.0	5	0.045
**Sub-catchment 7 added as part of the FRMS&P, described in 4.1.1*				

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.

While these losses were applied in accordance with guidance available at the time, the design losses applied in this FRMS&P are based on guidance from ARR 2019. These are discussed further in Section 5.3.5.

4.2. Hydraulic Model Review

4.2.1. MIKE11

4.2.1.1. Introduction

Mainstream flood behaviour in Morundah, to a large extent, is controlled by breakouts from the left (southern) bank of the Murrumbidgee River discharging into Yanco Creek some 31 km northeast of Morundah at the Yanco Weir. Between this point and Morundah exists many breakouts and braiding of various creeks, flood runners and minor flowpaths. The complex behaviour and interactions between these creeks led the Flood Study (Reference 4) to adopt a modelling approach based on flows at a gauged point (i.e. Yanco Weir), and a MIKE11 model with sufficiently wide cross sections to represent the terrain between the Yanco Weir and the Morundah Study Area.

4.2.1.2. Model Extent

The MIKE11 model developed by Jacobs (Reference 4) was used to route the gauged flows from the Murrumbidgee River to the upstream boundary of the Morundah TUFLOW model, and simulate the distribution of flows between Yanco and Colombo Creeks for 20%, 10%, 5%, 2%, 1% AEP events and an extreme event equivalent to three times the 1% AEP event. The one-dimensional MIKE11 model simulated the flow in Yanco Creek from the Murrumbidgee offtake to approximately 6.5 km downstream of Morundah, and Colombo Creek from its bifurcation with Yanco Creek to approximately 3.5 km downstream of Morundah. Link channels between these main flow paths were included in the model to simulate the interchange of flows across the floodplain.

4.2.1.3. Inflows

The Flood Study (Reference 4) developed design inflow hydrographs (for input into the MIKE11 hydraulic model) using the following method:

- Design flow hydrographs in the Murrumbidgee River were taken from the Narrandera Floodplain Risk Management Study (SKM, 2009, Reference 14);
- A relationship was developed between flows in the Murrumbidgee River and Yanco Creek using gauged data from the 2012 event (i.e. peak flows in Yanco Creek as a proportion of those in the Murrumbidgee River*);

- This relationship was used to derive design flow hydrographs in Yanco Creek;
- These hydrographs were applied as the inflows to the MIKE11 model.

*the Flood Study (Reference 4) based the scaled design hydrographs on those adopted by the Narrandera Floodplain Risk Management Study and Plan (SKM, 2009, Reference 14). In 2015, Lyall & Associates completed the Narrandera Flood Study Review and Levee Options Assessment (Reference 5) which updated the Flood Frequency Analysis at Narrandera. As the peak design flows established in each study were comparable, the MIKE11 inflow hydrographs used in the Morundah Flood Study (Reference 4) were adopted for use in the FRMS&P without modification.

4.2.1.4. Topography, Roughness and Hydraulic Structures

The MIKE11 cross-sections were derived from the LiDAR data for the Yanco Creek. A Manning's n value of n = 0.075 had been adopted as a global value for the floodplain, based on the aerial imagery, which is considered reasonable given the degree of vegetation within and between the riparian areas of Yanco and Colombo Creeks, if a little on the high side. The MIKE11 model included hydraulic structures and obstructions such as road crossings, railway crossings, weirs and regulators, based on the topographical survey data. Stage-discharge relationships were used as the downstream boundaries for Yanco and Colombo Creeks based on a normal depth, which are located downstream of Morundah and a sufficient distance from the Yanco 35100 and Colombo 29350 to ensure flood behaviour was not influenced.

The MIKE11 model developed in the Flood Study (Reference 4) was deemed to use appropriate methods and parameters; and was considered suitable for use in the current study. The design flow hydrographs developed in the Flood Study (using the MIKE11 model) were adopted without modification for use in the FRMS&P.

4.2.2. TUFLOW

The Flood Study (Reference 4) developed a 1D-2D TUFLOW model for Morundah. 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).

4.2.2.1. Hydraulic Model Extent

The hydraulic model extent (from the Morundah Flood Study, Reference 4) is shown in Diagram B1. The TUFLOW model domain encompasses the area south of Federation Way and west of the Newell Highway, however omits the area north of Federation Way (shown in white below). In the Federation Villages FRMS&P technical brief, Council expressed concerns that the area southeast of Morundah (shown in the white polygon) had not been appropriately considered in the Flood Study, and that overland flow coming from the northern side of the railway embankment might flow through railway culverts, across Newell Highway and into the area to the east of the highway.

Diagram B1: Hydraulic Model Extent

Hydraulic Extent from the Morundah Flood Study

Zoomed in at Cnr Newell Highway and Federation Way

As detailed in a memorandum to Council on the 26th November 2018, WMAwater undertook a review of topographic data, site visit (to identify and locate railway culverts) and review of existing flood affectation. The investigation found the following:

- The area south east of Newell Highway and south of Federation Way (as shown in Figure A2-4 in the brief, and) is already within the current hydraulic model extent;
- The area east of Newell Highway and north of Federation Way (Diagram B1) is <u>not</u> within the current hydraulic model extent;
- There are no culverts through the railway embankment on the north eastern side of Federation Way within the current hydraulic model extent. The next closest culvert is 500 m northeast of the current hydraulic model boundary. Therefore, within the current model extent, flow would not be conveyed across the railway embankment and across the Newell Highway;

- The railway embankment is not overtopped in any design event lower than the PMF. In the PMF event, flow would continue onto land east of the Newell Highway, and be controlled by existing embankments and other irrigation infrastructure on the land. Extending the model to capture this area would require careful consideration of where water would flow within the fields; and
- Available topographic data and PMF mapping indicates that high ground along the southern shoulder of Federation Way prevents mainstream flow from breaking out of Colombo Creek and crossing Federation Way (and into the adjacent field), and that the hydraulic model boundary is not a constraint to modelled mainstream flood behaviour.

With these factors in mind, it was considered that there would be little value in extending the hydraulic model to include the field bounded by Newell Highway to the west and Federation Way to the south. The inclusion of this area is not considered likely to impact on flood behaviour within Morundah itself, nor significantly alter the approach to mitigation options assessed in the FRMS&P moving forward. The memorandum however identified that the area north of Morundah and immediately west of the railway embankment was not included in the Flood Study (Reference 4) hydrologic model. As part of the hydrologic model review and update, this additional catchment area was defined and included, as described in Section 4.1.1.

4.2.2.2. 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 an 8 m grid. The grid size was selected to appropriately represent the flood behaviour and balance model run time. The model DEM was adopted as is for use in this FRMS&P.

4.2.2.3. Bridges and Culverts

The model used in the Flood Study included eight bridges (six over Colombo Creek and two over Yanco Creek) and six culverts, (three culvert structures through the levee, two culverts under Yamma Road and one culvert at the edge of Morundah village). The bridges and culverts were modelled as 2D and 1D elements, respectively, using the data obtained from the topographic survey by TJ Hinchcliffe and Associates in 2015 within the study area. The representation of hydraulic structures was considered appropriate and has been adopted for use in the current study without modification.

During the site visit, one additional circular pipe culvert was identified through the railway embankment approximately 1.6 km north of the Newell Highway/ Federation Way intersection. The culvert was measured as being 1.05 m diameter, and invert levels were estimated using photos from the site visit and LiDAR data.

4.2.2.4. Levee

In accordance with DPIE advice, a properly constructed and maintained levee is considered to only offer protection against floods up to the magnitude of the design flood. For events larger than the design flood, the levee may be deemed to have failed, and therefore inundation of the protected area should be assumed, providing a conservative estimate of possible damage.

A definitive level of protection cannot be ascribed to the Morundah levee due to the lack of formal design, ad hoc construction, and unknown structural integrity. The elevation of the levee has therefore been set based on the levee survey discussed in Section 3.5.

4.2.2.5. 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. This approach has been adopted without modification from the Flood Study (Reference 4).

4.2.2.6. Roughness Parameters

The Flood Study (Reference 4) assigned hydraulic roughness to the catchment surface based on aerial photography (from 2008) and land use zoning. The Manning's 'n' layer was reviewed in the context of more recent aerial imagery (Dec 2018) which confirmed there had not been any changes in the land use compared to the original assignment of hydraulic roughness parameters. Table B3 lists the Manning's 'n' coefficients applied to define various types of surface roughness and Figure B7 illustrates their spatial distribution. The Manning's 'n' values assigned to densely vegetated area are considered to be at the upper limit of appropriate values, however have been adopted without modification for use in the FRMS&P.

Table B3: TUFLOW model hydraulic roughness values

Land use type	Hydraulic Roughness (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
Medium-High density urban and commercial	0.035
Lawn	0.03

4.2.2.7. Overland Inflows

The simulated hydrographs developed in the XP-RAFTS hydrologic model were adopted as upstream inflow hydrographs in the TUFLOW hydraulic model. For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the XP-RAFTS model. These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. The inflow locations are shown on Figure B5.

4.2.2.8. Mainstream Inflows (Colombo and Yanco Creeks)

The MIKE11 model developed by Jacobs (2017) (Reference 4) was calibrated to the 2010 and 2012 flood events and used to develop design hydrographs for the full suite of design AEP events and the PMF. The resulting flow hydrographs at MIKE11 cross section YANCO 35100 and COLOMBO 29350 were adopted as upstream inflow hydrographs in the TUFLOW model for Morundah (the two inflow boundary locations are shown on Figure B5).

4.2.2.9. Downstream Boundary Conditions

A normal depth condition was applied at the downstream boundaries for both Yanco and Colombo Creeks, located approximately 2 km downstream of the Morundah township. The downstream boundary was adopted directly from the Flood Study (Reference 4) which validated the applied tailwater levels through a sensitivity assessment. The location of the outflow boundaries are far enough downstream to not impact the modelled flood behaviour in the vicinity of the village.

5. DESIGN FLOOD MODELLING

5.1. Overview

Morundah is affected by mainstream flooding from Colombo and Yanco Creeks, as well as overland flow from the local catchment to the north and northwest of the town. Each mechanism is modelled separately then presented as enveloped results to provide a comprehensive picture of the flood risk in Morundah. The design flood estimation for each of the mechanisms is described in this section.

5.2. Mainstream Flooding

As described in Section 4.2.1, a MIKE11 model was used to route flows from the Murrumbidgee River, through Yanco Creek, Colombo Creek and (various other flow paths) through to Morundah and used as inflow into Morundah's TUFLOW model. These flows were adopted for input into the TUFLOW model without modification, as described in Section 4.2.1.3). Design hydrographs were extracted from the MIKE11 model at two locations – Colombo Creek (XS 29350) and Yanco Creek (XS 35100). The peak design inflows into the TUFLOW model at Colombo and Yanco Creeks are listed in Table B4.

