FEDERATION COUNCIL

APPENDIX C
OAKLANDS

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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Date 11 March 2022	**Verified by** Erin Askew

Revision	Description	Distribution	Date
5	Final	Council, DPIE	Mar 2022
4	Draft for Public Exhibition – Appendix C	Council, DPIE, PE	Dec 2021
3	Draft Report – Appendix C	Council, DPIE	Apr 2021
2	Stage 2 Report – Appendix E	Council, DPIE	Feb 2020
1	Stage 1 Report	Council, DPIE	Jun 2019

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1. BACKGROUND

1.1. Study Area

The Oaklands township is approximately 615 km southwest of Sydney and 105 kilometres northwest of Albury. The region of Oaklands has a population of 227 (2016 Census), and 134 private dwellings. The major watercourse in the vicinity of Oaklands is Nowranie Creek, a flood runner of Billabong Creek. Flows in Billabong Creek break out and flow along Nowranie Creek and Wangamong Creeks downstream of Walbundrie and upstream of Rand. Nowranie Creek has two major breakout points which are located upstream of Urana-Corowa Road which re-join Billabong Creek downstream of the Oaklands Railway line.

Oaklands is located approximately 2.6 km south of Nowranie Creek, and is elevated some 20 m above the creek level. As such, the township is outside of the Nowranie Creek floodplain and is not subject to mainstream flood risk from this creek. Flood risk in the Oaklands urban area stems from overland flow generated by local rainfall rather than mainstream flooding. Characterised by shallow sheet flow, the flood risk is relatively limited, however does cause nuisance inundation of roads and lower lying parts of Oaklands. The Oaklands Study Area is presented on Figure C1.

1.2. Land Use

The entire town of Oaklands is zoned as “RU5 Village” with the surrounding areas zoned as “RU1 Primary Production”. Nowranie Creek located 2.6 km north of the town, is zoned as a “Major River” as shown on Figure C2.

The major facilities in town include: Oaklands Train Station, Oaklands Central School, Doug Kerr Vintage Museum, Oaklands RSL Bowling Club, Oaklands Swimming Pool and Oaklands Recreation Reserve. The Doug Kerr Vintage Museum is one of few museums located in the region and contains the local history of agricultural and mining machinery. The Oaklands Swimming Pool is located in the centre of the town, within walking distance from the main street (Milthorpe Street), and the Oaklands Recreation Reserve functions as the local AFL ground.

A railway line passes through the town on its west side, connecting neighbouring towns and transporting goods such as wheat and rice as it is a major grain handling area. Seasonal trains service the grain silos.

1.3. Demographic Overview

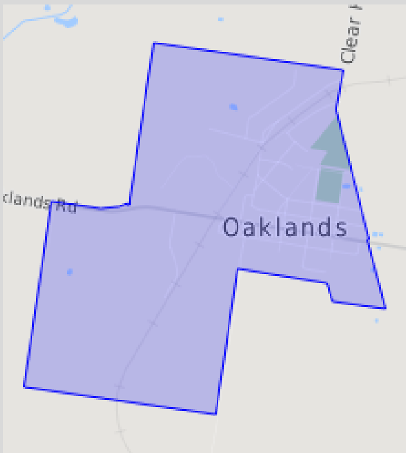
Understanding the social characteristics of the Study Area can help in ensuring appropriate risk management practices are adopted, and shape the methods used for community engagement. Census data regarding house tenure and age distribution can also provide an indication of the community’s lived experience with recent flood events, and hence an indication of their flood awareness.

According to The Bureau of Meteorology Flood Preparedness Manual (Reference 5), it is also possible, using population census data and other information held by councils and state agencies, to identify the potential number and location of people in an area (or the proportion of the community's population) with special needs or requiring additional support during floods. The Flood Preparedness Manual identifies that, in general, people who belong to the following groups may be considered especially susceptible to the hazards floods pose:

- **The elderly**, especially those living alone and/or frail, who are often unable to respond quickly or without assistance;
- **Those with low incomes**, including the unemployed and others on pensions, who may lack resources which would give them independence of decision making and action;
- **Single-parent families, large families or families with very young children**: these may be characterised by 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 Oaklands and are relevant to the above considerations. Population Characteristics are compared to the NSW average in Table C 1.

Oaklands Region Demographic Overview



Population: 227

No. of Private Dwellings: 134

No. of lone person households: 33

Property Tenure:

- 76.5% owned (either outright or with a mortgage)
- 17.6% rented

Language

- 95.2% of people speak only English at home

No. persons over the age of 75: 21

Elderly people are often frailer and may be unable to respond as quickly to flood emergencies without requiring some assistance.

No. single-parent families: 8

Single parent families can mean a low adult-to-child ratio within the household and therefore can make evacuation more difficult.

Statistics from: http://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/UCL122112?opendocument#internet

Table C 1: Characteristics of Oaklands (Australian Bureau of Statistics, 2016)

Characteristic	Oaklands	NSW
Population Age: 0 – 14 years 15 - 64 years > 65 years	 18.5% 58.1% 23.4%	 18.5% 65.3% 16.2%
Average people per dwelling	2.1	2.6
Own/mortgage property **Rent property** **Other tenure type/not stated**	76.5% 17.6% 5.9%	64.5% 31.8% 3.7%
No cars at dwelling	4%	9.2%
Speak only English at home	95.2%	68.5%

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

In addition to informing communication strategies, census data can be used as an indicator of a community's vulnerability in regard to flood risk management. In particular, aged residents are more likely to be frail and physically unable to respond as quickly to flood emergencies. Provision of assistance to such residents should be a key consideration when developing flood evacuation systems and the lead time with which warnings are provided. The family composition within a residence can also affect flood awareness and capacity to respond. In Oaklands there are 33 lone person households, who are at greater risk of being unaware of flood warnings or evacuation orders.

There are also a number of single-parent families, which can mean a low adult-child ratio and result in difficulties preparing for and safely undertaking evacuations). It is noted however that with small communities often comes a high degree of connectedness between residents, which can significantly reduce the effect of these challenges.

1.4. Local Environment

Oaklands, in the Wiradjuri nation located 105 km northwest of Albury, is a remote village in the Riverina district of New South Wales and 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. Oaklands is located approximately 2.6 km south of Nowranie Creek and 2 km east of O'dwyer Main Channel, tributaries that indirectly flow into the Murrumbidgee River and ultimately towards the Murray River in the Murray Darling Basin.

Oaklands consists of a small village surrounded by land primarily used for agriculture producing wheat, rice, and grain. Oaklands railway line ships local produce towards Benalla, Victoria. Large portions of the area surrounding Oaklands has been cleared for farming, though native fauna is still present.

The sandy loam soils allow fast drainage of water, however cannot easily retain moisture. Local agriculture can cause soil compaction which reduces the hydraulic conductivity of the soil and hinder water infiltration rates.

Oaklands can be prone to extended periods of no rainfall, which can increase surface water pollution, decrease agricultural yield, cause soil erosion, and water shortages.

The use of on-site sewage management systems (OSSMS) in the Federation Council area has brought attention to the issues on the negative impacts by these systems. OSSMS are miniature sewage treatment plants. If poorly designed and maintained, it will cause problematic effects including public health risk, water pollution of local creeks/rivers, agricultural land degradation and local amenity issues. OSSMS is commonly used on properties on the outskirts of Oaklands where the current reticulated sewerage network does not reach. However, many of these properties are situated on larger lots, allowing enough space for effective wastewater disposal. Oaklands is fortunate to be supplied potable drinking water by Riverina Water, however environmental protection of the nearby tributaries of the Murray Darling Basin are a high priority. Council recently adopted an OSSMS strategy in November 2018 providing a management framework, allowing effective regulation of the system as well as the protection of the environment and public health associated with the system (Federation Council 2018).

2. PREVIOUS STUDIES

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

The Flood Study Report for Oaklands was completed for Council in 2017 by Jacobs to define the nature and extent of flood behaviour for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF. The town has not been impacted by riverine flooding in the past but may be impacted by local runoff flooding from severe storm events. The Flood Study (Reference 4) approached the estimation of design flood modelling as follows:

- A RORB hydrologic model was established for the full Billabong Creek catchment (as part of the Flood Study for Rand, covering 2,620 km^2) to develop design hydrographs at the Billabong Creek gauge at Walbundrie;
- A MIKE11 hydraulic model was developed to route flows from Walbundrie gauge, along Billabong Creek (to Rand, as well as a range of flood runners). Nowranie Creek is a flood runner of Billabong Creek. Design flows in Nowranie Creek were extracted from the MIKE11 model (at 'Nowranie 43910' location) for input into the upstream boundary of the TUFLOW hydraulic model (see below);
- The local catchment to Nowranie Creek (approx. 160 km^2 was not incorporated into the flood modelling, as it was not considered to be a major source of flooding in Nowranie Creek (compared to the flood behaviour driven by Billabong Creek);
- An XP-RAFTS hydrologic model was established to convert rainfall to runoff within the local catchment of Oaklands itself, and produce local inflows to the TUFLOW model. The Oaklands local catchment covers approximately 6.68 km^2; and
- A TUFLOW hydraulic model was developed to estimate design flood behaviour using mainstream inflows for Nowranie Creek from the MIKE11 hydraulic model, and local inflows from the XP-RAFTS hydrologic model.

The models were calibrated to the flood events of 2010, 2011 and 2012, using daily rainfall data from the BoM at Rand Post Office (GS 74131), Mahonga (GS 74065), Daysdale (Dennison St) (GS 74038) and Oaklands General Store (GS 74088), as well as from the DPI Water for the closest pluviography data for flood events of 2010, 2011 and 2012. In the absence of recorded flood marks in Oaklands to calibrate the TUFLOW model to to, typical hydraulic parameter values have been used in the TUFLOW model and a sensitivity analysis has been undertaken to assess sensitivity of key model parameter values on the flood behaviour. However, details on the flood frequency analysis for Billabong Creek at Walbundrie gauge provided in the Flood Study Report for Rand (Jacobs, 2017) were used for calibration and verification of a hydraulic model for the flood study of Oaklands.

The key findings from the Flood Study report for Oaklands (Reference 4) are summarised below:

- The township of Oaklands is not subjected to mainstream flooding from Nowranie Creek;
- A number of small isolated areas within the township are subject to up to a maximum flood depth of 0.5 m in the 1% AEP event due to rainfall-runoff generated from sub-catchments located within the township;
- The open space located west of Daysdale Street between Thompson Street and Thornber Street is subject to up to 0.5 m depth of flooding in the 1% AEP event; and

- Sections of several roads within the town are impassable in the PMF event including Daysdale Road, Gunambil Street, Patey Street, Websters Street, Gaffney Street and Thompson Street.

The modelled flood behaviour is consistent with that described by the Council and community during the consultation undertaken as part of this FRMS&P.

