Moulamein Flood Study

Final Report

November 2019

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Table of Abbreviations

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AAD	Average Annual Damage
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
DEM	Digital Elevation Model
DPIE	Department of Planning, Industry and Environment
EY	Exceedances per Year

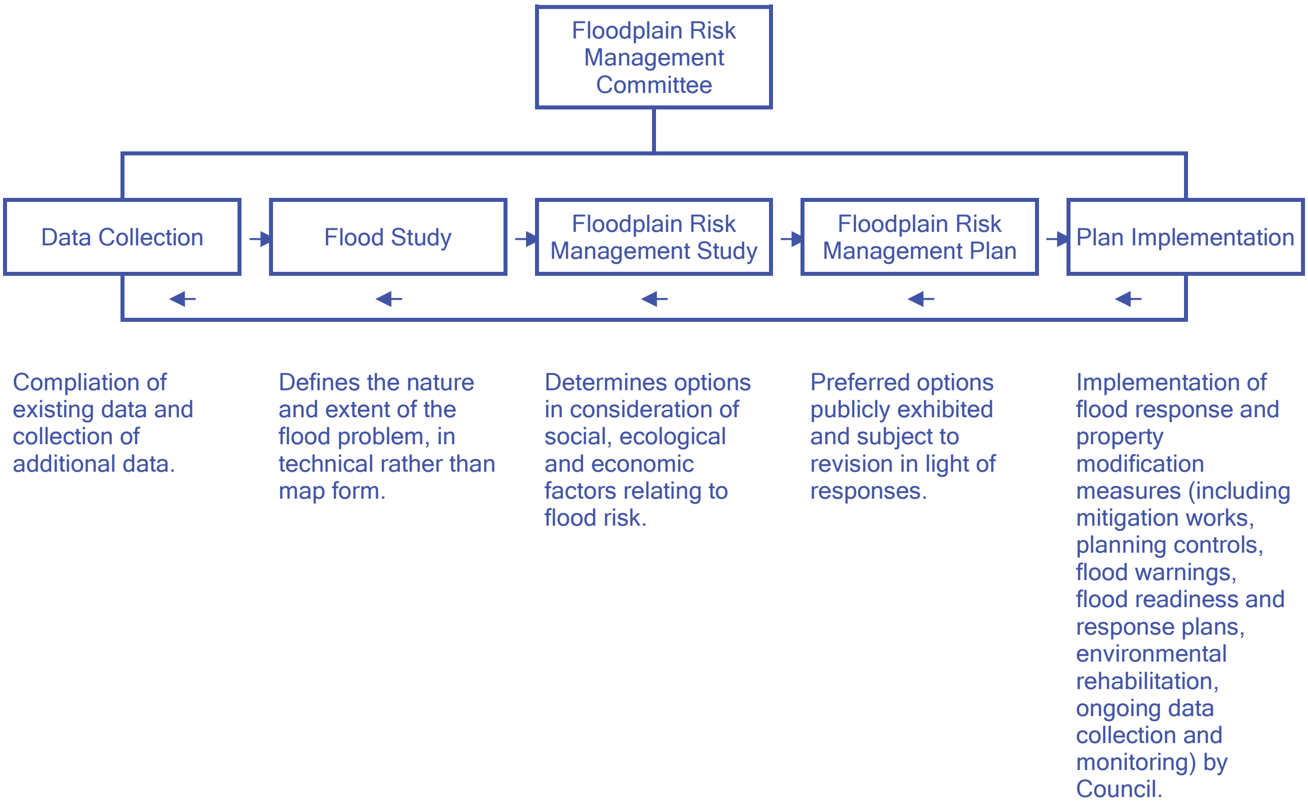
FMC	Floodplain Management Committee
FPA	Flood Planning Area
FPL	Flood Planning Level
LGA	Local Government Area
LiDAR	Light Detection and Ranging
NSW	New South Wales
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Services

Forward

Flood-Related Legislation, Policies and Guidelines

The New South Wales (NSW) State Government's *Flood Prone Land Policy* places the primary responsibility for floodplain risk management with Councils and the *Local Government Act 1993 - Section 733* indemnifies Council from liability if the Council has acted in "good faith" in relation to floodplain risk management. Additionally, the State Government, through the Department of Planning, Industry and Environment (DPIE), provides financial and technical support to Council in meeting its floodplain risk management obligations.