Table B4 Design Peak Inflows (MIKE 11)

Design Event	Mainstream Inflows (Peak Flows) (MIKE 11 Model) (m^3/s)	
	Colombo Ck (XS 29350)	Yanco Ck (XS 35100)
20% AEP	42.84	48.06
10% AEP	48.95	60.41
5% AEP	51.43	70.94
2% AEP	55.34	92.67
1% AEP	59.82	131.87
0.5% AEP*	63.41	143.74
0.2% AEP*	67.00	167.47
Extreme Event**	71.26	277.20

*the 0.5% and 0.2% AEP events were not assessed in Reference 14, and as such the Flood Study (Reference 4) derived design discharge hydrographs by scaling up the 1% AEP design hydrographs in Colombo and Yanco Creeks.
** the Extreme Event was equivalent to 3 times the 1% AEP event at the MIKE11 Inflow (Reference 14).

5.3. Overland Flow

The estimation of overland flow in the local Morundah catchment has been undertaken using the linked hydrologic/ hydraulic models developed in the Flood Study (Reference 4), with (limited) revisions and updates described in Section 4.1. The hydrologic modelling has been undertaken using Australian Rainfall and Runoff 2019 guidelines, including the use of ARR 2019 IFD data, temporal patterns and losses. The PMF flows were derived using the Bureau of Meteorology's Generalised Short-Duration Method (Reference 8) to estimate the probable maximum precipitation (PMP).

5.3.1. 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 (of local catchment runoff only) produced in the Flood Study was to be updated to implement the methodologies provided in ARR 2019, as these represent best practice and would increase the longevity of the outputs of the Study. The subsequent sections describe the application of ARR 2019 as they relate to local overland flow modelling in Morundah. It is noted that the XP-RAFTS model version was changed from 2013 to 2018 to better facilitate the implementation of ARR 2019 methodologies.

5.3.2. 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 B5 and the Data Hub metadata is presented in Attachment 1.

Table B5: Design rainfall depths (mm) at the centroid (Longitude 146.313, Latitude -34.913) of the Morundah local overland catchment

Duration	AEP							
(min)	20%	0.2EY	10%	5%	2%	1%	0.5%	0.2%
60	22.2	22.7	26.6	31.1	37.2	42.1	47.2	53.7
90	25.3	25.8	30.2	35.3	42.2	47.8	53.5	61.0
120	27.6	28.1	33.0	38.4	46.0	52.0	58.3	66.5
180	31.1	31.8	37.1	43.2	51.6	58.3	65.4	74.6
270	35.1	35.8	41.7	48.5	57.7	65.0	73.1	83.4
360	38.2	38.9	45.3	52.5	62.4	70.2	78.9	90.1
540	42.9	43.8	50.8	58.6	69.5	78.0	87.7	100

5.3.3. ARR 2019 Temporal Patterns

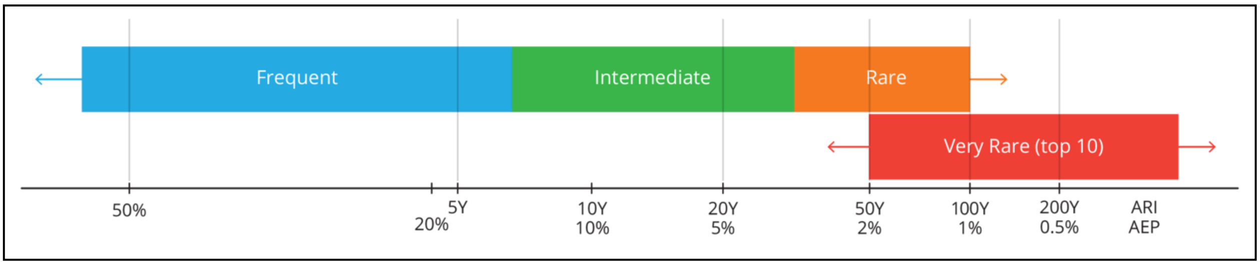
Temporal patterns describe how rain falls over time and form a component of storm hydrograph estimation. Previously, with ARR 1987 guidelines (Reference1), a single temporal pattern was adopted for each rainfall event duration. However, ARR 2019 (Reference 2) discusses the potential deficiencies of adopting 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 guideline has adopted an ensemble of ten different temporal patterns for a particular design rainfall event. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to identify 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 ARR 2019 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The ARR 2019 method provides patterns for 12 climatic regions across Australia, with the Morundah 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 B2 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 B2: 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 local catchment centroid is presented in Attachment 1. The method employed to estimate the PMP utilises a single temporal pattern (Reference 8).

5.3.4. 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 5.3.3) 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). 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 B6.

Table B6: Adopted durations and temporal patterns for design flood events

Event	AEP Bin	Adopted Duration (mins)	Adopted Temporal Pattern	XP-RAFTS Total peak flood discharge (m^3/s) at the catchment outlet
20% AEP	Frequent	540	TP5: 4072	19
10% AEP	Intermediate	540	TP6: 4063	25
5% AEP	Intermediate	540	TP6: 4063	31
2% AEP	Rare	540	TP7: 4054	41
1% AEP	Rare	540	TP7: 4054	48
0.5% AEP	Rare	540	TP7: 4054	54
0.2% AEP	Rare	540	TP7: 4054	62
PMF	Not applicable	120	Not applicable	1261

5.3.5. 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 13), in the absence of calibrated losses (i.e. calibrated to flows at a stream gauge) in the catchment or nearby, the continuing loss value provided by the ARR 2019 is to be multiplied by a factor of 0.4. In the Morundah overland catchment, the continuing loss value provided by the ARR 2019 Data Hub is 0.0 mm/hr. This is used in conjunction with probability neutral burst initial loss values (presented in Table B7). It is noted that the values applied in the 1% AEP event were also used for rare 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 B7. An initial loss of 0 mm and a continuing loss of 1.0 mm/hr were adopted for the PMP event.

Table B7: Probability Neutral Burst Initial Loss at the Centroid of the Study Area (mm)

Duration	AEP				
(min)	20%	10%	5%	2%	1%
60	11.9	10.5	10.2	10.5	10.1
90	11.2	10.2	10.5	10.4	9.6
120	10.9	10.7	11.1	10.9	8.3
180	13.4	12.2	12.4	11.3	9.2
360	14.2	13.2	13.4	11.4	7.8
720	16.4	15.9	16.1	14.1	9.1

5.3.6. Areal Reduction Factors

Areal Reduction Factors (ARF) are an estimate of how the intensity of a design rainfall event varies over a catchment, based on the assumption that large catchments will not have a uniform depth of rainfall over the entire catchment. The ARF is extracted via the ARR Data Hub and applied to each sub-catchment. An ARF of 0.9474 is applied for the 1% AEP event (6 hour duration).

6. DESIGN FLOOD MODELLING RESULTS

6.1. Summary of Results

Morundah is subject to flood risk from both mainstream and overland sources. For each mechanism, the flood models described in Section 4 were run for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and the PMF design flood events, using design inputs detailed in Section 5.

Each mechanism has been discussed separately below, however the figures present enveloped results to capture the peak flood depths to which Morundah is subject, considering both flood sources. Enveloped peak flood depths and levels for the full suite of design events are shown on Figure B8 to Figure B15 respectively.

6.2. Peak Flood Depths and Levels

6.2.1. Mainstream Flooding

In the vicinity of Morundah, both Yanco and Colombo Creeks are characterised by well defined, incised channels. However, in events as frequent as the 20% AEP, a number of breakouts and flood runners from both Yanco and Colombo Creeks occur, with much braiding and interaction between the two creeks. The area between the two creeks is completely inundated (to varying depths) in the 1% AEP, however the floodplain is constrained by higher ground immediately west of Yanco Creek. On the left bank (north-eastern side) of Colombo Creek, a levee (raised substantially after the 2012 event) and naturally occurring high ground separates the township from mainstream flooding. The levee is made up of a licenced section on Crown Land and a section on private property. A long section has been prepared to indicate the levee crest/ground level compared to the adjacent 1% AEP flood level and shows that, for the most part, the ground level is at or above the 1% AEP level, with much of the length of the existing crest more than 0.5 m above the 1% AEP level (shown on Figure B23). No formal design work exists for the levee and much of the previous works have not involved compaction elements and therefore details of the structural integrity are not known. A definitive level of protection cannot be ascribed to the Morundah levee, and a risk of failure or overtopping exists, depending on the structural integrity and condition of the levee at the time of flooding.

While properties may not be directly affected by mainstream flooding (with the levee at its current level), elevated water levels in Yanco and Columbo Creeks restrict access to Morundah in all directions except via Urana Road (i.e. roads cut between Morundah and Coleambally, and Morundah and Narrandera).

It is noted that the mainstream flood affectation modelled in this Study is consistent with the results produced in the Flood Study (Reference 4), as the design flows were not modified.

6.2.2. Overland Flow

Morundah is subject to flood risk from overland flow approaching the town from the north - northeast, flowing across paddocks towards the creek. The overland flow is generally shallow and widespread across the relatively flat terrain, however areas of ponding occur upstream (northeast) of Milvain Drive, and behind the levee. In a 1% AEP event, this ponding can reach depths of around 0.75 m upstream (east) of Back Morundah Road, and up to 1.6 m in the showground, upstream of the levee.

Overland flow affectation is the main cause of flood damage to properties in Morundah, particularly following upgrade of the levee. Overland flow results in approximately 7 times the average annual damage of mainstream flooding. The design peak flows at the local overland flow catchment outlet are provided in Table B8. Note that the flows listed for ARR1987 were produced by re-running the XP-RAFTS model (as per the Flood Study (Reference 4)) for a selection of events, as the Flood Study did not report flows at the overland catchment outlet.

Table B8 Peak Design Flows at the Local Overland Catchment Outlet

Design Event	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet	
	ARR 2019	ARR 1987
20% AEP	18.71	-
10% AEP	25.24	-
5% AEP	31.09	17.65
2% AEP	41.37	24.41
1% AEP	47.88	30.60
0.5% AEP	53.98	39.62
0.2% AEP	62.10	-
PMF	1261.01	-

6.3. Comparison to Flood Study

A comparison between the 1% AEP peak flood levels from this FRMS&P and the Flood Study (Reference 4) is provided on Figure B16. As described in Section 5.2, the mainstream design inflows were adopted directly from the Flood Study (and not subject to changes in ARR methodologies), resulting in consistent flood behaviour between the two projects. In the local overland catchments however, the additional runoff generated as a result of ARR 2019 updates (47.88 m^3/s using ARR 2019 compared to 30.60 m^3/s using ARR 1987, mainly as a result of lower applied losses), and with the additional catchment area incorporated into the XP-RAFTS model (see Section 4.1.1), the inundated area within the newly modelled area (see Section 4.1.1) is classified as 'newly flooded', and peak flood levels across the Morundah township increase by up to approximately 0.3 m.