2.2. Flood Intelligence Collection and Review for 24 Towns and Villages in the Murray and Murrumbidgee Regions following the March 2012 Flood, Final Report, June 2013 (Reference 9)

This report was completed for the NSW State Emergency Service (SES) in 2013 by Yeo to develop an understanding of flood behaviour in the Riverina. The March 2012 event affected a number of towns and villages, including Tumbarumba, Great Hume, Urana, Tumut, Gundagai, Wagga Wagga, Lockhart, Coolamon, Narrandera and Griffith. The report provides general information about the floods in the region, including rainfall data, flood extents, 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. While flooding in Oaklands was not reported, the document contains information regarding flooding in Billabong Creek and its floodplain including Nowranie Creek.

2.3. Billabong Creek Floodplain Management Plan, Phase A: Data Review and Flood Behaviour (Reference 11)

Bewsher Consulting was engaged by the NSW Department of Land and Water Conservation in 1999 to undertake a floodplain management plan for Billabong Creek in two phases. The phase A of the study included the flood data, overview of the past flood events and influences, flood frequency analysis, flood extend mapping, investigating flood behaviour via MIKE11 to simulate the flooding conditions for several past events (i.e. 1970, 1974, 1981, 198 and 1995). The phase 2 of the study included the application of the MIKE11 model to estimate flow distribution in the floodways for a range of floodplain management options. The Billabong Creek Floodplain Management Plan (DNR 2006) identifies a network of floodways across the Billabong Creek floodplain that need to be kept clear of obstructions, such as levees or other flood control works to ensure the free flow of floodwater within Billabong Creek and across the floodplain. The design flood selected in the Plan (DNR 2006) is a combination of two historical flood events including the 1983 event (25-year average recurrence interval) and the 1974 flood (32-year average recurrence interval) adopted for the upper floodplain and the lower floodplain, respectively. The 1983 event was the design flood adopted for Nowranie Creek corresponding to a peak flow of 2,400 ML/day (27.8 m^3/s).

3. AVAILABLE DATA

3.1. Site Visit

A site inspection was carried out by WMAwater staff accompanied by Council staff on 9th August 2018 to gain an overall appreciation of the study area, and to identify areas of Oaklands that experienced the greatest flood risk. In Oaklands, ponding affects areas including the corner of Buller and French Street, the western end of Milthorpe Street, and over the sports field and Oaklands Recreation Reserve. Erosion is another problem caused by local rainfall, with observed erosion on the western end of Buller Street. A subsequent site visit was undertaken on 18th of 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 C3 illustrates the site inspection photographs.

3.2. Topographic Data

Light Detection and Ranging (LiDAR) survey of the Study Area and its immediate surroundings were provided for the study by 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. Lower resolution (5 square metre and 10 square meter) LiDAR data was also supplied. The data for the Oaklands area was collected in 2014 and was used for the 2017 Oaklands Flood Study (Reference 4). The vertical accuracy is typically ±0.15 m for clear terrain. The horizontal accuracy of the data is 0.8 m at 95% confidence interval (CI), while the vertical accuracy is 0.3 m at 95% CI. A digital elevation model with a 5 m x 5 m grid cell size was sampled using the 1 m grid data. The data is projected in MGA55 with the GDA94 datum. Topographic data is shown on Figure C4.

Shuttle Radar Topography Mission (SRTM) data was utilised to delineate catchment boundaries for Billabong Creek which are located beyond the extent of the LiDAR data. This work was undertaken for, and documented in, the Flood Study Report for Rand, reviewed in Appendix D to this FRMS&P.

3.3. Aerial Photography

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

3.4. Hydraulic Structures

Details of key hydraulic structures within the Study Area, including culverts and bridges, were obtained from the Flood Study (Reference 4). A topographic survey undertaken as part of the Flood Study provided the following details (e.g. size, shape, invert level, top of road level etc) for two culverts (Culvert No. 32 and Culvert No. 34), shown in Table C 2. Details were surveyed by TJ Hinchcliffe & Associates in 2015. No additional culvert details were collected as part of this FRMS&P.

Table C 2: Key hydraulic structures in Oaklands

ID	Location	Type	Diameter (m)	Length (m)	No. barrels/ cells
32	Maxwelton Road	Pipe	0.9	6.85	4
34	Clear Hills Road	Pipe	0.9	11.1	4

3.5. Pit and Pipe Network

Local stormwater drainage is conveyed through Oaklands via a series of roadside table drains and culverts beneath driveways a limited number of culverts beneath roads. The kerb and gutter system is incomplete and allows water to drain directly from roads into the adjacent table drains. Details of the underground stormwater pits and pipes were not available.

3.6. Floor Level Database

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

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

The floor level database includes all properties within the PMF extent. WMAwater used LiDAR data and visual inspection to estimate floor levels for all properties within the PMF extent. A summary of the floor level estimates is provided in Table C 3 below.

Table C 3: Floor Level Database – Oaklands

Property Type	No. Included in Damages Assessment
Residential	132
Non-Residential	43
Total	175

3.7. Design Rainfall (ARR 2019) IFD

The design flood modelling inputs and methodology applied in the Flood Study (Reference 4) were based on Australian Rainfall and Runoff (ARR) 1987. Late in the Flood Study project in 2016, a substantial update to the ARR guidelines was released, with a subsequent update released in 2019. Following discussion with NSW DPIE (then Office of Environment and Heritage) and Council, it was decided that the design flood modelling produced in the Flood Study was to be updated to implement the methodologies provided in ARR 2019, as these represent best practice and would increase the longevity of the outputs of the Study.

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

4. FLOOD MODELLING REVISIONS AND UPDATES

The Flood Study for Oaklands (Reference 4), completed in 2017 by Jacobs for Federation (Council), was undertaken in accordance with the NSW Government's Flood Prone Land Policy. The Flood Study aimed to determine design flood behaviour in the area based on ARR 1987 methodologies and used an XP-RAFTS hydrologic model and a TUFLOW hydraulic model. Figure C5 illustrates the XP-RAFTS hydrologic model extent and the TUFLOW hydraulic model extent. The models were reviewed by WMAwater to determine the suitability for use in the Floodplain Risk Management Study and are described below. The review found that the models were largely fit for use in the FRMS&P, however the model version was updated to allow for the application of ARR 2019 methodologies (See Section 5.2).

4.1. Hydrologic Model Review

4.1.1. Mainstream Flows

Mainstream flooding in Nowranie Creek is driven by breakouts from Billabong Creek upstream of Oaklands. Design hydrographs for Billabong Creek at the Walbundrie gauge were developed using a RORB hydrologic model, covering the full Billabong Creek catchment to Walbundrie (some 2,620 km^2). A full review of the RORB model, and updates using ARR 2019 methodologies, is documented in Appendix D which pertains to the modelling developed for flood estimation in Rand. A MIKE11 model was developed in the Flood Study (Reference 4) to route flows from Walbundrie along Billabong Creek and into Nowranie Creek. Design hydrographs in Nowranie Creek were extracted at cross section "NOWRANIE 43910" and used as the mainstream upstream boundary condition for the Oaklands TUFLOW model. This approach was adopted for use in the FRMS&P without modification, however the design inflows have changed as a result of the RORB model updates and implementation of ARR 2019 methodologies (see Appendix D), and are reported in Section 5.

4.1.2. Overland Flow

The local runoff draining to Nowranie Creek through Oaklands village was modelled using XP-RAFTS (2018 version). The XP-RAFTS model was updated from Version 2013 to 2018 model for the efficient application of ARR 2019 methodologies (see Section 4.2.2.6). The sections below describe the comprehensive review of the overland flow models and describe any modifications made as part of this FRMS&P.

4.1.3. Model Extent

The Flood Study (Reference 4) developed an XP-RAFTS hydrologic model that covered the catchment to Nowranie Creek across the Oaklands township with a total area of approximately 6.7 km^2, shown on Figure C5. The catchment boundary was reviewed in conjunction with the available topographic data confirming the boundary was appropriately represented.

The catchment was divided into 14 sub-catchments, delineated based on the 1 m LiDAR data, with the resulting delineation shown on Figure C6. The sub-catchment delineation was deemed appropriate and adopted for use without modification.

4.1.4. Model Configuration

4.1.4.1. Parameters

The parameters used in the Flood Study for the XP-RAFTS hydrologic model simulation were assessed for suitability of their application. The XP-RAFTS model parameters adopted in the Flood Study (Reference 4), are presented in Table C 4. The slope assigned to Sub-catchment 1F is inconsistently low (at 0.007%) compared to the other sub-catchments. After confirming that flood behaviour was not dependent on the applied slope in this sub-catchment via sensitivity testing, the adopted XP-RAFTS parameters were adopted from the Flood Study without modification.

The Flood Study assigned a Manning's 'n' roughness parameter to each sub-catchment based on review of available aerial photography over the catchment from 2008. The assigned parameters, listed in Table C 4 are within the acceptable range typically used for these surface types. While 0.04 is considered on the higher side for cleared land, in this case it is considered appropriate to account for crops, long grasses, and variable tilling practices associated with agricultural activities. The Flood Study assigned impervious fraction across the catchment based on available aerial photography. The impervious fractions is considered appropriate.

Table C 4: XP-RAFTS Parameters

Sub-catchment No.	Area (ha)	Slope (%)	Impervious fraction (%)	Hydraulic Roughness (Manning's 'n' value)
2	218.5	1.5	15	0.04
3	119.2	1.3	15	0.04
5	17.0	1.2	10	0.04
6	79.3	1.4	5	0.04
1A	11.2	1.4	20	0.03
1B	33.2	1.4	40	0.025
1C	20.5	1.5	30	0.025
1D	28.2	0.8	30	0.03
1E	9.9	1.5	10	0.05
1F	22.6	0.007	20	0.04
4A	7.2	0.5	10	0.04
4B	13.8	1.2	50	0.02
4C	31.3	1.2	35	0.04
4D	56.4	0.4	5	0.04

The sub-catchment delineation was reviewed and deemed appropriate for use in the FRMS&P.

4.1.5. 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 the FRMS&P are based on guidance from ARR 2019. These are discussed further in Section 5.4.3.

4.2. Hydraulic Model Review

4.2.1. MIKE11

The Flood Study Report for Oaklands (Reference 4) developed a MIKE11 model to route flows from the Billabong Creek gauge at Walbundrie along Billabong Creek (e.g to Rand) as well as its various flood runners. The design hydrographs generated by the MIKE11 model at cross section “Nowranie 43910” were extracted for use in the Nowranie Creek TUFLOW model. The MIKE11 model was adopted without modification for use in the FRMS&P. For further detail on the MIKE11 model see the Flood Study (Reference 4).

4.2.2. TUFLOW

A combined 1D-2D TUFLOW model was developed in the Flood Study (Reference 4) for Oaklands. 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 was 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. Model Extent

The TUFLOW hydraulic model extent (from the Oaklands Flood Study, Reference 4) includes a 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use, a 2D representation of the obstructions to flow, including buildings. The TUFLOW hydraulic model extent is bounded in the east by Mulwala Road, to a point approximately 5.8 km downstream (west) of Mulwala Road, and from 1.3 km south of Jerilderie- Oaklands Road to 800 m north of Nowranie Creek. The TUFLOW extent covers a total area of 27 km^2, is presented on Figure C5.