The NSW *Floodplain Development Manual* (2005) supports the NSW *Flood Prone Land Policy*. The manual provides direction on the floodplain risk management process, as detailed below.



There are a number of industry guidelines that provide technical guidance through the floodplain risk management process. This includes the *Australian Emergency Management Series* (particularly *Handbook 7: Managing the Floodplain Best Practice in Flood Risk Management in Australia*), and *Australia Rainfall and Runoff* (ARR). ARR has undergone several revisions since its inception; with the first publication in 1958, the second publication in 1977, the third publication in 1987 and the fourth (and latest) publication in 2019.

The current study has been undertaken in accordance with the aforementioned legislation, policies and guidelines.

Terminology

ARR 2019 has standardised the design flood terminology used in the industry. Very frequent events are expressed as Exceedances per Year (EY), frequent to very rare events are expressed as Annual Exceedance Probability (AEP) as a percentage, and very rare to extreme events are expressed as a 1 in x AEP. This is detailed in Table 1-1, which has been extracted from Section 2.2.5., Chapter 2, Book 1 of ARR 2019.

Table 1-1: Design Event Terminology

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
Very Frequent / Frequent	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
Frequent / Rare	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
Rare / Very Rare	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
Very Rare / Extreme	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			PMP	

Executive Summary

The NSW State Government, through the Department of Planning, Industry and Environment (DPIE), oversee the Floodplain Management Program. The program provides support to local councils in the implementation of the NSW Government's Flood Prone Land Policy as outlined in the NSW Government's Floodplain Development Manual. The primary objective of the policy and manual is to reduce the impacts of flooding and flood liability on individual owners and occupiers. As a result of flooding experienced in 2016, the Moulamein Flood Study was commissioned and funded by Murray River Council and DPIE.

Moulamein is located in the Murray River Council Local Government Area (LGA) in South West NSW. The town is a limited service town for the local area, with government administration, post office, a primary school, a residential aged care facility and some commercial facilities. The suburb of Moulamein has a population of 484 people, according to the 2016 Census.

The Moulamein town centre is located on the confluence of the Edward River and Billabong Creek. The town is largely surrounded by irrigation development that are protected by private rural levees and confine flood waters near the town; whilst the town itself is protected by a series of public levees.

The following Flood Study consists of a data collection phase, hydrologic model development, hydraulic model development, and historical flood simulations. A data collection process was carried out to gather flood-related information that is used to inform the model development and historical flood modelling process. A flood frequency analysis was carried out to calculate the design discharges for a range of design events. The hydraulic model development was undertaken to estimate the flood levels, depths, velocities and extents generated from the catchment conditions and the design discharges. The hydraulic model developed for this study used the TUFLOW software. Historical flood simulations were carried out to calibrate and validate the model's performance in representing flood behaviour in historical flood events.

1 Introduction

1.1 Overview

Murray River Council, with the support of the NSW DPIE, has commissioned HydroSpatial Pty Ltd to prepare the following Moulamein Flood Study.

1.2 Study Objectives

The objectives of the Flood Study were to develop a hydrologic and hydraulic model to:

- Identify existing flood risks and consequences;
- Consult with the community to improve their understanding of flood risk management;
- Provide information to emergency management agencies;
- Provide information for land-use planning and infrastructure planning; and
- Prepare tools suitable for use in the Floodplain Risk Management Study and Plan (FRMS&P).

1.3 Study Area Description

Moulamein is located in the Murray River Council Local Government Area (LGA) in South West NSW. The town is a limited service town for the local area, with government administration, post office, a primary school, a residential aged care facility and some commercial facilities. The suburb of Moulamein has a population of 484 people, according to the 2016 Census.