6.4. Hydraulic Hazard Classification

Hazard classification plays an important role in informing floodplain risk management in an area as it reflects the likely impact of flooding on development and people. In the Floodplain Development Manual (Reference 3) hazard classifications are essentially binary – either Low or High Hazard as described on Figure L2 of that document. However, in recent years there has been a number of developments in the classification of hazard especially in *Managing the floodplain: a guide to best practice in flood risk management in Australia (Third Edition)* (Reference 9). 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 9.

The classification is divided into 6 categories (H1-H6), listed in Table B9, 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 B3.

Table B9: 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 B3: Hazard Classifications

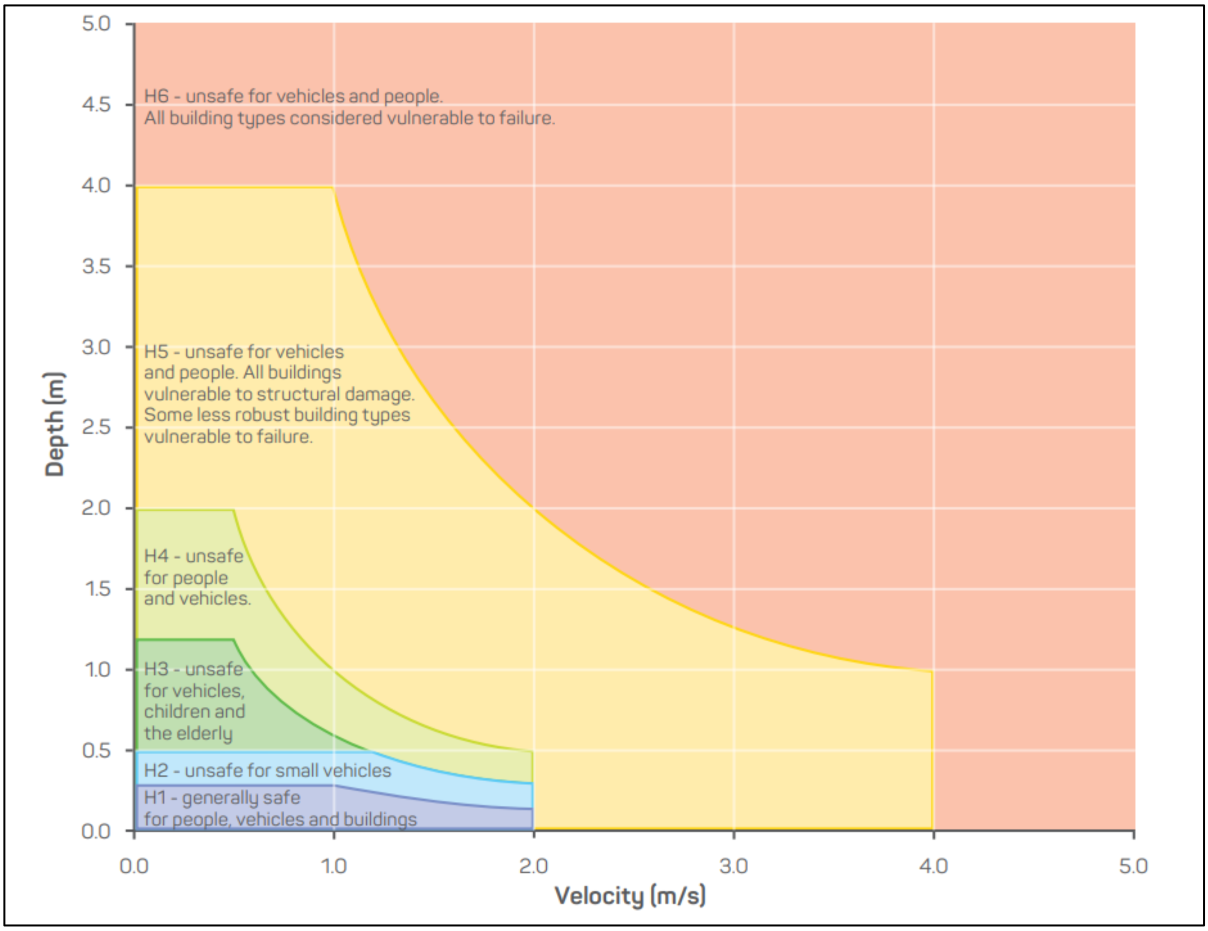


Figure B17 to Figure B19 present the hazard classifications based on the H1-H6 delineations for the 5% and 1% AEP events, as well as the PMF, respectively. In the 5% AEP event, most areas within the developed area of Morundah are classified as H1 "generally safe for people, vehicles and buildings".

Parts of George Street are classified as H2 "unsafe for small vehicles", and Colombo Street near the intersection with Yamma Road is categorised as H3 "unsafe for vehicles, children and elderly". In the 1% AEP event, areas located on the western side of Browley Street are classified as H2 and some areas located on both sides of the Yamma Street are classified as H3. The entire length of Browley Street/ Back Morundah Road are classified as H1. The southern section of Yamma Street is categorised as H2. Much of George Street and Colombo Street are classified as H3.

In the PMF event, most of the developed area in Morundah is categorised as H4 "unsafe for people and vehicles", while parts of Back Morundah Road are categorised as H5 "Unsafe for vehicles and people".

6.5. Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the Floodplain Risk Management process to assist in the assessment of the suitability of future types of land use and development, and the formulation of floodplain risk management plans. The Floodplain Development Manual (Reference 3) defines land inundated in a particular event as falling into one of the three hydraulic categories listed in Table B10.

Table B10: 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.

The 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 in the local overland flow area. The definition of the floodway was reviewed using the Howells et al. (Reference 10) methodology, starting with the depth and velocity criteria adopted by the Flood Study.

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 B11. 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 B11: Hydraulic Category Definition Parameters

Category	Floodway Definition Parameters
Floodway	$V{\times}D > 0.15$ m^2/s and $V > 0.15$ m/s, or $V > 1.0$ m/s and $D > 0$ m
Flood Storage	Areas outside floodway where $D > 0.5$ m
Flood Fringe	Areas outside floodway where $D < 0.5$ m

The resulting hydraulic categorisation for the 5% AEP, 1% AEP and PMF events are shown on Figure B20 to Figure B22, respectively. The analysis indicates that in the 5% and 1% AEP events, only the Yanco and Colombo Creeks and its tributaries are classified as floodways, and out of bank flooding generally classified as flood storage or flood fringe. As Colombo Creek moves downstream of town it appears to be no longer classified as floodway. Majority of areas located within the developed areas of Morundah's township categorised as flood fringe. In the PMF event, the Morundah township is classified as floodway. The 1% AEP results from this FRMS&P are largely consistent with those presented in the Flood Study (Reference 4), with the Floodway generally contained to the channel, flood storage across the showground and upstream of Milvain Drive, with a broad area of flood fringe to the northeast.

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 Morundah 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 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 Morundah. 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, bypass floodways and road raising were found to not be appropriate for Morundah, other types of measures were considered and are discussed in the following sections. Table B12 a summary of the flood modification options considered for Morundah.

Table B12: Flood modification options considered for Morundah

ID	Configuration	Initial Assessment	Recommended for FRMS&P
FMM-01: Morundah Levee Formalisation	Consideration of three alternatives for the Morundah Levee, upgrade, removal and maintenance ('Carry on').	The existing height of the levee is for the most part at or above the 1% AEP flood level. The levee is shown to be protecting 4 properties from over floor inundation but potentially limiting the ability of overland flows to drain, worsening flood behaviour for 9 properties in the 1% AEP event.	Considering the economic viability of the assessed scenarios, FMM-01c ('Carry on' approach) is recommended as a floodplain risk management measure.
FMM-02: Internal drainage improvements (pipe only)	Upgrade the three existing pipes through the levee embankment on Colombo Creek to four 750mm diameter pipes with modified inverts.	Refer to Figure B24 (5% AEP) and Figure B25 (1% AEP). Peak flood levels lower by 0.15m in the 5% AEP event and 0.1m in the 1% AEP event on the western side of Back Morundah Road. Overland flow flood behaviour is not affected upstream (east) of Back Morundah Road (or Browley Street), and properties on Milvain Drive are not directly affected.	**Yes** (Discussed in Section 7.1.2)

ID	Configuration	Initial Assessment	Recommended for FRMS&P
FMM-03: Internal drainage improvements (channel only)	New 3m wide channel with average depth of 0.5m – 1m, and a slope of approximately 0.2% from Back Morundah Road to the Morundah levee. Involves excavation of 2,500 m^3 and culvert upgrades at various road crossings.	Refer to Figure B26 (20% AEP), Figure B27 (5% AEP), Figure B28 (1% AEP). In the 20% AEP event, the channel accelerates the concentration of flow behind the levee and results in an increase in the peak depths of approximately 0.05m – 0.1m in the ponding between the levee and the township. In the 5% AEP and 1% AEP events, the capacity of the channel is far exceeded and has no material impact on flood levels.	No, does not materially change flood risk, high construction costs
FMM-04: Milvain Drive diversion bund	Construction of a 0.6m bund (or embankment) on Milvain Drive to redirect overland flow from the northeast away from properties.	Refer Figure B29 (5% AEP) and Figure B30 (1% AEP). In the 5% AEP event, the properties on both sides of Milvain Drive are completely flood free, as well as some properties on Yamma Street. Upstream of the bund, peak flood levels would be increased by 0.02 m - 0.05 m for a distance of 1 km along the railway line. In the 1% AEP event, peak flood levels in the protected area are reduced by up to 0.1 m (leaving depths of 0.5 m remaining), while on the upstream (eastern) side, peak flood levels would be increased by up to 0.1 m.	**Yes** (Discussed in Section 7.1.3)

7.1.1. FMM-01: Morundah Levee Formalisation

7.1.1.1. Option Description

Morundah is separated from Colombo and Yanco Creeks by a levee and naturally occurring high ground along Colombo Creek's left bank. The flood damages assessment has identified that flood damages resulting from overland flow flooding are far greater than those from mainstream flooding. The levee provides protection to the village from mainstream flooding only and ultimately presents a barrier to drainage of overland flow flooding, exacerbating impacts from this mechanism.