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 a 5 m grid (See Section 3.2). 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 two culverts crossing Nowranie Creek in the vicinity of Oaklands at Maxwelton Road and Clear Hills Road. These culverts include 4 culverts with 0.9 m diameter. The culverts were modelled as 1D elements, respectively, in the Flood Study using the data obtained from the topographic survey by TJ Hinchcliffe and Associates in 2015 within the study area. The culverts layers were reviewed indicting that the they were suitably represented in the TUFLOW model used in the Flood Study; therefore, the same approach was adopted to represent the culverts in the present study.

4.2.2.4. Buildings

The representation of buildings within the study area was based on the same approach used in the previous study completed by Jacobs (2017). In this method, 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.

4.2.2.5. Roughness Parameters

In the Flood Study, the catchment surface was assigned a hydraulic roughness parameter based on land use and aerial imagery. The new aerial photography of the area was investigated indicating no changes in the land use; therefore, the Manning's 'n' coefficients adopted in the Flood Study were applied in the current FRMS&P. Table C 5 lists the Manning's 'n' coefficient applied to define catchment surface roughness while Figure C7 illustrates their spatial distribution. The Manning's 'n' values assigned to densely vegetated area (0.12) are considered to be at the upper limit of appropriate values, however are representative of a range of cropping types and practices and so have been adopted without modification for use in the FRMS&P.

Table C 5: TUFLOW model hydraulic roughness values

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

4.2.2.6. Overland Inflows

The simulated hydrographs via XP-RAFTS were adopted as upstream inflow hydrograph in the TUFLOW model for overland flow of Oaklands. 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 boundaries are shown on Figure C5, and indicate that the flows generated by the XP-RAFTS model were redistributed across all cells within the inflow polygon. While this results in the runoff being 'double routed', the relatively short response time (~10 min) is not considered to be unduly exaggerated, and so the inflows were not altered.

4.2.2.7. Mainstream Inflows (Nowranie Creek)

Simulated flow hydrographs generated at MIKE11 cross section "Nowranie 43910" were adopted as inflow hydrographs in the TUFLOW model for Nowranie Creek at Oaklands, input into the model at Mulwala Road.

To reduce model run times (in TUFLOW classic), the Flood Study (Reference 4) condensed the inflow hydrograph, increasing the gradient of the rising limb so as to reach the peak within 2 hours rather than 30 hours. With the conversion to GPU, the FRMS&P was able to run the full, original inflow hydrograph produced by the MIKE11 model without modification. However, increasing the duration over which the same volume of flow was input into the model resulted in slightly lower peak flood levels in Nowranie Creek generated in this FRMS&P. This is evident in the comparison between the Flood Study and FRMS&P results, described further in Section 6.1.3.

4.2.2.8. Downstream Boundary Conditions

The TUFLOW model downstream boundary was located approximately 2.5 km downstream of the Oaklands village, to eliminate the potential influence of the boundary conditions on flood behaviour in the study area. The Flood Study (Reference 4) assumed a normal depth condition at the boundary, which has been adopted for use in this FRMS&P without modification.

5. DESIGN FLOOD MODELLING

5.1. Overview

The hydrologic and hydraulic models developed as part of the Flood Study (Reference 4) have been adopted for use in design flood modelling. The surrounding areas of Oaklands is affected by mainstream flooding from Billabong Creek, the main urban area is impacted by overland flow from the local catchment surrounding the town. Each mechanism is modelled differently, as described in Section 4. Key parameters such as topography, slope and Manning's "n" remain unchanged from the Flood Study (Reference 4). All other parameters, data and assumptions that form the basis of the design flood modelling are based on inputs from ARR 2019 and are detailed below.

5.2. ARR 2019 Update

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

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

1. The recommended Intensity, Frequency and Duration (IFD) rainfall data, pre-burst, and initial and continuing loss values across Australia have been updated based on analysis of available records;
2. ARR 2019 recommends an ensemble assessment of 10 temporal patterns for each storm duration. The temporal pattern producing the mean level within each duration is selected. The *critical duration* is the duration for which the selected temporal pattern produces the maximum flood level;
3. The inclusion of Areal Reduction Factors (ARFs) based on Australian data for short (12 hours and less), long duration (larger than 24 hours) and durations between 12 and 24 hours.

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

The updates that relate to mainstream flooding in Nowranie Creek are documented in Appendix D (Rand), as it involved modifying the Billabong Creek RORB hydrologic model, which forms the basis of design flood estimation in Billabong Creek at Rand, noting that Nowranie is a flood runner of Billabong Creek.

5.3. Mainstream Flooding

The estimation of mainstream flow in Nowranie Creek has been revised using the following process:

- The RORB hydrologic model for Billabong Creek (to the gauge at Walbundrie) was re-run for the full suite of design flood events using ARR 2019 methodologies. A full description of the parameters and methods used is documented in Appendix D, the FRMS&P report for Rand;
- The MIKE11 hydraulic model was re-run using the revised design hydrographs to route flows from Walbundrie Gauge, along Billabong Creek (to Rand), and into the various flood runners along Billabong Creek;
- The resulting design hydrographs developed in the MIKE11 model were extracted at cross section "Nowranie 43910" and applied as inflows to the Nowranie Creek TUFLOW model. The revised peak design inflows are listed in Table C 6, there are relatively minor changes to the applied peak flow and resulting flood levels.

Table C 6: Design Mainstream Inflows to Nowranie Creek

Design Event	FRMS&P (ARR 2019) Nowranie Ck Inflow (m^3/s)	Flood Study (ARR 1987, Reference 4) Nowranie Ck Inflow (m^3/s)
20% AEP	-	3.7
0.2EY	2.6	-
10% AEP	16.9	16.7
5% AEP	34.9	34.9
2% AEP	44.9	49.3
1% AEP	50.7	49.7
0.5% AEP	55.7	56.1
0.2% AEP	61.2	62.7
PMF	2,889.0	2,869.4

5.4. Overland Flooding

The estimation of overland flow in the local Oaklands catchment has been undertaken using the linked hydrologic/ hydraulic models developed in the Flood Study (Reference 4), with various revisions and updates described in Section 5. The hydrologic modelling has been undertaken using Australian Rainfall and Runoff 2019 guidelines, including the use of ARR 2019 IFD information, temporal patterns and losses. The PMF flows were derived using the Bureau of Meteorology's Generalised Short-Duration Method (Reference 6) to estimate the probable maximum precipitation (PMP).

5.4.1. 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 C 7 and the ARR2019 Data Hub metadata is presented in Attachment 1.

Table C 7: Average design rainfall depths (mm) at the centroid (Longitude 146.162, Latitude -35.563) of the local Oaklands catchment

Duration	AEP							
(min)	20%	0.2EY	10%	5%	2%	1%	0.5%	0.2%
15	15.5	15.8	18.6	21.7	25.8	28.9	32.4	37.0
30	20.5	20.9	24.7	28.9	34.4	38.7	43.4	49.7
45	23.6	24.0	28.4	33.3	39.7	44.7	50.1	57.5
60	25.8	26.3	31.1	36.4	43.4	48.9	54.9	63.0
90	29.0	29.6	35.0	40.9	48.8	55.0	61.7	70.8
120	31.5	32.1	37.9	44.2	52.7	59.4	66.6	76.4
180	35.2	35.9	42.2	49.2	58.6	65.8	73.8	84.5
270	39.4	40.2	47.1	54.7	64.9	72.9	81.5	93.2
360	42.7	43.6	50.9	58.9	69.9	78.4	87.7	100
540	47.9	48.9	56.8	65.7	77.8	87.3	97.5	111
720	52.0	53.0	61.6	71.1	84.2	94.4	105	120

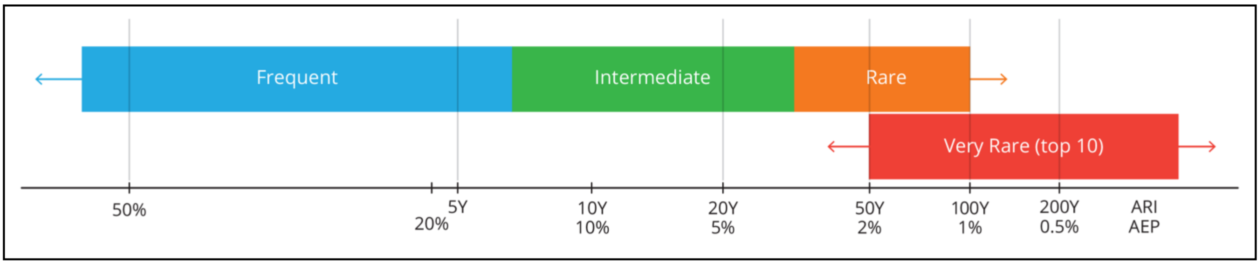
5.4.2. ARR 2019 Temporal Patterns

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

As hydrologic modelling has advanced, it is becoming increasingly important to use realistic temporal patterns. The ARR 1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the 2016 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The ARR 2019 method provides patterns for 12 climatic regions across Australia, with the Oaklands 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 C 1 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The “very rare” bin is currently unavailable and was not used in this flood study. 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 C 1: Temporal Pattern Bins



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

5.4.3. Critical Duration Assessment

To determine the critical duration (the duration of rainfall over the catchment that will result in the greatest depth of flooding), ARR 2019 recommends than an ensemble approach is used, where 10 temporal patterns (see Section 5.4.2) 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 local XP-RAFTS hydrologic model, with the 60 minute, 90 minute and 120 minute durations found to result in the highest mean peak flows across the floodplain. Using the TUFLOW results, a representative temporal pattern was selected based on statistical analysis of the results of the ensemble (i.e. identification of the pattern producing peak flood levels just above the mean for the critical duration). Further description of the assessment method and box plots for each AEP duration are presented in Attachment 1. The results of the critical duration assessment are provided in Table C 8.

Table C 8: Adopted durations and temporal patterns for design flood events

Event	Critical Duration (min)	Adopted Temporal Pattern	IFD (mm)	ARF	Initial Loss (mm)	Continuing Loss (mm/hr)	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet
20% AEP	180	TP3: 3982	35.9	0.9616	11.1	0.28	22.8
10% AEP	120	TP3: 3913	37.9	0.9498	9.7	0.28	28.9
5% AEP	120	TP3: 3913	44.2	0.9436	9.7	0.28	35.7
2% AEP	120	TP5: 3935	52.7	0.9355	9.1	0.28	45.5
1% AEP	120	TP5: 3935	59.4	0.9293	7.8	0.28	54.2
0.5% AEP	120	TP5: 3935	66.6	0.9231	7.8	0.28	62.7
0.2% AEP	120	TP5: 3935	76.4	0.9149	7.8	0.28	74.2
PMF	60	Not applicable			0.0	1.0	571.0

5.4.4. Rainfall Losses

Design rainfall losses were obtained from the ARR 2019 data hub (http://data.arr-software.org/). Based on the recent guideline developed by NSW DPIE (Reference 12), in the absence of calibrated losses (i.e. calibrated to flows at a stream gauge) in the catchment or nearby, the continuing loss value provided by the ARR 2019 Data Hub is to be multiplied by a factor of 0.4. In the local Oaklands catchment, the continuing loss is therefore taken as: 0.4 × 0.7 = 0.28 mm/hr, and used in conjunction with probability neutral burst initial loss values (presented in Table C 9). It is noted that the values applied in the 1% AEP event were also used for rarer events (0.5% AEP and 0.2% AEP). Note that XP-RAFTS uses linear interpolation to estimate the probability neutral burst initial loss of durations other than the presented ones in Table C 9.