The Moulamein town centre is located on the confluence of the Edward River and Billabong Creek, shown in Figure 1. The town is largely surrounded by irrigation development that are protected by private rural levees and confine flood waters near the town; whilst the town itself is protected by a series of public levees.

The town levees were constructed in the 1950's with minimal engineering or planning. Plans and design standards for the levees do not exist. Therefore, the integrity of the levees is largely unknown and recent work undertaken by NSW Public Works has identified a number of levee deficiencies.

Since their construction, the levees have protected the town from a number of floods, including the October 2016 flood. However, given the lack of data and questions about levee deficiencies, the NSW State Emergency Services (SES) cannot rely on the levee not breaching and therefore order evacuations when the flood is forecast to reach the levee level (rather than the levee crest/freeboard).

During the October 2016 flood, the NSW SES ordered the evacuation of the town. However, the levees successfully held back the floodwaters and the "unnecessary" evacuation caused some angst within the community.

A levee upgrade study was completed in 2006 by Paterson Britton Partners. This study is now largely obsolete in terms of the data used, the methods and software employed and the floodplain management process.

2 Study Methodology

The following tasks were undertaken as part of Stage 3 of the Moulamein Flood Study Project:

- Stakeholder consultation;
- Data collection;
- Hydrologic analysis;
- Hydraulic model development; and
- Historical flood simulation; and
- Design flood simulation.

Stakeholder consultation was undertaken to gather local information on historical flood levels and flood behaviour. Further details on the stakeholder consultation are discussed in Section 3.

A data collection process was carried out to gather flood-related information from a number of sources. This included collating topographic data, infrastructure data, field trips, historical flood level data, historical rainfall data, and design rainfall data etc. During the data collection process, community consultation was also undertaken to gather data from the community on historical flood events in the study area. This data was then used to inform the model development and historical flood modelling process. Further details on the data collection are discussed in Section 3 and 4.

A flood frequency analysis was carried out to calculate the design discharges for a range of design events. Further details on the flood frequency analysis are discussed in Section 0.

The hydraulic model development was undertaken to estimate the flood levels, depths, velocities and extents generated from the catchment conditions and the runoff hydrographs (the latter of which was calculated in the hydrologic model). Further details on the hydraulic model development are discussed in Section 6.

Historical flood simulations were carried out to calibrate and validate the model's performance in representing flood behaviour in historical flood events. Further details on the historic simulations are discussed in Section 7.

Design flood simulations were carried out to determine the flood behaviour across the study area through a range of statistically-based rainfall events. Further details on the design simulations are discussed in Section 8.

3 Consultation

As part of this study, consultation has been undertaken with a number of stakeholders, as discussed within the following.

3.1 Floodplain Management Committee

The Floodplain Management Committee (FMC) included representatives from the NSW DPIE, NSW SES, Council, and community representatives. The latter two were the only members with voting rights for decisions to be made by the FMC. The former two were involved to provide technical advice to the FMC.

3.2 Community Consultation

3.2.1 First Round

A community consultation process was undertaken during the data collection stage of the study through the July-August 2018 period. The purpose of this community consultation work was to gather data from the community on historical flood events in the study area. This was achieved by distributing an information sheet and conducting a community drop-in meeting.

The community drop-in meeting was held at the Moulamein Bowling Club on the 23 August 2018 between 6pm and 8pm. The community meeting was attended by representatives from HydroSpatial, the SES, Council and two Councillors. Three community members (including a member of the FMC) took part in the community meeting.

Tim Morrison from HydroSpatial presented a brief powerpoint presentation to introduce the project and purpose of the meeting. Following this, a round table discussion was held regarding historical flooding issues and the availability of flood data in the community.