The levee is made up of a licenced section on Crown Land and a section on private property. The levee was initially constructed sometime between 1959 and 1974, with emergency repairs undertaken during the 1974 flood event. Following the 2012 flood event, the Crown Land section of the levee was raised a further 0.8 – 1.0m.

A long section has been prepared to indicate the levee crest/ground level compared to the adjacent 1% AEP mainstream flood level and shows that, for the most part, the ground level is at or above the 1% AEP mainstream flood level, with much of the length of the existing crest more than 0.5 m above the 1% AEP mainstream flood level (shown on Figure B23). No formal design work exists for the levee and much of the previous works have not involved compaction elements and therefore details of the structural integrity are not known.

A definitive level of protection cannot be ascribed to the Morundah levee, and a risk of failure or overtopping exists, depending on the structural integrity and condition of the levee at the time of flooding.

The community and FRMC have suggested the formalisation of the entire levee and an upgrade to the sections located on private property. The following assessment considers the formalisation and upgrade of the Morundah Levee as a flood risk mitigation measure for Morundah. Alternative measures of levee removal and maintenance and 'carry on' have also been considered.

7.1.1.2. Option Assessment

As shown on Figure B23 much of the existing levee crest is already at or above the 1% AEP mainstream flood level and therefore current property affectation in Morundah resulting from mainstream flooding is relatively minimal. Table B13 shows the property affectation and estimated cost of flooding in each design event and mechanism (mainstream and overland) individually. As previously noted, the main cause of property damage in Morundah is derived from overland flooding, which has an estimated damage cost of approximately 7 times that of mainstream flooding.

For reference it is estimated that the 1974 and 2012 flood events, are between a 5% and 2% AEP event and slightly less than a 5% AEP event, respectively for mainstream flooding from Colombo Creek.

Table B13: Property Affectation and Flood Damages

Event	Mainstream			Overland		
	No. Properties Affected (Flooded below floor)	No. Properties Flooded Above Floor Level	Total Damages for Event	No. Properties Affected (Flooded below floor)	No. Properties Flooded Above Floor Level	Total Damages for Event
20% AEP	2	1	$72,900	17	3	$192,000
10% AEP	2	1	$73,300	21	8	$597,700
5% AEP	2	1	$73,400	23	9	$805,100
2% AEP	2	1	$73,600	24	14	$1,145,700
1% AEP	2	1	$73,800	25	19	$1,608,500
0.5% AEP	2	1	$73,900	27	27	$2,473,200
0.2% AEP	3	1	$80,700	27	27	$2,473,200
PMF	6	2	$168,600	30	30	$3,893,000
Average Annual Damages (AAD)			**$25,600**			**$169,000**
Average Annual Damages (AAD) of Combined Mechanism - $194,600*						

* with the levee in place there is relatively limited interaction between the two (mainstream and overland) flood mechanisms.

Given the minimal property affectation due to mainstream flooding and the existing height of the Morundah levee, the benefits to property affectation from raising the levee would be minimal. This, of course does not account for potential structural integrity issues and failure of the levee as a result of this.

When considering options for the Morundah levee, it is important to gain an understanding of what is being protected by the levee, that is the existing value provided by the levee. To understand this, the levee has been removed from the hydraulic model and the results reviewed for the full range of design events for both mainstream and overland flood mechanisms. A comparison of the results for the 1% AEP mainstream event is shown in Diagram B4 and shows that with the levee removed the extent of inundation extends to Back Morundah Road, however flood depths are generally around 0.2m through the township.

Diagram B4: Peak Flood Depth with and without Morundah Levee

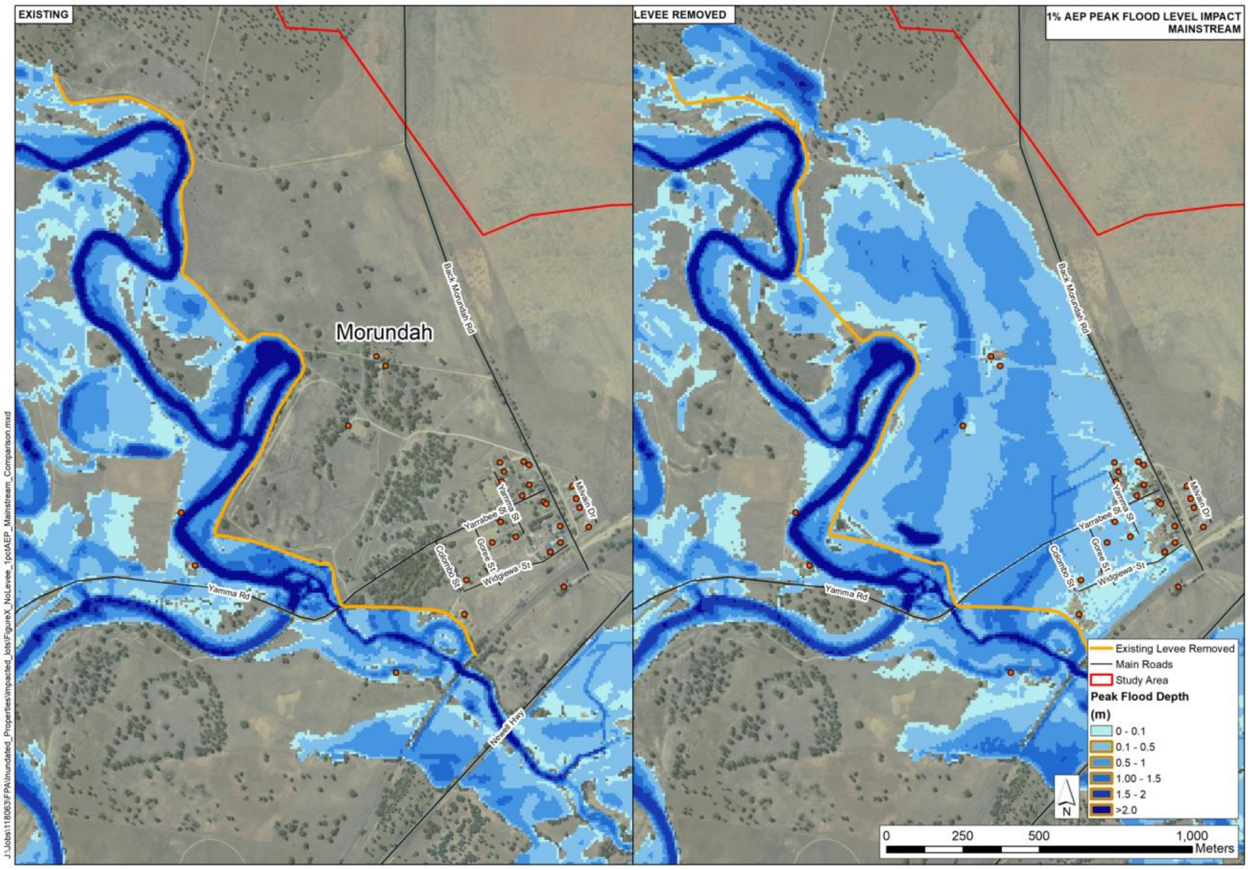


Table B14 shows the change in property affectation and estimated cost of flooding in each design event and mechanism (mainstream and overland), assuming the events occur independently, if the levee was no longer in place. There are an additional 4 properties flooded over floor during a mainstream flood event including the 1% AEP, one of which is located in the township. Conversely, during an overland 1% AEP flood event without the levee in place, there are 9 properties no longer flooded over floor, 6 of which are located in the township. When the levee is removed the overland flow is able to freely drain into Colombo Creek, with flood depths reduced by up to 0.4m through the township.

Looking specifically at the single property in the township impacted during the 1% AEP, under existing conditions with the levee in place, the property does not experience over floor flooding in the mainstream 1% AEP flood event but experiences 0.38m depth of flooding over floor in the 1% AEP overland event. With the levee removed, the same property experiences a depth of 0.06m over floor during the mainstream flood event, while the depth of flooding over floor in the overland flood event is reduced to 0.07m.

Table B14: Change in Property Affectation and Flood Damages (Levee Removed)

Event	Mainstream			Overland		
	No. Properties Affected (Flooded below floor)	No. Properties Flooded Above Floor Level	Total Damages for Event	No. Properties Affected (Flooded below floor)	No. Properties Flooded Above Floor Level	Total Damages for Event
20% AEP	+8	+4	+$123,400	-2	-	-$22,100
10% AEP	+9	+4	+$245,800	-4	-3	-$156,300
5% AEP	+9	+4	+$248,200	-3	-2	-$228,400
2% AEP	+9	+4	+$311,400	-3	-7	-$537,000
1% AEP	+10	+4	+$374,800	-4	-9	-$851,500
0.5% AEP	+10	+4	+$380,500	-3	-15	-$1,631,600
0.2% AEP	+10	+4	+$376,900	-2	-14	-$1,482,800
PMF	+10	+5	+$404,000	-1	-	-$276,600
Average Annual Damages (AAD)			**+$64,900**			**-$54,100**
Average Annual Damages (AAD) of Combined Mechanism - -$18,200*						

* without the levee in place more properties would be impacted by both flood mechanisms (mainstream and overland), the AAD for the combined mechanism takes the worst case.

Overall, the levee prevents over floor inundation to 4 properties across a range of event sizes and reduces average annual damage during mainstream flooding by $64,900 but results in an additional 9 properties flooded over floor in a 1% AEP event and increases average annual damages by $54,100 during overland flood events. A net reduction in average annual damages of $10,800 is provided by the levee when the two mechanisms are considered independently and a net increase in average annual damages of $18,200 when the worst case is taken at each property during a coincident flood event.

As a best case, a net reduction in average annual damages of $10,800, equates to a Net Present Value of $159,481 assuming an effective asset life of 50 years and a 7% discount rate.

The capital costs of the levee upgrade work would derive from investigation, design, earthworks and pipe / culvert installation (as per FMM-02), as well as works to the levee. They will depend on the site specific challenges (such as presence of existing sub-surface services and condition of levee) but are estimated to be approximately $1,030,000 (plus annual maintenance of $5,000). Additional costs may be derived from gate configurations on the creek side of the pipes to prevent backflow during mainstream events. This results in a BCR of 0.14. As such, upgrade of the levee is not considered to be economically viable.

Other aspects that would need to be considered and may increase the capital cost of this option include:

- Review of Flood Frequency Analysis at Narrandera (from which design flows in Yanco Creek are derived) and confirmation of design flood levels at Morundah;
- Freeboard assessment, a high level assessment has indicated that potentially 0.5m may be suitable but this would need to be confirmed;
- Land tenure and easement acquisition of the privately owned portion of the levee;
- Space constraints;
- Internal drainage and flood gate operation, considered as part of option FMM-02 but may need to also include pumping for coincident events;
- Current condition of levee, testing of existing structure would be required to determine structural integrity and suitability.