Table C 9: Probability Neutral Burst Initial Loss at the Catchment Centroid (mm)

Duration (min)	AEP				
	20%	10%	5%	2%	1%
60	9.5	8.9	9.3	9.2	7.3
90	10.6	9.5	9.3	8.8	8.1
120	11.0	9.7	9.7	9.1	7.8
180	11.1	10.2	10.5	9.0	6.6
360	13.9	12.2	12.0	10.4	6.9
720	15.2	14.1	14.0	11.7	7.9

5.4.5. Areal Reduction Factors

Areal Reduction Factors (ARF) are an estimate of how the intensity of a design rainfall event varies over a catchment, based on the assumption that large catchments will not have a uniform depth of rainfall over the entire catchment. The ARF is extracted via the ARR Data Hub (Reference 2), and applied to each sub-catchment. The full suite of ARFs across all design events and durations are taken directly from the Data Hub, and are presented in Attachment 1.

6. DESIGN FLOOD MODELLING RESULTS

6.1. Design Flood Behaviour

The hydrologic and hydraulic models described in Section 4 and the design flood inputs discussed in Section 5 have been used to estimate design flood behaviour for the 20%, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP events and the PMF. Results have been mapped for all investigated events, presented as an envelope of mainstream and overland flow flood mechanisms. The flood behaviour across the full range of design events is described below, and shown on Figure C8 to Figure C15 respectively.

6.1.1. Mainstream Flooding

Nowranie Creek flows from east to west, passing Oaklands approximately 1.3 km north of the Answerth Drive – Coreen Street Intersection. In the 10% AEP event, obstructions caused by the former The Rock- Oaklands railway and Clear Hills Road creek crossings cause flows to back up behind each structure (ponding to the east). More widespread out of bank flow occurs in the 5 AEP event and rarer, however, even the PMF event does not directly affect the township of Oaklands. While the town centre and development is outside the Nowranie Creek floodplain, access is restricted to the north by inundation from Nowranie Creek at its various crossings. The design peak inflows in Nowranie Creek are described in Section 5.3 and tabulated in Table C 6.

6.1.2. Overland Flow

The terrain in Oaklands slopes gently downwards from southwest to northeast towards Nowranie Creek. Without well-defined flowpaths, runoff generated by rainfall over the local catchment (approximately 6.7 km^2) travels towards the creek as shallow sheet flow across the town. Overland flow behaviour does not differ significantly from frequent to rare events other than the total flood extent increasing slightly. For the most part, flood depths are less than 0.1 m, with some localised ponding in low-lying areas, including parts of Milthorpe Street, Buller Street, and Coreen Street. The lack of defined flowpath through the Webster Street/ Patey Street timbered area, and the Oaklands Recreation Reserve, means that overland flow spreads out and ponds for days (or even weeks) at a time.

While the overland flow is not considered hazardous to persons or property (refer to Section 6.2), the nuisance associated with ponding over roads and across the recreation reserve affects the Oaklands community frequently (from an 20% AEP event and up). A comparison between the design peak outflows at the XP-RAFTS catchment outlet are provided in Table C 10, noting that the Flood Study (Reference 4) reported flows at this location for the 5% AEP and 1% AEP events only.

As shown in Table C 10, the 1% AEP peak flow derived from ARR 2019 is nearly 20 m^3/s greater than that derived from ARR 1987. This is a result of the rainfall depths nearly doubling for the critical duration, from 26.5 mm (1% AEP, 90 minute duration) to 52.7 mm (1% AEP, 120 minute duration), coupled with a decrease in initial loss (from 10 mm to 7.8 mm), and considerable reduction in continuing loss (from 2.5 mm/hr to 0.28 mm/hr).

Table C 10: Design peak outflows (overland) at the XP-RAFTS catchment outlet

Design Event	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet	
	FRMS&P (ARR 2019)	Flood Study (ARR 1987)
20% AEP	22.8	-
10% AEP	28.9	-
5% AEP	35.7	19.3
2% AEP	45.5	-
1% AEP	54.2	34.7
0.5% AEP	62.7	-
0.2% AEP	74.2	-
PMF	571.0	-

6.1.3. Comparison to Flood Study

A comparison between the 1% AEP peak flood levels is provided on Figure C16. The minor model updates discussed in Section 4 and 5 and application of ARR 2019 guidelines has not materially affected the estimation of design peak flood levels throughout the village. Aside from slightly increasing the extent of overland flows, peak flood levels are within +/- 100 mm of those estimated in the Flood Study (Reference 4).

Following on from Section 5.3, peak flood levels in parts of Nowranie Creek, particularly downstream of Clear Hills Road, are estimated to be up to 0.3 m lower than modelled in the Flood Study (Reference 4). The discrepancy is due to the changed timing of the inflows: in the Flood Study, the inflow hydrograph was condensed to reach the peak flow within approximately 2 hours (to manage model run times), while the revised inflow hydrograph developed using ARR 2019 rises steadily over 30 hours. With the conversion to TUFLOW GPU, model run times are significantly lower, and the full hydrograph can be run efficiently.

6.2. Hydraulic Hazard Classification

Hazard classification plays an important role in informing floodplain risk management in an area as it reflects the likely impact of flooding on development and people. In the Floodplain Development Manual (Reference 3) hazard classifications are essentially binary – either Low or High Hazard as described on Figure L2 of that document. However, in recent years there has been a number of developments in the classification of hazard especially in *Managing the floodplain: a guide to best practice in flood risk management in Australia (Third Edition)* (Reference 7). The Flood Study (Reference 4) presents hazard categorisation mapping based on the Floodplain Development Manual, while this study presents revised mapping based on the methodology outlined in Reference 7. The classification is divided into 6 categories (H1-H6), listed in Table C 11, which indicate constraints of hazard on people, buildings and vehicles appropriate to apply in each zone. The criteria and threshold values for each of the hazard categories are presented in Diagram C 2.

Table C 11: Hazard Categories

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

Diagram C 2: Hazard Classifications

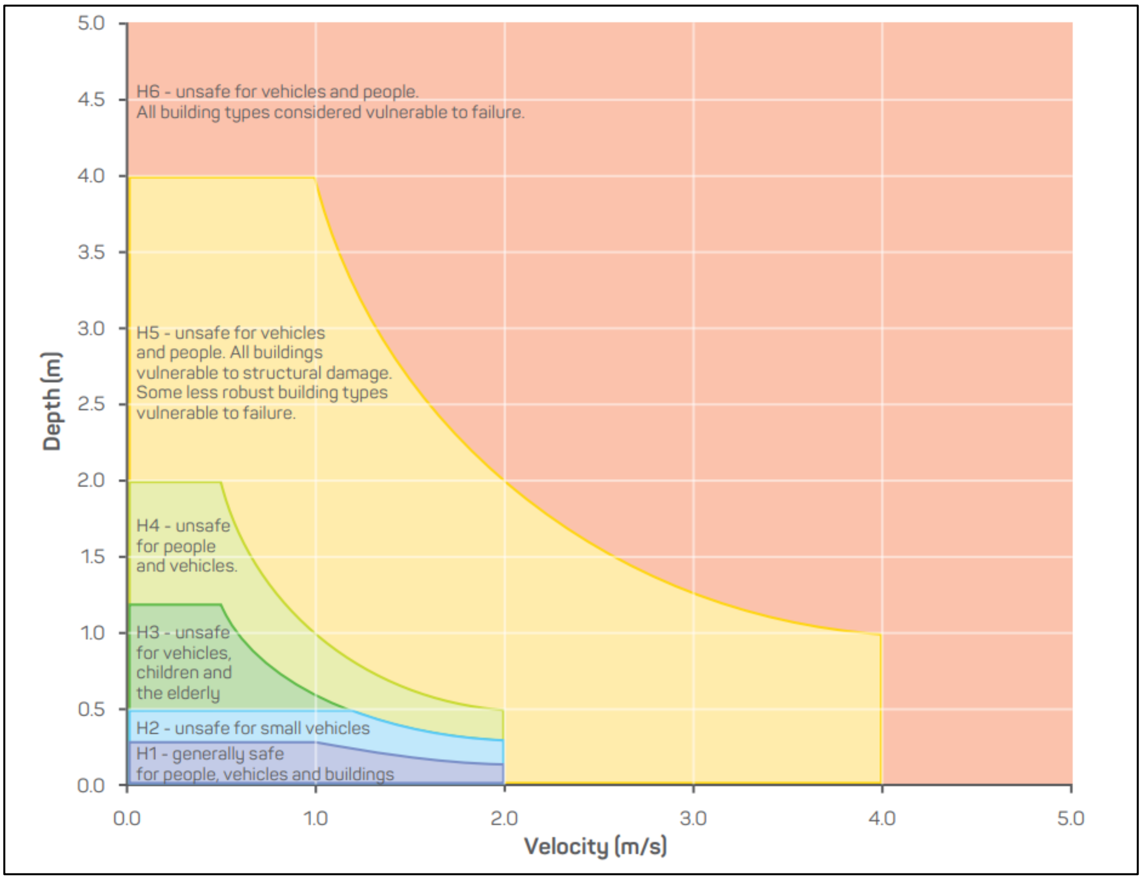


Figure C17 to Figure C19 present the hazard classifications based on the H1-H6 delineations for the 5% and 1% AEP events, as well as the PMF event, respectively. These maps indicate that the township itself is subject only to the lowest hazard category (H1) in the 5% and 1% AEP events, and even for the most part in the PMF, consistent with the majority of flooding being characterised by shallow sheet flow. The only exception to the H1 categorisation in the PMF occurs in the timbered area and recreation reserve, where a flowpath forms between Webster Street and Dayside Street (mainly H3, with some parts classified as H4), which then flows further east and to the north towards Nowranie creek.

6.3. Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the Floodplain Risk Management process to assist in the assessment of the suitability of future types of land use and development, and the formulation of floodplain risk management plans. The Floodplain Development Manual (Reference 3) defines land inundated in a particular event as falling into one of the three hydraulic categories listed in Table C 12.

Table C 12: Hydraulic Categorisation Definitions (*Floodplain Development Manual* (Reference 3))

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

Draft hydraulic categories were not defined for Oaklands in the Flood Study (Reference 4).