The key notes from the community meeting were:

- Significant upstream development on both the Edward River and Billabong Creek has led to a greater proportion of flow directed towards Moulamein (e.g. capacity has decreased at the Barmah choke point potentially due to sedimentation and development).
- Private works recommended in the Edward and Wakool River Floodplain Management Plan have not been implemented.
- Significant upstream constriction of floodways that flow to the north of Moulamein (e.g. Balpool and Barham Road causeways are no longer running).
- Floodwater travel times are roughly 14 days from Tocumwal and 7 days from Deniliquin.
- Coincident flooding along the Edward River and Billabong Creek occurs on occasion. In 1956 there was coincident flooding; however less so in 1993 and 2016.
- In 1956, significant flow came from the Murrumbidgee Catchment via Yanco Creek. This flooded the town to the north and cut Balranald Road (Moulamein Kyalite Road).
- The community estimated that the 1956 flood was 6 - 8 inches higher than 2016 flood.
- In 2016 there was little flooding from Billabong Creek, with flow backwatering up Billabong Creek from the confluence.
- The Moulamein nursing home was evacuated during the 2016 flood; however most of the other town residents did not evacuate.
- Council is aware that the current SES high safety risk rating for Moulamein can be attributed, to a large extent, to a few weak points on the levee. The Department of Public Works Advisory has identified these locations. Work on these locations will not mitigate the flood risk for Moulamein, but will improve the safety risk rating and reduce the likelihood of the SES ordering a town evacuation. The solutions for Moulamein's flood problems will depend on the outcome from the current FS & FRMS&P. Note that the FRM process takes time. If the 2016 flood was to hit again today, there is no basis

for not making the same evacuation call last time. The safety risk profile is still the same.
- Anecdotally, channels are silting up and have reduced capacity.
- The community would like to see mapping extend further upstream.
- No known above floor flooding from local rainfall.
- Some local drainage works planned but waiting for this study to complete.

3.2.2 Second Round

A community consultation process was undertaken during the public exhibition stage of the study through the October 2019 period. The purpose of this community consultation work was to inform the community of the Draft Flood Study Report and gain feedback, including to stimulate discussion on possible mitigation measures to be investigated at the next stage of the process. However, no community feedback was received during this community consultation process.

4 Available Data

Data is an important component of every study. As such, the first stage within a flood study is to collect and review the available data.

The data available for the study area included:

- Previous studies;
- Aerial-based survey data;
- Ground-based survey data;
- Historic flood data;
- Historic stream flow data;
- Historic rainfall data; and
- Design rainfall data.

The data available was found to be of sufficient quantity and quality to enable the flood frequency analysis and establishment of the hydraulic models used in the study.

4.1 Previous Studies

A number of previous studies have been undertaken in and around Moulamein to investigate flooding. All were undertaken prior to the 2016 floods, one had limited topographic data, one was focused on the levee only and one was focused on an area upstream of and outside of the study area. However, these studies provide some regional context to the current study and are discussed in the following.

4.1.1 Edward/Wakool Rivers Rural Floodplain Management Plan (SMEC Australia Pty Ltd, 2004)

The Edward/Wakool Rivers Rural Floodplain Management Plan was undertaken by SMEC Australia Pty Ltd on behalf of the Department of Infrastructure, Planning and Natural Resources. The study was completed in May 2004. The aim of the study was to develop an overall floodplain management plan for the Central Murray System spanning from Liewah to Deniliquin. This included the major watercourses and effluent streams and tributaries of the major watercourses listed in Table 4-1.

Table 4-1: Water Courses Modelled in the Rural Floodplain Management Plan

Major Water Courses	Tributaries/Effluent Streams of the Water Courses
Edward River	Colligen Creek Cockran Creek Tumudgery Creek Yallakool Creek Jimaringle Creek Bullock Creek Yarrein Creek
Niemur River	Murrain Yarrein Creek Bigantic Creek Cunninyeuk Creek Buccaneit Creek Papanue Creek
Wakool River	Barbers Creek Thule Creek Merran Creek

This study pre-dated the collection of aerial-based survey data (such as LiDAR) and therefore relied on ground-based survey data collected for the study at specific locations. This cross-section data was then used to develop a one-dimensional (1D) hydraulic model using the MIKE-11 software package. This model was calibrated to the 1993, 1975, and 1956 flood events, and validated to the 1996 event.