7.1.1.3. Alternative Options

Remove Levee

The above assessment has shown that when considering the cost of flooding in Morundah, the existing levee has a nearly equitable positive and negative impact on Average Annual Damages in independent mainstream and overland flood events. Given that, it is reasonable to give consideration to the removal of the levee as a potential flood mitigation strategy.

Removal of the levee would involve lowering the crest height and removing the fill from the floodplain. The capital costs of the work would derive from earthworks (6,600 m^3), haulage of spoil out of the floodplain and surface reinstatement and are estimated to be approximately $1,090,000. Additional costs may be derived from bank stabilisation works and supplementary works to reduce third party impacts.

Removal of the levee increases the extent of inundation and flood depths through the township by typically 0.2m (in the 1% AEP mainstream flood event) and would increase average annual damages during a mainstream flood event by $64,900. Approximately one third of this increase is derived from 4 additional properties flooded over floor. Given the small number, it is likely that supplementary works could be developed that would reduce the impacts to these properties. It would not be possible to reduce the impacts of the additional inundation to yards and agricultural land or to roadways, which would result in inconvenience. Due to the limited range of flooding from Colombo Creek, these negative impacts would occur in relatively frequent events such as the 20% AEP, albeit to a slightly shallower depth.

Benefits to flood behaviour would be achieved during overland flood events, where flows could drain more freely into Colombo Creek and flood depths are typically reduced by up to 0.4m through the township in the 1% AEP overland event. This results in a reduction to average annual damages of $54,100.

It is unlikely that this option would be acceptable to the community, particularly given the impacts to areas beyond over floor flooding and the increased nuisance. There is unlikely to be negative environmental impacts, however standard sediment and erosion control measures would be required during levee removal.

Assuming the full benefit to average annual damages in overland flood events could be achieved ($54,100) and the increase to average annual damages in mainstream events could be reduced by one third (to $43,300), the net benefit to average annual damages would be $10,800. This equates to a Net Present Value of $159,481 assuming an effective asset life of 50 years and a 7% discount rate, and results in a BCR of 0.15. As such, removal of the levee is not considered to be economically viable.

'Carry on' Maintenance Approach

This option considers the maintenance and upkeep of the existing levee at its current level and formalisation of the portion of the levee on private property.

As shown on Figure B23 much of the existing levee crest is already at or above the 1% AEP flood level with a significant portion at least 0.5m above the 1% AEP flood level. A high level review of the local factors in Morundah that are accounted for in freeboard, has indicated that 0.5m may potentially be appropriate in this case.

No formal design work exists for the levee and much of the previous works have not involved compaction elements and therefore details of the structural integrity are not known. This option would therefore require a review of the structural integrity of the levee, appropriate repairs, confirmation of the required freeboard, easement acquisition, and ongoing maintenance. Following this assessment, a definitive level of protection could be ascribed to the Morundah levee, allowing for improved operations during flood events including determining appropriate flood gate operation (as part of FMM-02).

The capital costs of work are derived from the investigations, required repairs, and easement acquisition and are estimated to be approximately $550,000. There will also be an ongoing annual maintenance cost in addition to post flood repair work, estimated to be $10,000 per annum.

The option maintains benefits to property and building inundation during a mainstream flow event and is therefore likely to be generally well received. There is unlikely to be negative environmental impacts, however standard sediment and erosion control measures would be required during maintenance works.

As previously noted, the main cause of property damage in Morundah is derived from overland flooding, which has an estimated damage cost of approximately 7 times that of mainstream flooding. The assessment of the removal of the levee has identified that the impacts of overland flooding are increased by the levee with a lift to average annual damages of $54,100. Alternative options to improve overland flooding have therefore been considered in FMM-02 and FMM-04.

Assuming the full benefit to average annual damages in mainstream flood events could be achieved ($64,900) and the increase to average annual damages in overland flood events could be reduced by alternative options, the net benefit to average annual damages would be $58,900. This equates to a Net Present Value of $869,764, assuming an effective asset life of 50 years and a 7% discount rate, and results in a BCR of 1.25. As such, maintaining the existing levee is considered to be economically viable.

With the potential reduction in impacts due to overland flooding as part of FMM-02 and FMM-04, and maintaining the levee there are benefits to property during all design events modelled and therefore the works are likely to be eligible for grant funding to cover the capital costs.

7.1.1.4. Recommendation

FMM-01: Morundah Levee Formalisation

☒ FMM-01a (Formalisation and Upgrade) is not recommended as a floodplain risk management measure.

☒ FMM-01b (Removal) is not recommended as a floodplain risk management measure.

☑ FMM-01c (Carry On) is recommended as a floodplain risk management measure.

7.1.2. FMM-02: Internal Drainage Improvements (Pipes Only)

7.1.2.1. Option Description

Local overland flow draining towards Colombo Creek is obstructed by the existing levee embankment and ponds on the upstream (eastern) side. At the time or writing, there were three pipes through the levee, with diameters of 0.205 m, 0.375 m and 0.450 m. This option proposes replacing the existing three pipes with 0.75 m pipes, the addition of a 4th pipe and refining the invert levels to better facilitate drainage of internal runoff. The objective of the option is to allow internal overland flow to drain more readily through the pipes, and reduce the depth of ponding behind the levee. It is noted that this option would not be effective in reducing internal flooding when levels in Colombo Creek are elevated, however would assist in drainage when flood levels recede, and may reduce pumping requirements, which may have assisted in the March 2012 event. The following changes have been proposed:

Table B 15 FMM-01 Proposed Pipe Modifications

Culvert ID	Type	Original Size	Proposed Size
L1	CU	ϕ 0.205m	ϕ 0.75m
L2	CU	ϕ 0.375m	ϕ 0.75m
L3	CU	ϕ 0.45m	ϕ 0.75m
L4 (new)	CU	-	ϕ 0.75m

7.1.2.2. Options Assessment

Modelled Flood Behaviour

The effect of the above works on peak flood levels in the 5% AEP and 1% AEP overland flow events are shown on Figure B24 and Figure B25 respectively. The modified pipes improve drainage across Morundah on the downstream (western) side of Back Morundah Road, however the impact on peak levels is widespread but relatively minor – reducing levels by 0.15 m in the 5% AEP event and 0.1 m in the 1% AEP event. Overland flow flood behaviour is not affected upstream (east) of Back Morundah Road (or Browley Street), and properties on Milvain Drive would not benefit directly from this option. The option does not alter mainstream flood behaviour.

Costs and economic viability

The capital costs of the work would derive from design, earthworks and pipe / culvert installation, as well as works to the levee. They will depend on the site specific challenges (such as presence of existing sub-surface services and condition of levee) but are estimated to be approximately $130,000 (plus annual maintenance of $2,000). Additional costs may be derived from gate configurations on the creek side of the pipes to prevent backflow during mainstream events. Average annual damages were calculated assuming the option is in place, which provided a reduction to the AAD of $34,000 (20%). This equates to a Net Present Value of $502,071 assuming an effective asset life of 50 years and a 7% discount rate, and results in a BCR of 3.15. As such, the option is considered to be economically viable.

Social and environmental impacts

The option provides benefit to property and building inundation during an overland flow event, as well as likely to reduce nuisance ponding from heavy rainfalls, and is therefore likely to be generally well received. There is unlikely to be negative environmental impacts, however standard sediment and erosion control measures would be required during construction.

Financial viability

During both the 2% and 1% AEP overland flow events, 4 properties are no longer flooded over floor with this option in place. There are other minor benefits to property during all design events modelled and therefore the works are likely to be eligible for grant funding to cover the capital costs.

Other considerations

The main difficulties would lie in the operation of the flood gates (assuming a manual system), during a mainstream flood. There are likely to be some construction challenges with tunnelling or trenching through existing levee bank whilst maintaining levee structure. These aspects may possibly increase the capital costs of the works.

7.1.2.3. Recommendation

FMM-02: Internal Drainage Improvements (Pipes Only)

☑ Option FMM-02 is recommended as a flood risk management measure.

7.1.3. FMM-04: Milvain Drive Diversion Bund and Culvert Upgrades

7.1.3.1. Option Description

Following reports of over-floor flooding of properties in Milvain Drive in the 2012 flood event, this option was suggested by the FRMC and involves construction of a low bund (or embankment) to redirect overland flow from the northeast around these dwellings to prevent property damage. The alignment of the proposed bund (or embankment) is shown on Figure B29.

The bund was assumed to be 0.6 m high, and designed to protect the properties from flooding in a 5% AEP event, and provide some relief from the 1% AEP event. A range of alignments were tested, and it was found that the bund had to extend to the south east across Back Morundah Road to prevent flow from entering on the downstream side.

7.1.3.2. Options Assessment

Modelled Flood Behaviour

The effects of this bund on peak flood levels in the 5% AEP and 1% AEP overland flow events are shown on Figure B29 and Figure B30. In the 5% AEP event, the properties on both sides of Milvain Drive are completely flood free, as well as some properties on Yamma Street. Upstream of the bund, peak flood levels would be increased by 0.02 m - 0.05 m for a distance of 1 km along the railway line, however it is unlikely that this increase would materially increase the flood risk, particularly as no dwellings would be adversely affected. In the 1% AEP event, peak flood levels in the protected area are reduced by up to 0.1 m (leaving depths of 0.5 m remaining), while on the upstream (eastern) side, peak flood levels would be increased by up to 0.1 m. The current alignment was selected to retain clearance from the railway embankment (so as not to trigger a demanding approvals process), however this would result in a small portion of the Browley Street roadway subject to exacerbated flood levels. Locally raising Browley Street may be a preferred solution to this, and may be necessitated to grade up to the bund crest.

Costs and economic viability

Costs of the option would comprise design and earthworks for the bund, and roadworks associated with the crossing of Back Morundah Road. Ongoing maintenance would also be required. The costs of the works are estimated to be $370,000 (plus annual maintenance of $2,000). Additional costs may be derived from related easement acquisition costs. Average annual damages were calculated assuming the option is in place, which provided a reduction to the AAD of $89,900 (53% reduction). This equates to a Net Present Value of $1,327,535 assuming an effective asset life of 50 years and a 7% discount rate, and results in a BCR of 3.32. As such, the option is considered to be economically viable.

Social and environmental impacts

There may be social equity issues regarding which dwellings to protect, as well as negative impacts on some areas, although no dwellings are impacted. Tenure issues of land along the proposed easement would need to be resolved. Unlikely to result in environmental impacts, though standard sediment and erosion control measures would be required during construction.