The definition of the floodway was defined using the Howells et al. (Reference 8) methodology, starting with the depth and velocity criteria adopted in Rand. These parameters were refined 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 C 13. Following application of these criteria, the resulting floodway areas were examined to ensure continuity of flowpaths, and to remove any isolated grid cells inappropriately classified (for example as an artefact of the modelling).

Table C 13: 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 hydraulic categorisation for the 5% AEP, 1% AEP and PMF events are shown on Figure C20 to Figure C22 respectively. Nowranie Creek itself is classified as floodway, while the majority of Oaklands is categorised as flood fringe – consistent with the shallow overland flow to which it is subject in the full range of design events. As with hydraulic hazard, the exception to this classification occurs in the PMF, where a flowpath develops from Rankin Street, travelling eastwards through the timbered area and the recreation reserve through to Dayside Street, then northwards to the creek. This flowpath is categorised as ‘floodway’ in the PMF event, but not in the 5% AEP nor 1% AEP.

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 Oaklands catchment, whilst the main report considers LGA-wide options.

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

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

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

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

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

7.1. Flood Modification Measures

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

Flood modification measures were identified by Council, Emergency Services or by members of the community (as part of the community consultation process) and through the examination of available flood modelling and identified hotspots; as having the potential to reduce flood risk at Oaklands. 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.

Oaklands typically experiences shallow overland flooding and as such measures to minimise flood risk are unlikely to attract funding via the NSW Government Floodplain Management Program.

Table C 14 provides a summary of the flood modifications options considered for Oaklands.

Table C 14: Flood modification options considered for Oaklands

ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMO-01: Milthorpe Street Regrading	Regrading Milthorpe Street to create additional slope from its high point at Coreen Street to the dam near the Corowa Road and Milthorpe Street intersection, west to east (bringing it to a continuous slope of 1%) to assist in the conveyance of runoff.	Refer to Figure C23 (5% AEP) and Figure C24 (1% AEP). Decrease in flood levels up to 0.15 m along Milthorpe Street, Young Street, and Thornber Street, as well as areas in between for the 5% AEP event. However, in Milthorpe Street this relates larger depths than existing scenario as road is lowered. Decreased flood levels are also to be expected west of the high point on Hunter Street in the vicinity of the proposed swale. The large decrease in elevation at the east end of the works exaggerates the existing low point and convey water northwards across private property. This will result in a previously flood free area (north of Corowa Road and east of Daysdale Street) to be newly flooded by up to 0.11 m in the 5% AEP event. A similar trend with increased magnitude can be expected in the 1% AEP event with decreases in flood levels up to 0.21 m.	No, significant cost, significant aesthetic impacts, increased flow and depths along Milthorpe Street including areas with hazardous depths.
FMO-02: Milthorpe Street Trunk Drainage	850m long, 900mm Ø trunk drainage line installed beneath Milthorpe Street, with outlet at the modified basin directly south of Corowa Road. 80m of 600mm Ø lateral connections from crossroads to the trunk drainage line and 14 inlet pits.	Refer to Figure C25 (5% AEP) and Figure C26 (1% AEP) for the 5% and 1% AEP. No significant change in peak flood levels or duration of ponding on Milthorpe Street in either event. Conversely, the draining of water to the lowered basin led to previously flood free area (north of the basin) to be inundated by depths of up to 0.10 m in the 5% AEP event. This newly flooded area is clear of any properties. A similar trend can be expected to occur in the 1% AEP event.	No, results in no material change to flood risk, significant costs.
FMO-03: Buller Street Trunk Drainage	Regrading Buller Street from the high point to the intersection between Buller Street and White Street so that it retains a consistent 0.85% grade. Requires lowering/regrading of MIlthorpe Street, Hunter Street, Roberts Street, French Street, and Gunambil Street so as to tie into the newly graded levels along Buller Street.	Refer to Figure C27 (5% AEP) and Figure C28 (1% AEP). Flood levels decrease by less than 0.1 m in both events between Hunter Street and Robert Street, extending north along Coreen Street up to Thompson Street. The area between White Street and Gunambil Street towards the eastern end of the works becomes completely flood free in both events. Conversely, the option results in the previously flood free area northeast of White Street being in inundated by up to 0.17 m and 0.20 m for the 5% and 1% AEP events respectively. This new flow path however, allows the utilisation of the dam directly south of Corowa Road as additional flood storage in both events and is clear of any properties.	**Yes**, localised drainage improvements to be undertaken at intersections when opportunities arise

ID	Configuration	Summary of Assessment	Recommended for FRMS&P
FMO-04: Oaklands Recreation Reserve Swale Drain	Creating a formalised drainage path through the Webster Street timbered area and Oaklands Recreational Reserve via a 0.6 km long, 4m wide swale with average depth of 1 m with an average slope of 0.5% to the eastern edge of the oval. 4 x 0.5m Ø circular culverts add at each street crossing.	Refer to Figure C29 (5% AEP) and Figure C30 (1% AEP). Flood levels by up to 0.13 m in the 5% AEP event, however it does not completely protect the oval from overland flow affectation and peak depths of up to 0.16 m can still be expected in the oval in a 5% AEP event. Additionally, directly downstream of the swale outlet, peak flood levels are increased by approximately 0.03 m, however the shallow increase in flood levels do not affect properties or materially increase flood risk.	No, option FMO-05 preferred
FMO-05: Oaklands Recreation Reserve Spectator Bund	A 0.5 km long low-level bund surrounding the northern portion of the field, to redirect flow to the north to the north. Rainfall that falls over the oval is designed to drain to the east via a culvert through the bund.	Refer to Figure C31 (5% AEP) and Figure C32 (1% AEP). Flood levels decrease by up to 0.15 m in the 5% AEP event, however depths of up to 0.13 m still persist within the oval. While the bund is effective in mitigating flow into the oval, there are significant increases of up to 0.26 m in the 5% AEP event in flood levels surrounding the bund. A similar trend can be observed in the 1% AEP event with a greater extent and magnitude of increased flood levels surrounding the bund. No impacts beyond the vicinity of the bund in both events.	**Yes**
FMO-06: Oaklands Recreation Reserve Swale and Bund	Combined FM FMO-04 (swale) and FMO-05 (bund).	Refer to Figure C33 (5% AEP) and Figure C34 (1% AEP). The resulting peak flood depths in the combined case (Option FMO-06) are not materially different to the swale alone (Option FMO-04), and are also comparable to the bund option alone (Option FMO-05).	No, option FMO-05 preferred

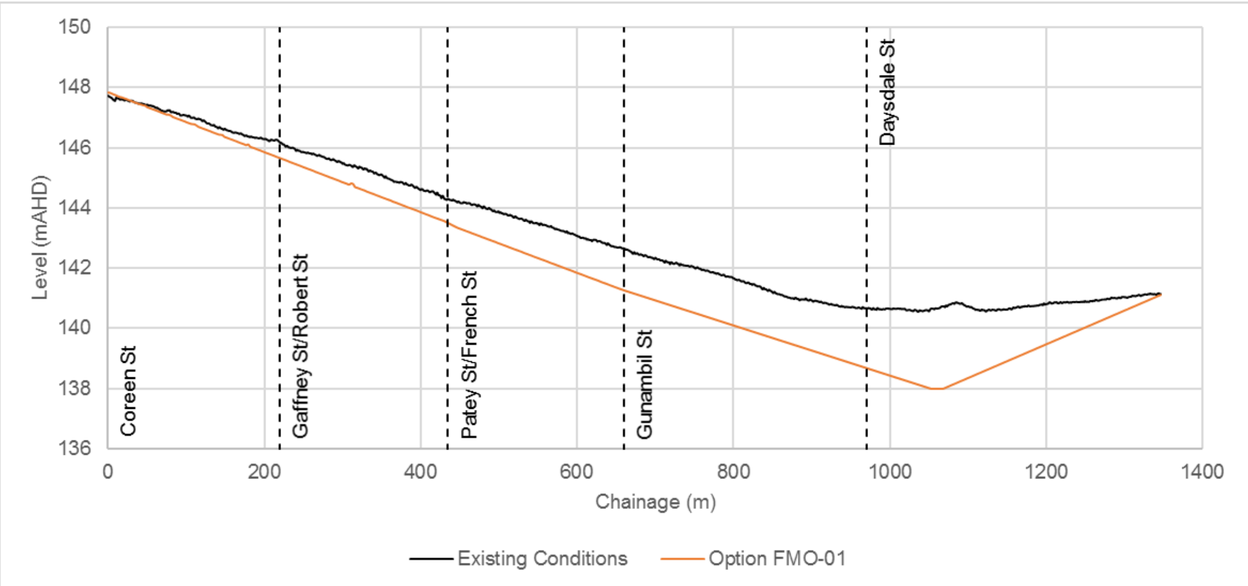
7.1.1. FMO-03: Buller Street Trunk Drainage

7.1.1.1. Option Description

Buller Street, similar to Milthorpe Street relies on the natural slope of the street to convey runoff. From the available LiDAR data, it is determined that Buller Street has an overall slope of approximately 0.85% from its high point slightly west of Hunter Street (falling approximately 8.5 m over a length of ~1 km). However, Buller Street does not follow a consistent grade and has several sag points, also identified in the community consultation session, that trap this runoff and cause it to pond for extended periods (at times several days) after the rain has ceased.

This option looks at regrading Buller Street from the high point to the intersection between Buller Street and White Street so that it retains a consistent 0.85% grade in an attempt to remove any sag points and improve the conveyance of runoff (refer to Diagram C 3). Increasing the grade of the road is not possible without lowering Milthorpe Street (due to the level of the Milthorpe Street and White Street intersection) or creating new sag points along Buller Street or White Street. The total excavation required for the regrading of Buller Street is estimated to be approximately 4,850 m^3. Cross roads including Hunter Street, Roberts Street, French Street, and Gunambil Street were also regraded to tie into the newly graded levels along Buller Street (approximately 950 m^3 of excavation required, over 50-100 m on each road).

Diagram C 3: Long Section of Buller Street



7.1.1.2. Option Assessment

Modelled Flood Behaviour

The modelled changes in peak flood levels shown on Figure C27 and Figure C28 for the 5% and 1% AEP events respectively. A decrease in flood levels up to 0.07 m for the 5% AEP event can be expected between Hunter Street and Robert Street (depths of up to 0.42 m remain on Buller Street), with the extent of positive impact reaching north along Coreen Street up to Thompson Street. A similar trend can be expected in the 1% AEP event with decreases in flood levels up to 0.08 m (depths of up to 0.46 m remain on Buller Street). Additionally, the area between White Street and Gunambil Street towards the eastern end of the works becomes completely flood free in both the 5% and 1% AEP events. On the other hand, the regrading of the road results in the previously flood free area northeast of White Street to experience inundation up to 0.17 m and 0.20 m for the 5% and 1% AEP events respectively. This new flow path however, allows the utilisation of the dam directly south of Corowa Road as additional flood storage in both events and is clear of any properties. There may be opportunities to consider variations on this option to achieve localised improvements at identified sag points.

Costs and economic viability

The option involves significant earthworks, which would have high capital costs. The reduction in property affectation is likely to be very limited, resulting in low economic benefits. Therefore the option is unlikely to be considered economically viable.