A flood frequency analysis was undertaken using the gauges at Edward River at Deniliquin, Edward River at Moulamein, Wakool River at Gee Gee Bridge, and Murray River at Barham.

Although the study was fit-for-purpose and used the modelling approaches that were available at the time, it recognised the following limitations to the study were:

- The lack of LiDAR data, necessitating the use of ground-based survey which was a limitation "given the area being modelled is very large and the stream system within that area is highly complex".
- The calibration process required a number of assumptions due to the limited accurate historical records on the agricultural infrastructure within the floodplains; such as when was the infrastructure constructed, what height was it constructed to, has it been topped up since construction and how did it perform during flood periods.

These limitations have been negated in the current study via:

- The collection of LiDAR data over the period of 2013 to 2017 (discussed in Section 4.3.1), thereby negating the former limitation.
- The 2016 flood event occurred recently enough that the agricultural infrastructure present at the time of the flood would likely have been captured within the LiDAR data collected thereby negating the latter limitation.

4.1.2 Moulamein Levee Upgrade Flood Study (Patterson Britton & Partners Pty Ltd, 2006)

The Moulamein Levee Upgrade Flood Study was undertaken by Patterson Britton & Partners Pty Ltd on behalf of the former Wakool Shire Council (since amalgamated with the Murray Shire Council to form the Murray River Council). The study was completed in April 2006. The aim of the study was to define the flood characteristics in the vicinity of Moulamein to assess the suitability of the existing crest elevation and potential options for levee rehabilitation or replacement.

This study relied on a combination of topographic datasets to develop a 2D hydraulic model using the RMA-2 software package. The topographic data used consisted of:

- A 1:50,000 series topographic map covering the study area (*Moulamein 7727-N*) from 1976 that, due to its 10m contour intervals, was used primarily as a basis for road and river locational alignment.
- An existing DEM from 2001 developed by the Department of Infrastructure Planning and Natural Resources (DIPNR) that only partially included the study area.
- An existing survey of the levee banks undertaken by the NSW Department of Commerce.
- Additional GPS survey data collected for the study that included cross-sections of both the rivers and the floodplain.

This model was calibrated to the 1956 and 1975 flood events. A flood frequency analysis was undertaken using data from the Edward River at Moulamein gauge (station number 409014) that spanned from 1922-2002 using the FLIKE software package and implementing the Log Pearson III (LP3), Generalised Extreme Value (GEV) and Gumbel distributions. The three distributions were then compared to existing data points and the LP3 distribution was chosen to be used in the study due to it lying within the 90% confidence interval.

The study concluded that, as of 2006, the predicted cost of flood damages from a 100 year ARI flood would be approximately $620,000 (2006 dollars). The study recommended the levees be upgraded to a Flood Planning Level (FPL) equivalent to the level of a 100 year ARI flood, plus a freeboard of 1 m. It was recommended that these upgrades be achieved through a series of three upgrade types, including standard earth levee construction, road raising, and the installing of concrete walls. It was estimated that these upgrades would cost $2.92 million. Further, the study also recommended a maintenance program that included annual inspections, tree/bush removal and damage repair.

The limitations to the study were:

- The lack of complete DEM data, necessitating the use of ground-based surveying that created a limitation due to large areas of the study area lacking in elevation data.

4.1.3 Edward River at Deniliquin Flood Study (WMAwater Pty Ltd, 2014)

The Edward River at Deniliquin Flood Study was undertaken by WMAwater Pty Ltd on behalf of Deniliquin City Council. The study was completed in November 2014. The aim of the study was to investigate flood behaviour within the immediate vicinity of Deniliquin.