Financial viability

There are significant benefits to over floor inundation up to the 2% AEP overland event with this option in place; 2 properties in the 20% AEP, 5 properties in the 10% AEP, 6 properties in the 5% AEP and 2 properties in the 2% AEP are no longer impacted by overland flow events. There are limited benefits in the larger events. The works are likely to be eligible for grant funding to cover the capital costs.

7.1.3.3. Recommendation

FMM-04: Milvain Drive Diversion Bund and Culvert Upgrades

☑ Option FMM-04 is recommended as a flood risk management measure.

7.1.4. FMM-02 and FMM-04 COMBINED

7.1.4.1. Option Description

A scenario was assessed which included FMM-02 (internal drainage pipe upgrades) (Section 7.1.2) and FMM-04 (Milvain Drive diversion bund) (Section 7.1.3) to determine if there are potentially cumulative benefits from implementing both options. As overland flow is the main cause of flood damage in Morundah (approximately 7 times the average annual damages than caused by mainstream flooding), a combined option that improves the impacts of an overland flow event will significantly benefit Morundah.

7.1.4.2. Options Assessment

Modelled Flood Behaviour

The effect of the combined works on peak flood levels in the 5% AEP and 1% AEP overland flow events are shown on Figure B31 and Figure B32 respectively. In comparison to the assessment of options alone, the combined option shows a greater improvement to flood behaviour to the south of Widgiewa Street, with flood level reductions increasing to 0.015m in both events. There is a slightly greater impact to flood behaviour immediately upstream of the Milvain Drive bund with flood level increases up to 0.05m, again this area contains no dwellings. Other changes in flood behaviour remain the same as the assessment of the options individually. The combined option does not alter mainstream flood behaviour.

Costs and economic viability

The capital costs of the combined works is likely in the order of $500,000 (plus annual maintenance of $2,000). There may be some potential savings by undertaking the design and construction of the works at the same time. Average annual damages were calculated assuming the combined option is in place, which provided a reduction to the AAD of $163,000 (96%). This equates to a Net Present Value of $2,406,988 assuming an effective asset life of 50 years and a 7% discount rate, and results in a BCR of 4.55. As such, the option is considered to be economically viable, removing a significant amount of the impacts of overland flooding.

Social and environmental impacts

The combined option provides benefit to property and building inundation during an overland flow event, as well as likely to reduce nuisance ponding from heavy rainfalls, and is therefore likely to be generally well received. The combined option also minimises potential social equity issues regarding which dwellings to protect. While some negative impacts remain, no dwellings are impacted. There is unlikely to be negative environmental impacts, however standard sediment and erosion control measures would be required during construction.

Financial viability

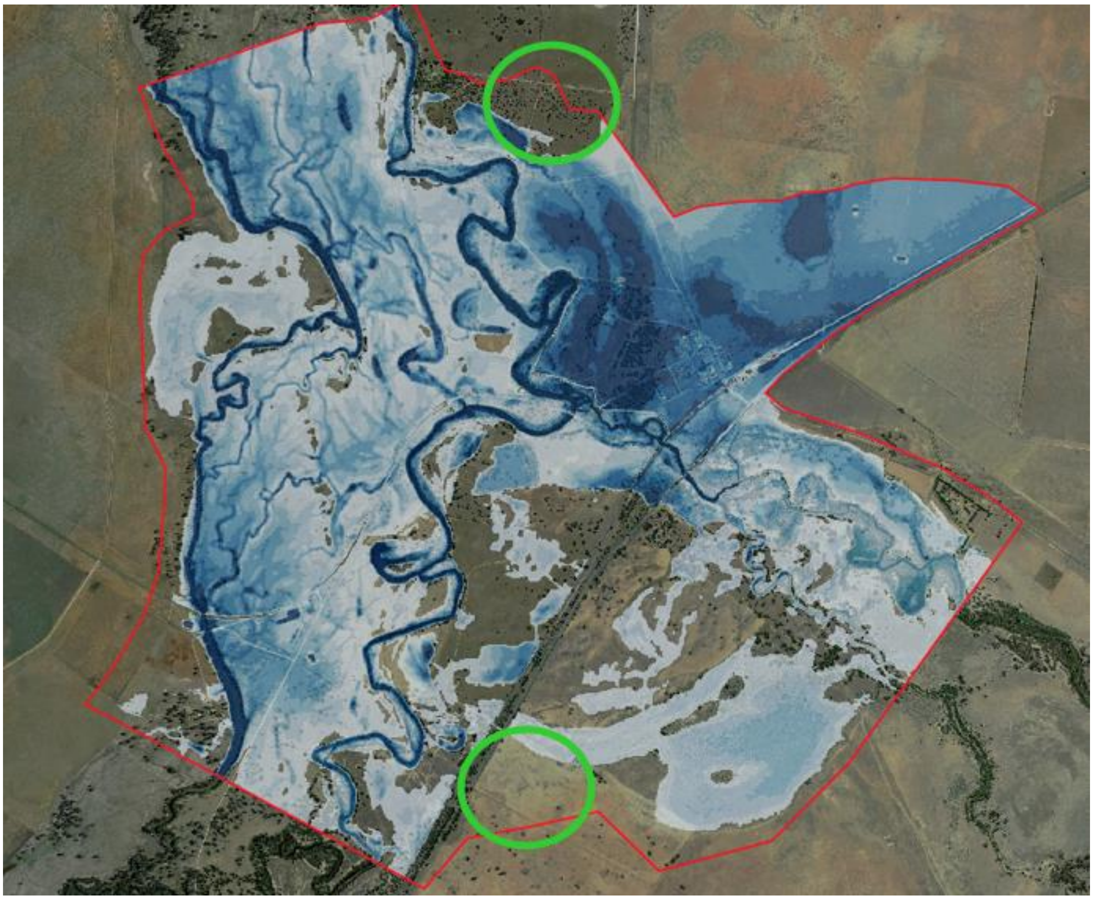
As with the individual options there is significant benefits to over floor inundation at properties. Additionally, two additional properties benefit from the additional reduction in flood levels in the vicinity of Widgiewa and Yamma Streets. The combined works are likely to be eligible for grant funding to cover the capital costs.

7.2. Response Modification Measures

7.2.1. RMM-01: Formal Evacuation Location

Currently, there is no formal location for sheltering following evacuation due to flooding for residents of Morundah. 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 is quite complex in the area surrounding Morundah, with a number of meandering tributaries and isolated areas of high ground. As such, a single evacuation point may not be suitable for the safe evacuation of the local residents.

A review of the floodplain and key access routes was undertaken, which identified high ground to the north and south as shown in the image below. The southern route would most likely service residents located in or near the town centre, with residents being able to walk along the raised railway embankment if required. In previous flood events it has been noted that the community utilise the elevated rail embankment for the storage of possessions.



These options should be discussed with the local community to determine the most appropriate location for an evacuation shelter. 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 should also be considered whether other, informal sites, should be identified to service residents nearer the western or eastern edges of the floodplain.

It will also 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.

7.2.1.1. Recommendation

RMM-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 15). 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. One property in Morundah 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 property is raised to the 1% plus 300mm level, and allowing for a 20% contingency factor. The option was tested for both 4%, 7% and 10% discount rates. Results are shown in Table B16..

Table B 16: VHR economic assessment for Morundah – overland flooding

Option	NPV Costs	Change in AAD	NPV Benefits	Discount rate	BCR
Raising B014	**$72,000**	**$1,567**	**$23,743**	**7%**	**0.16**
			$38,126	4%	0.26
			$17,215	10%	0.12

This shows that a voluntary house raising scheme is not economically viable, and other management options are likely to be more suitable for managing the flood risk.

7.3.1.2. Recommendation

PMM-01: Voluntary House Raising

VHR is not recommended for Morundah.

7.3.2. PMM-02: Voluntary Purchase

Voluntary Purchase (VP) schemes are a long-term option to permanently remove residential properties from areas of high flood hazard where there is a real risk to life (to residents and rescuers) during flood events. VP schemes can be eligible for state government funding if undertaken in accordance with the published guidelines (*Guidelines for Voluntary Purchase Schemes* (Reference 16)), which includes criteria for identifying properties; which in additional to properties in highly hazardous areas includes properties located in the floodway where their removal would improve conveyance or their removal enables other flood mitigation works to be implemented.

In the NSW Government *Guidelines for Voluntary Purchase Schemes* (Reference 16), 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.
The property spreadsheet developed as part of this FRMS was used to initially identify any potential properties which meet the criteria provided in state guidelines (Reference 16). For VP this is properties located within a floodway, or highly hazardous flood conditions (H4 to H6).

The 1% AEP floodway extent is generally confined to the Colombo and Yanko Creek channels, whereas he residential development in Morundah mainly occurs in areas of flood fringe, where the depths and risks are at lot lower. As such, no eligible properties were identified and a VP scheme is not recommended.

7.3.2.1. Recommendation

PMM-02: Voluntary Purchase scheme

A VP scheme is not recommended for Morundah.

7.4. Summary of Recommended Options

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

Reference	Name	Type
FMM-01	Morundah levee formalise ownership and maintenance of existing levee ('Carry On')	Flood modification
FMM-02	Morundah levee Internal Drainage Improvements (pipes only)	Flood modification
FMM-04	Milvain Drive diversion bund and culvert upgrade	Flood modification
RMM-01	Formalise evacuation locations	Response modification

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

8. REFERENCES

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February 2020

Attachment 1

Morundah Critical Duration Assessment – Supporting Material

To determine the critical duration (the duration of rainfall over the local catchment that will result in the greatest depth of flooding) in Morundah, ARR 2019 recommends than an ensemble approach is used, where 10 temporal patterns (see Section 5.3.3 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.

Four key sub-catchment outlet locations were chosen to assess the peak flows generated by rainfall over the Morundah catchment using the XP-RAFTS model. The chosen sub-catchments are listed below and are shown on Figure D5:

- No. 1 – Large area bounded by Back Morundah Road and the Railway Embankment, covering open rural area;
- No. 3 – Bounded by Browley Street,;Yarrabee Street, the railway embankment and Colombo Creek;
- No. 6 – Sub Catchment covering the racecourse; and
- No. 7 – Newly added catchment area northeast of Morundah, bounded along its eastern edge by the railway embankment.

The 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 D1 to Diagram D4.