Social and environmental impacts

The temporary closure of Buller Street and surrounding streets would cause temporary social disruption. There would be social equity issues resulting from newly flooded land as well as potential environmental impacts resulting from increased flood levels on agricultural land.

Financial viability

The option is unlikely eligible for grant funding due to the limited benefits to property. However, there may be an opportunity for road improvements to be incorporated into future maintenance / upgrade works and other potential funding opportunities.

7.1.1.3. Recommendation

FMO-03: Buller Street Trunk Drainage

☒ Option FMO-03 is not recommended as a flood risk management measure due to the limited benefits.

☑ The option may provide benefits to local stormwater drainage management and improvement works at intersections should be undertaken when opportunities arise.

7.1.2. FMO-05: Oaklands Recreation Reserve Spectator Bund

7.1.2.1. Option Description

With a similar purpose to Option FMO-04, this option aims to prevent runoff from flowing onto the sports field in the Oaklands Recreation Reserve, thereby reducing ponding and the duration for which the field cannot be used. A 0.5 km long low-level mound, or 'bund', is proposed to encircle the northern portion of the field, aiming to redirect flow around the field to the north. Rainfall that falls over the oval is designed to drain to the east via a culvert through the bund. With a proposed height of 0.5 m, this bund would have a dual benefit of providing elevated spectator seating around the oval.

7.1.2.2. Option Assessment

Modelled Flood Behaviour

The modelled changes in peak flood levels are shown on Figure C31 and Figure C32 for the 5% and 1% AEP events respectively. The results indicate a noticeable decrease in flood levels up to 0.15 m in the 5% AEP event, however depths of up to 0.13 m still persist within the oval. While the bund is effective in mitigating flow into the oval, there are significant increases of up to 0.26 m in the 5% AEP event in flood levels surrounding the bund. A similar trend can be observed in the 1% AEP event with a greater extent and magnitude of increased flood levels surrounding the bund. Despite this, there are no impacts beyond the vicinity of the bund in both events. The length of the bund as well as the bund height could be further optimised in later stages.

Costs and economic viability

Capital costs of the option would be derived from earthworks in creation of the bund, as well as ongoing maintenance once in place. The option provides no change to property impacts and therefore costs will exceed economic benefits, and the option is not considered economically viable from a flood risk management perspective. There would be community amenity benefit from the option.

Social and environmental impacts

There may be minor visual impacts from the elevated bund. The alignment should be refined so as not to encroach the playing field. There will be social amenity benefits of the bund through improved access to the sportsfield, and opportunity to use the bund as spectator seating. There are no environmental impacts anticipated as a result of the option, though standard sediment and erosion control measures should be deployed during construction.

Financial viability

The option would not be eligible for grant funding via the NSW Government Flood Program however Council should seek other community based grant funding opportunities.

7.1.2.3. Recommendation

FMO-05: Oaklands Reserve Spectator Bund	
☑	The option may provide benefits to local stormwater drainage management and will provide amenity benefit to the local community. It should be considered if funding opportunities were to become available.

7.2. Property Modification Measures

7.2.1. PMO-01: Voluntary House Raising or Purchase

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

The property spreadsheet developed as part of this FRMS was used to initially identify any potential properties which meet the criteria provided in state guidelines (Reference 13 and 14). For VHR this is properties locate outside of the floodway and within low to moderate hazard areas only (H1 to H3) that are inundated over floor in events up to and including the 1% AEP event under current conditions. For VP this is properties located within a floodway, or highly hazardous flood conditions (H4 to H6).

Based on current estimates, the majority of dwellings in Oaklands are estimated to have floor levels well above the FPL, with only three dwellings estimated to have floor levels below the 2% AEP and all with shallow affectation. As such, a VHR scheme is not recommended. Flooding in Oaklands is characterised by shallow overland flow, which is entirely classified as 'flood fringe'. As such, a VP scheme is not recommended.

7.2.1.1. Recommendation

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

7.3. Summary of Recommended Options

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

Reference	Name	Type
FMO-03	Buller Street Trunk Drainage	Flood modification
FMO-05	Oaklands Recreation Reserve Spectator Bund	Flood 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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Billabong Creek Floodplain Management Plan, Phase A: Data Review and Flood Behaviour
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Floodplain Risk Management Guide
Incorporating 2016 Australian Rainfall and Runoff in Studies
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Guidelines for voluntary purchase scheme
February 2020

Attachment 1

Oaklands Critical Duration Assessment – Supporting Material

This attachment provides supporting material relating to the critical duration assessment undertaken for the local runoff through Oaklands. It does not include information regarding the critical duration assessment that relates to the mainstream flooding in Nowranie Creek – please refer to the corresponding appendix for Rand (Appendix F) for this information.

To determine the critical duration (the duration of rainfall over the catchment that would result in the greatest depth of flooding) in Oaklands, ARR 2019 recommends than an ensemble approach is used, where 10 temporal patterns (see Section 5.3.3 of Appendix E) 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, using the 1% AEP event as an example.

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

- No. 1B – Urban Area
- No. 1C – Urban Area in southern parts of Oaklands
- No. 1D– Urban area including wooded area and recreation reserve
- No. 1F – relatively open area at the eastern side of town
- No. 4D – undeveloped, open rural land between Oaklands and Nowranie Creek

A range of storm durations (from 15 minutes to 72 hours) and the full ensemble of temporal patterns were run in XP-RAFTS, and the results were analysed at each of these locations. A box plot of 1% AEP flows for each of these locations can be seen in Diagram E1 to Diagram E5.

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.

The critical duration is the temporal pattern and duration that can best represent the flood behaviour for a specific design event. With ARR 2019 methodology, the adopted temporal pattern out of the ensemble of 10, is the pattern which produces the peak flows just greater than the average of the 10 peak flows for the critical duration. Thus, the temporal pattern adopted does not produce the largest peak flows for that storm duration. The critical storm duration for a location is then the design storm duration which produces the highest average flow across the full range of durations at that location of interest. The hydrologic model (XP-

RAFTS) was used to assess the peak flows at key locations to select the critical duration and representative temporal pattern to run in the TUFLOW model.