The study included a flood frequency analysis to estimate peak flows using the Edward River at Deniliquin stream gauge (gauge number 409003). The annual time series of historical levels was converted to a time series of equivalent discharges based upon a combination of existing ratings tables and a rating table derived from the calibrated hydraulic model. The annual flood maxima series was truncated to exclude events below 18,300 Ml/d, and included the 1867, 1870 and 1889 events based on the Albury gauge (as these events preceded the establishment of the Deniliquin gauge in 1889). The truncated annual flood maxima series was fitted to the Log-Pearson III (LP3) probability distribution as it was found to have better confidence intervals than the Generalized Extreme Value (GEV) distribution. From this the design flows were estimated as detailed in Table 4-2.

Table 4-2: Design Flows Extracted from the Edward River at Deniliquin Flood Study

AEP (%)	Discharge (m^3/s)	Discharge (Ml/d)
20	600	51,800
10	998	86,200
5	1391	120,200
2	1861	160,800
1	2204	190,400
0.5	2425	209,500

A 2D TUFLOW hydraulic model was established for the Deniliquin study area. A 10 m grid cell resolution was used to model the floodplain and river, which was deemed appropriate for the approximately 70 wide main channel of the Edward River and the roughly 40 m wide flood runners on the floodplain. The upstream boundary was a discharge time-series, which for the historical calibration events used the Edward River at Deniliquin stream gauge as there was considered to be little attenuation between the upstream boundary and the gauge (with the gauge located 12 km downstream of the upstream boundary). The downstream boundary used a stage-time relationship, which was estimated by interpolating the recorded height at the National Bridge gauge and the Edward River Downstream of Stevens Weir gauge (gauge number 409023). The latter gauge was located approximately 24 km downstream of the town, whilst the downstream boundary was located approximately 10 km downstream of the town, so this boundary condition was considered to be a rough estimate only.

The hydraulic model was calibrated and validated to the 1956 event, the 1975 event and the 1993 event. The modelled results were compared to the recorded water level height at the town gauge and a set of flood marks for the 1956 and 1975 events. From this, it was reported that the modelled results showed a strong correlation with the observed flood behaviour, with the model tending towards a slight over-estimation the flood level.

4.2 Field Trips

A field trip on the 21 June 2018 was undertaken to gain an understanding of the study area and to inspect the town levees. Billabong Creek was inspected from the Railway Crossing to the confluence with the Edward River. The Edward River was inspected from the Railway Crossing to the Moulamein Bowling Club. A selection of photographs from the June field trip are presented in Photo 4-1 to Photo 4-8.

Photo 4-1: Moulamein Road crossing the Edward River

Photo 4-2: Confluence of the Edward River and Billabong Creek

Photo 4-3: Boat ramp into Billabong Creek

Photo 4-4: Baratta Street / Pretty Pine Road crossing Billabong Creek

Photo 4-5: Moulamein Road crossing a flood runner from the Edward River, south-west of the confluence with Billabong Creek

Photo 4-6: Crest of the northern town levee

Photo 4-7: Street drainage

Photo 4-8: Street drainage

4.3 Topographic Data

4.3.1 Aerial-based Survey Data

A 1 m resolution Light Detection and Ranging (LiDAR) - derived Digital Elevation Model (DEM) for the study area was obtained from the Australian Government's Geoscience Australia. The dataset name, collection date, resolution and accuracy of the available data is presented in Table 4-3. The aerial-based topographic data extents and levels are shown on Figure 2.

Table 4-3: Aerial-based Survey Data

Name	Date Collected	Resolution	Horizontal Accuracy	Vertical Accuracy
Wakool-Murray	2015	1 m	0.8 m	0.3 m
Edward River	2013	1 m	0.8 m	0.3 m
Dry Lake and Moulamein	2017	2 m	0.8 m	0.3 m

Aerial-based topographic data (such as LiDAR) is a very efficient way to collect ground level data across a large area. However, there are some limitations to these collection methods such as the inability to penetrate water-bodies (such as rivers and dams) and solid structures (such as bridges or culverts over open channels). As such, these local features are often collected via ground-based surveying.

4.3.2 Ground-based Survey Data

The location of the ground-based survey data is shown on Figure 3.