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 D1: Box plot of peak local flows at sub-catchment No.1 of different durations: 1% AEP event

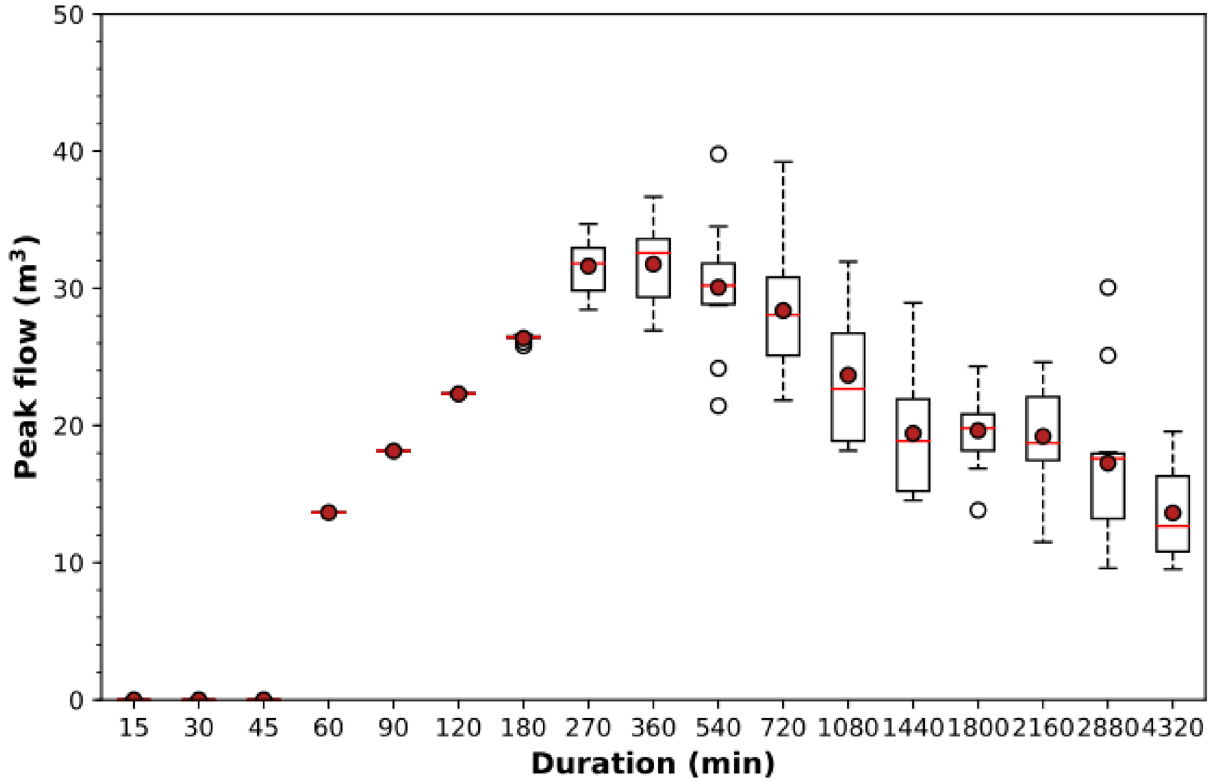


Diagram D2: Box plot of peak local flows at sub-catchment No.7 of different durations for 1% AEP event

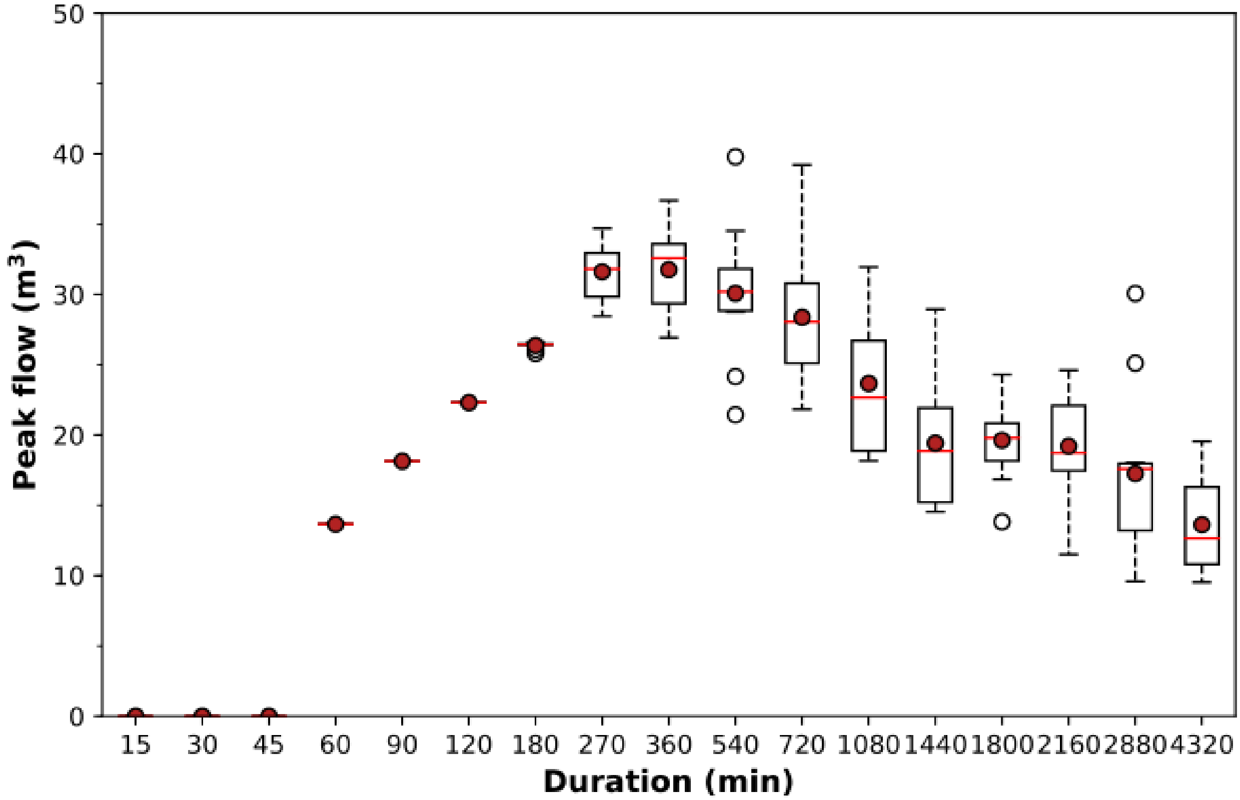


Diagram D3: Box plot of peak total flows at sub-catchment No.3 of different durations for 1% AEP event

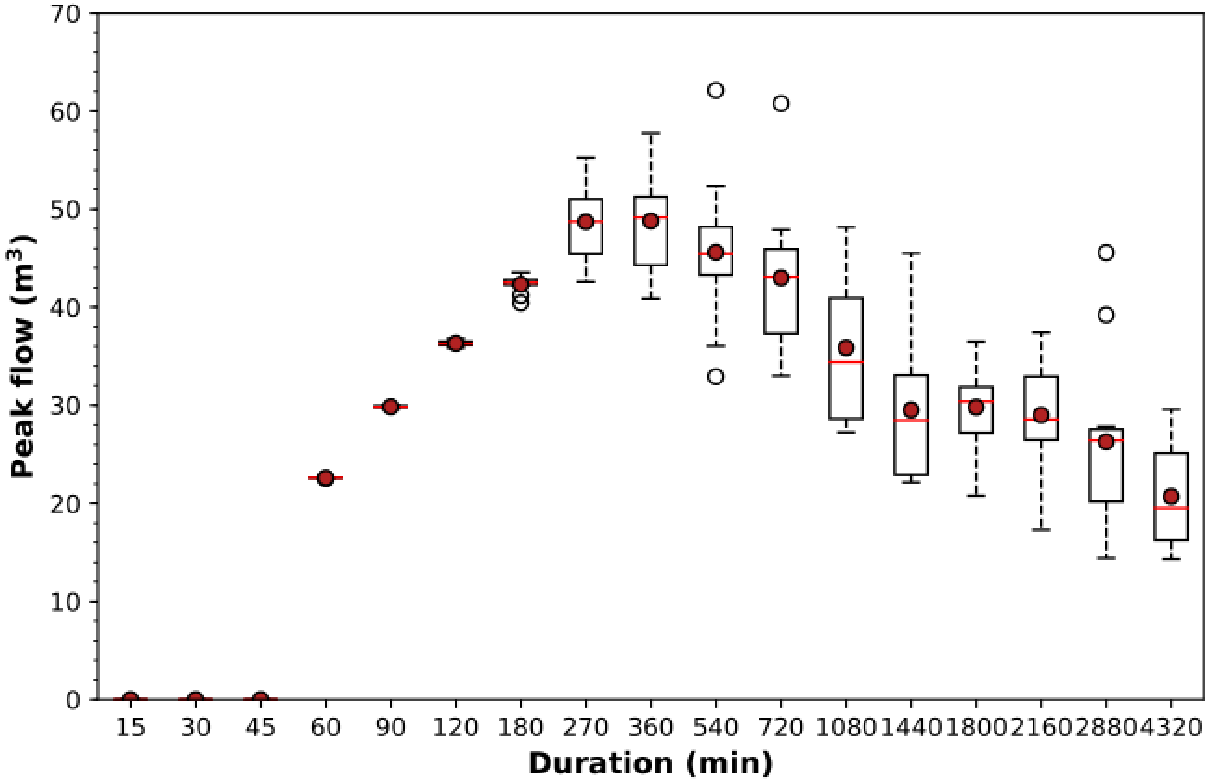
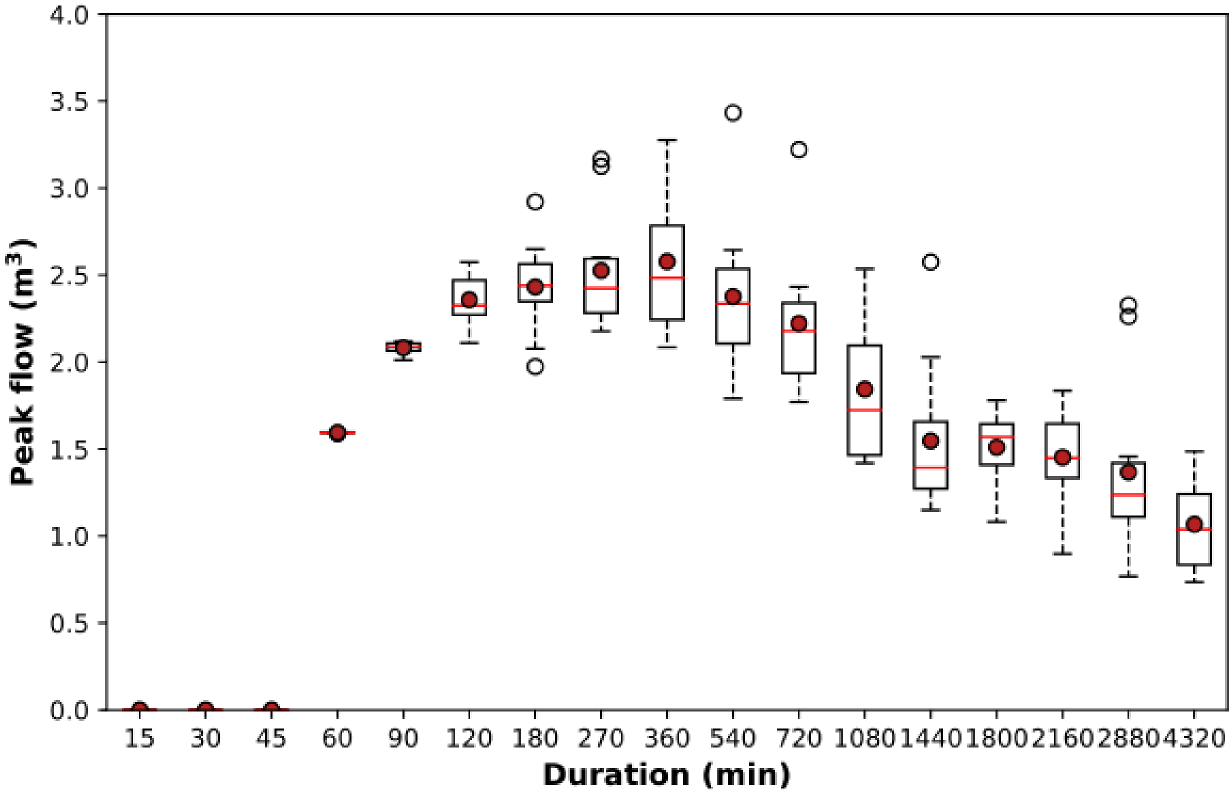