Diagram E1: Box plot of peak local flows at sub-catchment No.1C: 1% AEP event

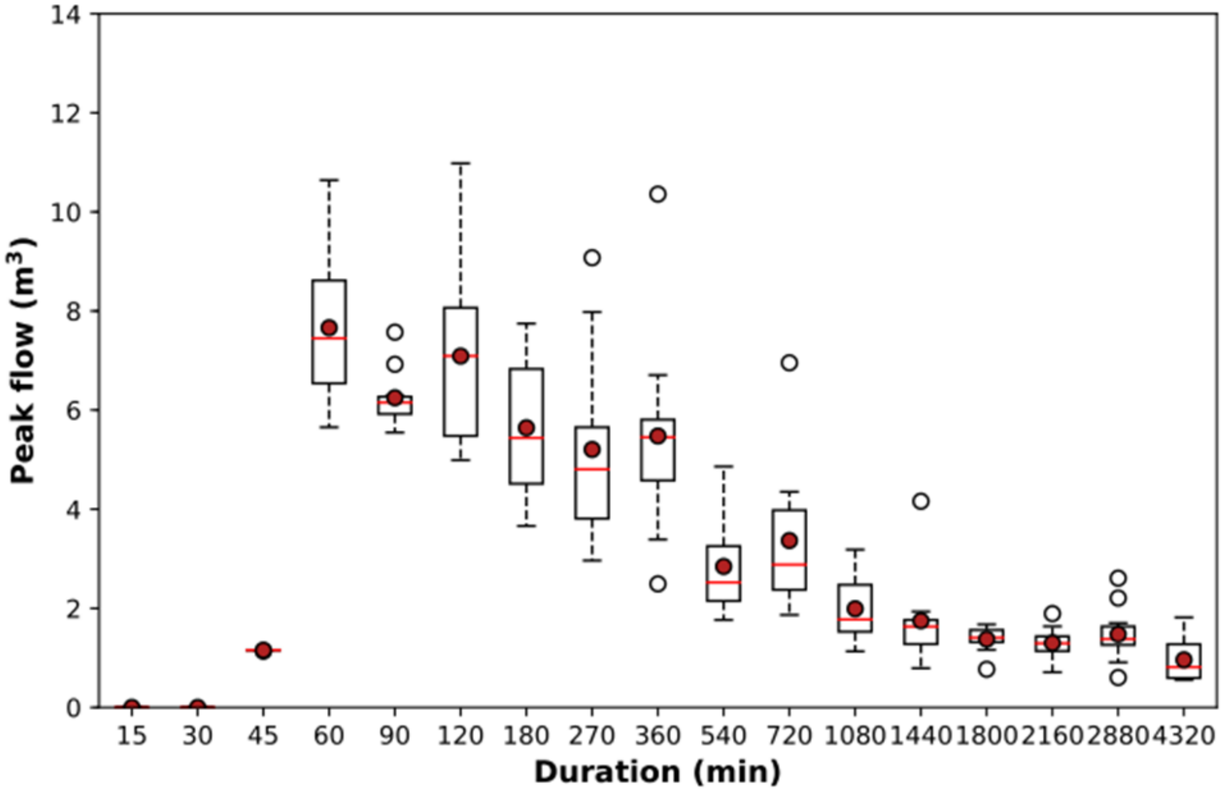


Diagram E2: Box plot of peak local flows at sub-catchment No.1D: 1% AEP event

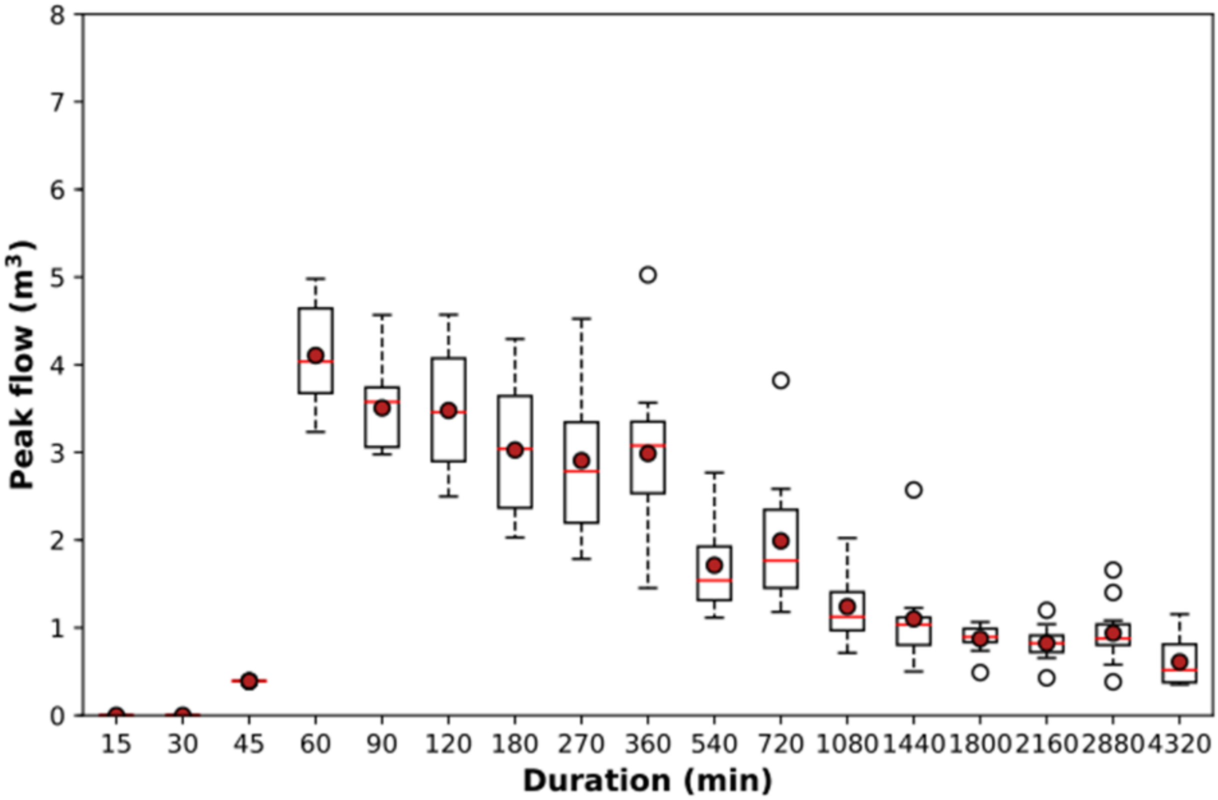


Diagram E3: Box plot of peak total flows at sub-catchment No.1B: 1% AEP event

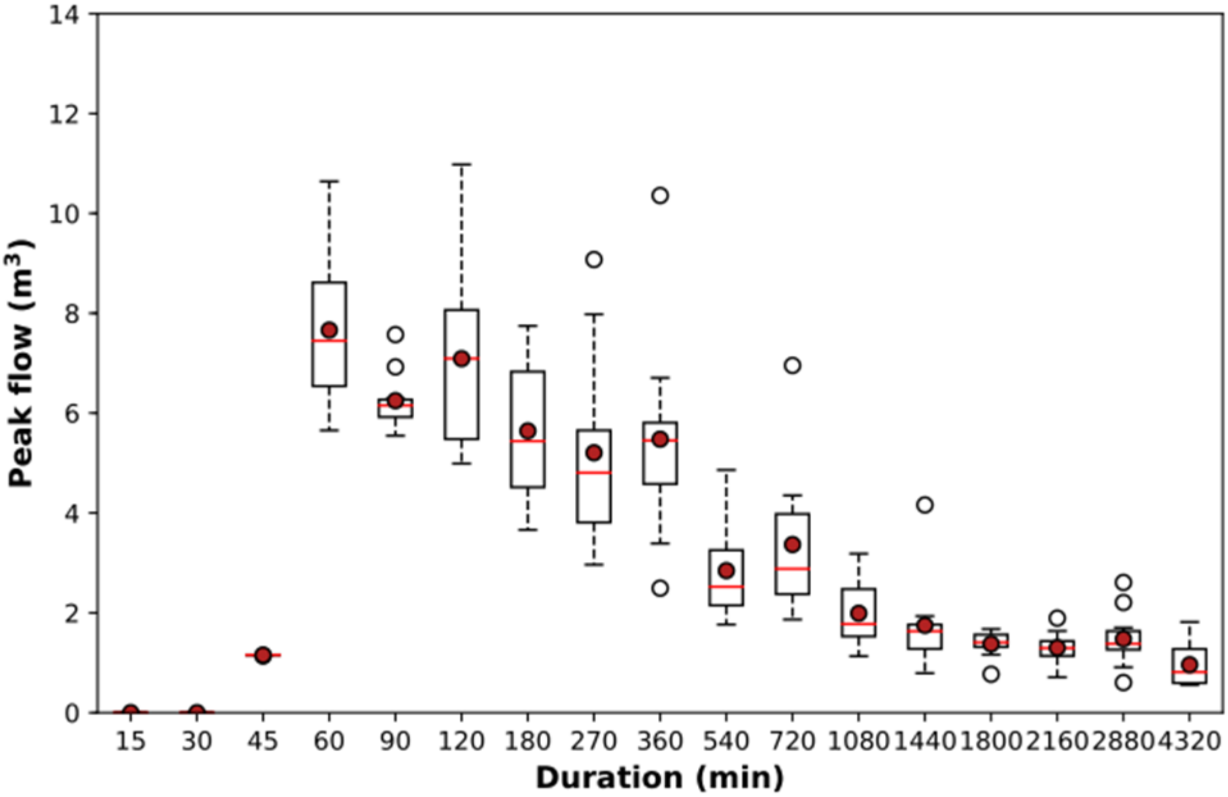


Diagram E4: Box plot of peak total flows at sub-catchment No.1F: 1% AEP event

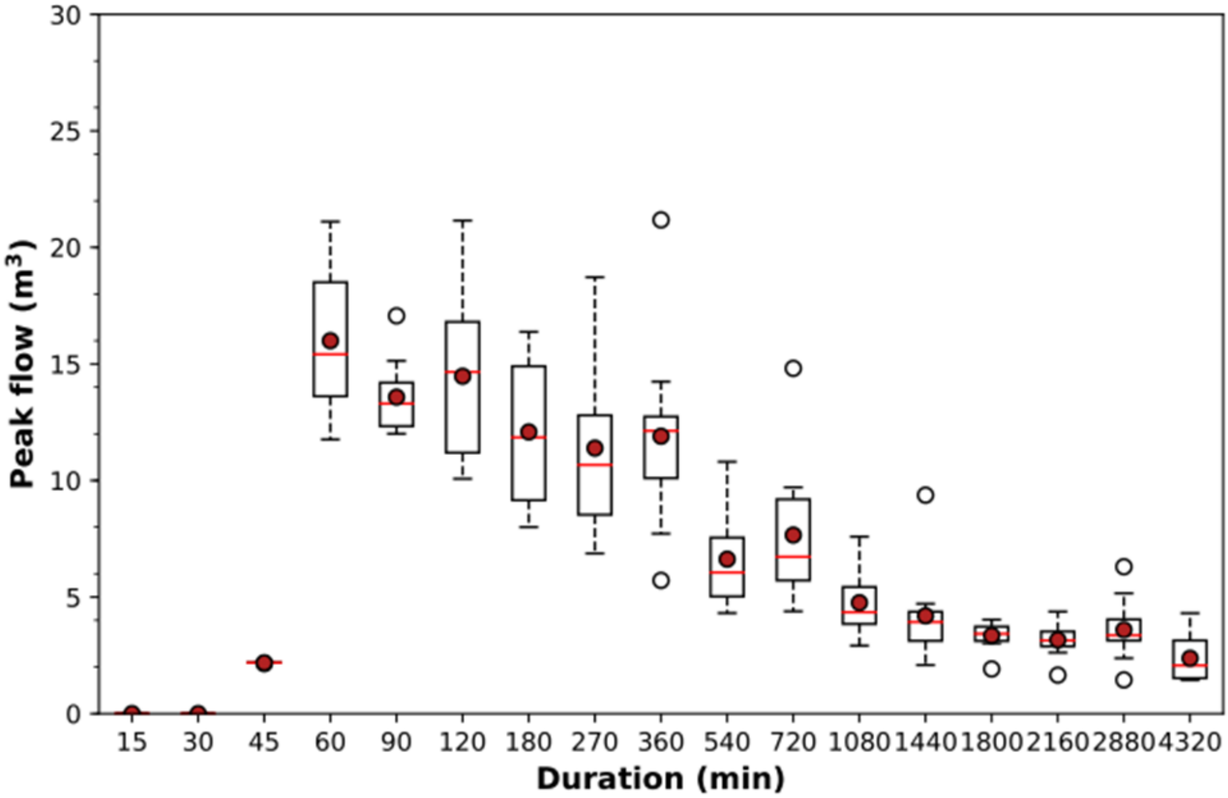
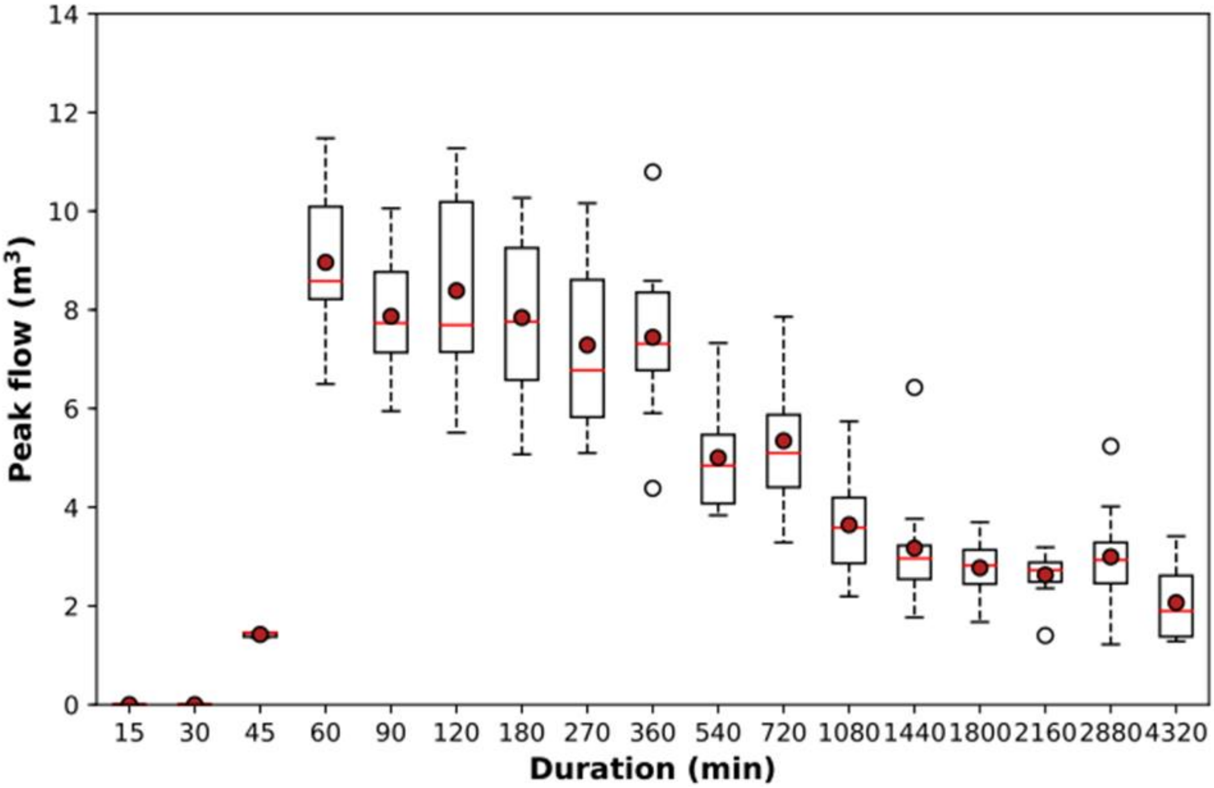


Diagram E5: Box plot of peak total flows at sub-catchment No.4D: 1% AEP event



It can be observed that for the 1% AEP event, similar mean peak flows occur for a range of durations from 60 minutes to 360 minutes. Diagram E1 to Diagram E4 show that in general, the 60 minute (1 hour) storm is critical at these sub-catchments, producing the highest mean flows from the ensemble of temporal patterns. It can be seen from the box plot in Diagram E5 (for sub-catchment No.4D), that the mean flow from the 60 minute storm (the critical flow) is within the range of flows produced in other storm durations – from 120 minutes to 180 minutes. This means that there is likely to be a temporal pattern in other durations that closely matches the critical flow.