Diagram D4: Box plot of peak total flows at sub-catchment No.6 of different durations for 1% AEP event



A preliminary determination of the critical duration based on XP-RAFTS box plots revealed that for 1% AEP event, similar mean peak flows occurred for a range of durations from 270 minutes to 540 minutes. Diagram D1 to Diagram D4 show that, in general, the 360 minute (6 hours) storm is critical at sub-catchments No.1, 3, 6 and 7, producing the highest mean flows from the ensemble of temporal patterns. It can be seen from the box plot in Diagram D1(for sub-catchment No.1), that the mean flow from the 360 minutes storm (the critical flow) is within range of flows produced in other storm durations – from 270 minutes to 540 minutes. This means that there is likely to be a temporal pattern in other durations that closely matches the critical flow.

Critical Duration Assessment Results

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), and the 'winning' storm duration and temporal pattern were applied to the smaller events within each bin. Table D1 presents a summary of the critical duration and adopted temporal pattern for each design flood event.

Diagram D5: Temporal Pattern Bins

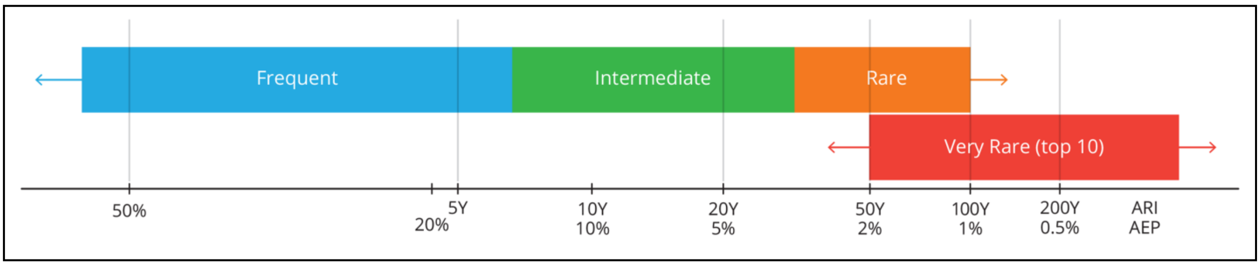


Table D1: Adopted durations and temporal patterns for design flood events

Event	AEP Bin	Adopted Duration (mins)	Adopted Temporal Pattern	XP-RAFTS Total peak flood discharge (m^3/s) at the catchment outlet
0.2EY	Frequent	540	TP5: 4072	19
10% AEP	Intermediate	540	TP6: 4063	25
5% AEP	Intermediate	540	TP6: 4063	31
2% AEP	Rare	540	TP7: 4054	41
1% AEP	Rare	540	TP7: 4054	48
0.5% AEP	Rare	540	TP7: 4054	54
0.2% AEP	Rare	540	TP7: 4054	62
PMF	Not applicable	120	Not applicable	1261

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	146.313
Latitude	-34.913
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

Data

River Region

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

Layer Info

Time Accessed	14 February 2019 03:55PM
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 03:55PM

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	10749.0
Storm Initial Losses (mm)	26.0
Storm Continuing Losses (mm/h)	0.0

Layer Info

Time Accessed	14 February 2019 03:55PM
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 03:55PM
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 03:55PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-34.9125&longitude=146.3125&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 03:55PM

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)	0.9 (0.054)	0.8 (0.037)	0.8 (0.030)	0.8 (0.025)	0.4 (0.010)	0.1 (0.002)
90 (1.5)	1.8 (0.101)	1.2 (0.046)	0.7 (0.024)	0.3 (0.009)	0.6 (0.014)	0.8 (0.017)
120 (2.0)	2.3 (0.114)	1.6 (0.058)	1.1 (0.035)	0.7 (0.019)	0.5 (0.011)	0.3 (0.006)
180 (3.0)	1.1 (0.047)	1.0 (0.033)	1.0 (0.028)	1.0 (0.023)	0.9 (0.018)	0.8 (0.014)
360 (6.0)	0.4 (0.015)	1.2 (0.031)	1.7 (0.038)	2.2 (0.042)	1.7 (0.026)	1.2 (0.018)
720 (12.0)	0.0 (0.000)	0.4 (0.009)	0.7 (0.012)	0.9 (0.015)	2.0 (0.027)	2.8 (0.033)
1080 (18.0)	0.0 (0.000)	0.1 (0.002)	0.1 (0.002)	0.2 (0.003)	0.8 (0.010)	1.2 (0.013)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.3 (0.003)	0.5 (0.005)
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 03:55PM

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 03:55PM
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)	0.0 (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 (0.002)	0.0 (0.001)	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 03:55PM
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)	6.8 (0.426)	8.9 (0.399)	10.2 (0.384)	11.5 (0.371)	8.8 (0.236)	6.7 (0.160)
90 (1.5)	11.3 (0.620)	12.6 (0.498)	13.4 (0.443)	14.2 (0.402)	13.4 (0.318)	12.9 (0.270)
120 (2.0)	11.4 (0.571)	11.9 (0.432)	12.3 (0.372)	12.6 (0.328)	13.3 (0.289)	13.8 (0.265)
180 (3.0)	8.1 (0.358)	9.8 (0.314)	10.9 (0.292)	11.9 (0.275)	13.6 (0.264)	14.9 (0.256)
360 (6.0)	5.0 (0.180)	8.4 (0.220)	10.6 (0.235)	12.8 (0.243)	15.1 (0.243)	16.9 (0.241)
720 (12.0)	3.6 (0.103)	5.3 (0.115)	6.5 (0.119)	7.7 (0.121)	11.8 (0.157)	14.9 (0.177)
1080 (18.0)	1.0 (0.027)	2.9 (0.057)	4.2 (0.069)	5.4 (0.077)	9.8 (0.118)	13.1 (0.141)
1440 (24.0)	0.0 (0.000)	1.4 (0.025)	2.3 (0.035)	3.2 (0.042)	5.2 (0.059)	6.7 (0.068)
2160 (36.0)	0.0 (0.000)	0.2 (0.004)	0.4 (0.005)	0.5 (0.007)	2.9 (0.030)	4.6 (0.042)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.3 (0.003)	0.6 (0.005)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	14 February 2019 03:55PM
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)	18.2 (1.135)	21.6 (0.973)	23.9 (0.898)	26.1 (0.839)	22.8 (0.613)	20.4 (0.484)
90 (1.5)	20.9 (1.143)	24.7 (0.978)	27.2 (0.901)	29.7 (0.841)	25.8 (0.612)	22.9 (0.480)
120 (2.0)	27.8 (1.392)	26.2 (0.950)	25.1 (0.762)	24.1 (0.627)	29.8 (0.648)	34.0 (0.654)
180 (3.0)	15.4 (0.678)	20.0 (0.644)	23.1 (0.623)	26.1 (0.604)	27.5 (0.534)	28.6 (0.491)
360 (6.0)	18.8 (0.669)	21.3 (0.558)	23.0 (0.507)	24.5 (0.468)	30.4 (0.488)	34.9 (0.497)
720 (12.0)	14.0 (0.406)	16.7 (0.359)	18.5 (0.336)	20.1 (0.318)	24.5 (0.327)	27.7 (0.330)
1080 (18.0)	8.0 (0.207)	11.6 (0.224)	14.0 (0.230)	16.3 (0.232)	21.8 (0.262)	25.9 (0.278)
1440 (24.0)	2.7 (0.064)	6.4 (0.115)	8.9 (0.136)	11.3 (0.150)	15.9 (0.179)	19.4 (0.194)
2160 (36.0)	0.4 (0.009)	3.9 (0.063)	6.1 (0.085)	8.3 (0.101)	16.1 (0.165)	21.9 (0.200)
2880 (48.0)	0.0 (0.000)	2.5 (0.039)	4.2 (0.055)	5.8 (0.066)	8.9 (0.086)	11.2 (0.097)
4320 (72.0)	0.0 (0.000)	1.5 (0.021)	2.5 (0.030)	3.4 (0.036)	8.6 (0.077)	12.6 (0.100)

Layer Info

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

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

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

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	**50**	**20**	**10**	**5**	**2**	**1**
60 (1.0)	16.0	11.9	10.5	10.2	10.5	10.1
90 (1.5)	18.3	11.2	10.2	10.5	10.4	9.6
120 (2.0)	18.5	10.9	10.7	11.1	10.9	8.3
180 (3.0)	20.5	13.4	12.2	12.4	11.3	9.2
360 (6.0)	20.7	14.2	13.2	13.4	11.4	7.8
720 (12.0)	21.9	16.4	15.9	16.1	14.1	9.1
1080 (18.0)	23.6	18.3	17.6	17.9	15.9	10.5
1440 (24.0)	24.8	20.2	19.8	19.9	18.0	13.3
2160 (36.0)	25.7	21.3	21.2	21.4	19.6	14.5
2880 (48.0)	25.9	21.6	22.0	22.3	21.1	17.1
4320 (72.0)	26.1	22.1	22.8	23.3	21.6	17.5

Layer Info

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

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