The final selection of critical duration was based on peak flood levels produced by TUFLOW. Following the above analysis, the number of durations was shortlisted to the three most likely to produce the greatest flood depths, i.e. the 60 minute, 90 minute and 120 minute storm durations, each run for the ensemble of 10 temporal patterns. The peak flood levels produced by these durations showed that the 120 minute storm (2 hours) resulted in the maximum peak flood depths across the Study Area. Overall, the results demonstrated that for the 1% AEP event, 120 minute duration and temporal pattern 5 resulted in the peak flood levels just above the mean across the area. This analysis was undertaken for all the design events, considering the key flow locations described above. A single duration and temporal pattern were adopted for each bin being representative across the range of events and locations.

The results of the critical duration assessment are provided in Table E1.

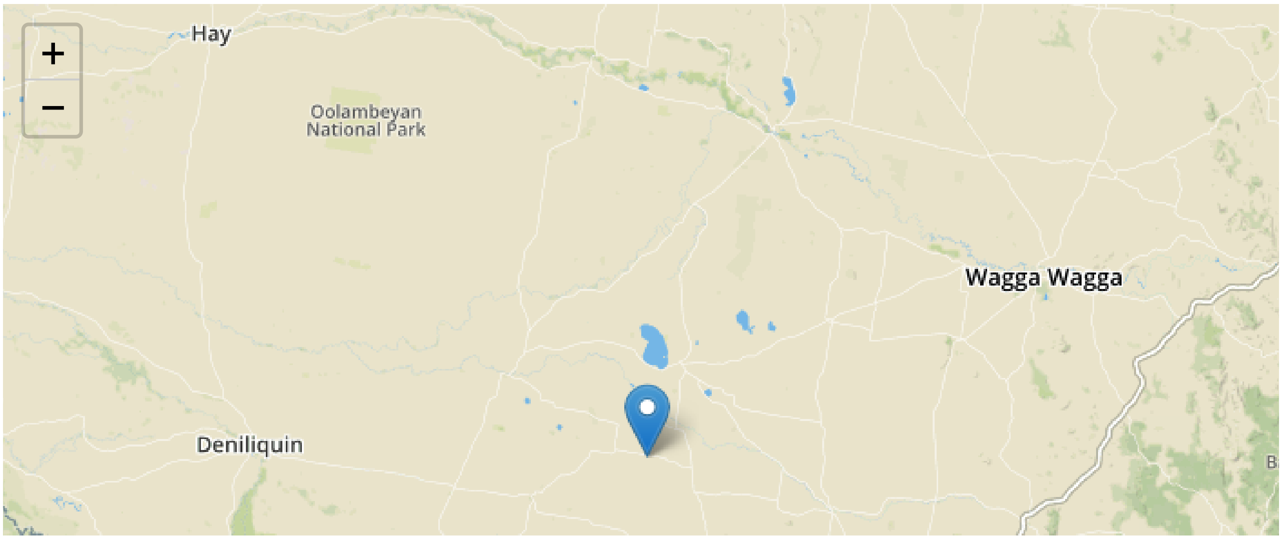
Table E1: Adopted durations and temporal patterns for design flood events

Event	Critical Duration (min)	Adopted Temporal Pattern	IFD (mm)	ARF	Initial Loss (mm)	Continuing Loss (mm/hr)	XP-RAFTS Peak flood discharge (m^3/s) at the catchment outlet
0.2EY	180	TP3: 3982	35.9	0.9616	11.1	0.28	22.8
10% AEP	120	TP3: 3913	37.9	0.9498	9.7	0.28	28.9
5% AEP	120	TP3: 3913	44.2	0.9436	9.7	0.28	35.7
2% AEP	120	TP5: 3935	52.7	0.9355	9.1	0.28	45.5
1% AEP	120	TP5: 3935	59.4	0.9293	7.8	0.28	54.2
0.5% AEP	120	TP5: 3935	66.6	0.9231	7.8	0.28	62.7
0.2% AEP	120	TP5: 3935	76.4	0.9149	7.8	0.28	74.2
PMF	60	Not applicable			0.0	1.0	571.0

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	146.162
Latitude	-35.563
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show
Baseflow Factors	show



Data

River Region

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

Layer Info

Time Accessed	14 February 2019 03:55PM
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	5405.0
Storm Initial Losses (mm)	23.0
Storm Continuing Losses (mm/h)	0.7

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=-35.5625&longitude=146.1625&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)	2.9 (0.159)	2.1 (0.080)	1.5 (0.049)	1.0 (0.028)	1.1 (0.025)	1.2 (0.024)
90 (1.5)	1.0 (0.049)	0.9 (0.031)	0.8 (0.024)	0.8 (0.019)	0.7 (0.013)	0.6 (0.010)
120 (2.0)	1.6 (0.073)	1.5 (0.049)	1.5 (0.039)	1.4 (0.032)	0.7 (0.013)	0.2 (0.003)
180 (3.0)	3.1 (0.124)	3.1 (0.088)	3.1 (0.074)	3.1 (0.063)	1.5 (0.025)	0.2 (0.003)
360 (6.0)	1.1 (0.036)	1.5 (0.035)	1.7 (0.034)	2.0 (0.033)	2.2 (0.032)	2.4 (0.031)
720 (12.0)	0.0 (0.000)	0.8 (0.014)	1.2 (0.020)	1.7 (0.024)	3.1 (0.037)	4.1 (0.043)
1080 (18.0)	0.0 (0.000)	0.0 (0.001)	0.1 (0.001)	0.1 (0.001)	1.1 (0.012)	1.8 (0.017)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.001)	0.1 (0.001)	0.5 (0.005)	0.8 (0.007)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	14 February 2019 03:55PM

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 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

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

75% Preburst Depths

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

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	14.4 (0.795)	15.2 (0.588)	15.6 (0.503)	16.1 (0.443)	16.8 (0.386)	17.3 (0.353)
90 (1.5)	11.0 (0.535)	13.9 (0.477)	15.8 (0.450)	17.6 (0.430)	15.7 (0.322)	14.3 (0.260)
120 (2.0)	8.6 (0.386)	13.7 (0.436)	17.1 (0.452)	20.4 (0.460)	15.0 (0.284)	10.9 (0.184)
180 (3.0)	15.4 (0.612)	16.3 (0.463)	16.9 (0.400)	17.5 (0.355)	16.6 (0.284)	16.0 (0.242)
360 (6.0)	5.6 (0.182)	10.9 (0.256)	14.5 (0.284)	17.8 (0.303)	19.1 (0.273)	20.1 (0.256)
720 (12.0)	5.0 (0.132)	7.7 (0.148)	9.4 (0.153)	11.1 (0.156)	16.0 (0.190)	19.6 (0.208)
1080 (18.0)	0.6 (0.015)	3.8 (0.065)	5.8 (0.085)	7.8 (0.099)	10.2 (0.109)	12.0 (0.114)
1440 (24.0)	0.0 (0.000)	4.6 (0.074)	7.7 (0.104)	10.6 (0.124)	9.4 (0.092)	8.5 (0.073)
2160 (36.0)	0.0 (0.000)	0.9 (0.013)	1.5 (0.018)	2.1 (0.022)	3.2 (0.028)	4.0 (0.031)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.7 (0.005)	1.2 (0.008)
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)	33.1 (1.826)	30.7 (1.190)	29.1 (0.935)	27.6 (0.757)	28.0 (0.645)	28.4 (0.580)
90 (1.5)	24.2 (1.182)	34.1 (1.176)	40.7 (1.163)	47.0 (1.149)	34.8 (0.714)	25.7 (0.468)
120 (2.0)	21.0 (0.940)	32.2 (1.023)	39.7 (1.047)	46.8 (1.058)	37.4 (0.709)	30.3 (0.511)
180 (3.0)	24.9 (0.991)	32.2 (0.915)	37.1 (0.878)	41.7 (0.848)	40.5 (0.692)	39.6 (0.602)
360 (6.0)	15.7 (0.508)	21.6 (0.505)	25.5 (0.501)	29.2 (0.495)	34.6 (0.496)	38.7 (0.494)
720 (12.0)	16.4 (0.433)	22.0 (0.423)	25.6 (0.416)	29.1 (0.410)	30.5 (0.362)	31.5 (0.334)
1080 (18.0)	10.2 (0.240)	15.1 (0.259)	18.3 (0.265)	21.4 (0.268)	24.4 (0.258)	26.6 (0.251)
1440 (24.0)	8.7 (0.190)	17.6 (0.281)	23.5 (0.316)	29.1 (0.338)	24.8 (0.242)	21.6 (0.187)
2160 (36.0)	0.5 (0.010)	8.8 (0.127)	14.2 (0.172)	19.5 (0.203)	17.1 (0.149)	15.3 (0.118)
2880 (48.0)	2.0 (0.037)	2.0 (0.027)	2.0 (0.023)	2.0 (0.020)	10.4 (0.083)	16.6 (0.118)
4320 (72.0)	0.0 (0.000)	1.0 (0.012)	1.6 (0.017)	2.3 (0.020)	5.9 (0.043)	8.7 (0.056)

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

Interim Climate Change Factors

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

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

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	**50**	**20**	**10**	**5**	**2**	**1**
60 (1.0)	15.5	9.5	8.9	9.3	9.2	7.3
90 (1.5)	16.3	10.6	9.5	9.3	8.8	8.1
120 (2.0)	16.2	11.0	9.7	9.7	9.1	7.8
180 (3.0)	15.9	11.1	10.2	10.5	9.0	6.6
360 (6.0)	18.6	13.9	12.2	12.0	10.4	6.9
720 (12.0)	19.7	15.2	14.1	14.0	11.7	7.9
1080 (18.0)	21.2	17.2	16.4	16.8	14.3	9.5
1440 (24.0)	22.3	17.7	16.6	16.1	15.6	11.3
2160 (36.0)	23.7	19.5	19.0	20.2	18.6	14.6
2880 (48.0)	23.9	20.6	22.1	23.2	21.7	16.3
4320 (72.0)	24.4	21.3	22.7	24.3	22.8	17.2

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

Baseflow Factors

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

Layer Info

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