4.3.2.1 Levee

The SES provided ground survey of the levee structures. This data was collected in October 2003 by Surveying and Spatial Information Services for the NSW Department of Commerce. The vertical datum was AHD and the horizontal datum was ISG Zone 55/1. For the purpose of this study, the ground survey data was converted from ISG to MGA 55.

4.3.2.2 Bridges and Culverts

Council provided ground survey of the bridges over the Edward River and Billabong Creek as well as the culverts underneath main roads through the study area (namely Moulamein Road, Balpool Road, Pretty Pine Road, Maude Road, Baldon Road, Balranald Road and Swan Hill Road). This data was collected in November 2018 by Price Merrett Consulting.

4.3.3 Verification of Aerial-based Survey Data with Ground-based Survey Data

The aerial-based survey data was verified against the ground-based survey data to ensure that the former was fit-for-use for this study. This was carried out on a sample set of approximately 3,400 ground-based survey points. From this assessment, the average difference between the data was found to be 0.07 m. As the average difference was within the range of the vertical accuracy of the given LiDAR data (i.e. 0.3 m), the data was deemed fit-for-use for this study.

4.4 Historic Flood Data

4.4.1 SES Flood Intelligence Card

The SES provided the Flood Intelligence Card for the Moulamein Gauge (station number 409014), effective as of the 7th March 1997. The gauge location was given as 100 m upstream of the bridge over the Edward River and gauge zero was given as 64.308 m AHD. The levee height was given as 5.91 m and 6.11 m. A threshold for a minor event classification was 4.60 m, a moderate event classification was 5.20 m and a major event classification was 6.10 m. Historical flood heights and the corresponding consequences are detailed in Table 4-4.

Table 4-4: SES Flood Intelligence Card of Flood Height and Consequences

Class	Height (m)	Consequences
	3.78	18/10/1996 Amors Road and Dhuragoon Road closed. Town stormwater drains under levee closed.
	4.47	22/10/1996 Narcurrie Road closed. Water over Buckenite Creek causeway; road still open.

Class	Height (m)	Consequences
MIN	4.70	25/10/1996 Pike Pike Lane closed.
MIN	4.81	28/10/1996 Maddys Lane and Balshaw Road closed.
MIN	4.83	30/10/1996 Peak height.
MOD	5.28	27/10/1993 Peak height
MOD	5.87	1974 Peak height
MOD	5.91	Low point on Moulamein north levee. If overtopped, only cemetery would remain dry to north of river.
MOD	6.11	Low point on Moulamein south levee. If overtopped, whole town would be inundated. Evacuation route (Moulamein - Hay Road) likely to still be open.

4.4.2 Council Database

Council provided photographs collected by the Manager of Design, Capital Works and Projects during the 2016 flood event. These are shown in **Photo 4-9** to Photo 4-12. From these it can be seen that flood water reached the underside of the Old Court House Bridge and the underside of the Moulamein Wharf.

Photo 4-9: 2016 Flood - Old Court House Bridge

Photo 4-10: 2016 Flood - Picnic Bench

Photo 4-11: 2016 Flood - Moulamein Wharf

Photo 4-12: 2016 Flood - Local Drainage

4.4.3 Old Court House and Library Archives

Research of the Old Court House and Library archives were undertaken on the 22nd August 2018 to gather data on the historical flood events and the historical catchment conditions. From these archives, records were found for the 1917, the 1956 and the 1974 flood events.

The 1917 flood event record consisted of anecdotal evidence in the "Memories of Moulamein" by Allen Cantwell (extracted in the following).

> *"When the drought broke it was followed the next year by a flood which was the worst in my time. The river started to rise rapidly and soon cut across the bends and kept on rising. It looked serious and the shire decided to put a levee bank round the shire residence and the school. Jack Wilson and his horses scooped a bank along the west side of the shire residence and schoolyard and along the Balranald Road for a portion thought necessary. The flood water came across the paddock west of the town and under a culvert under the Balranald Road and then up the creek through where the lake now is and flowed east to the dry lake up near the cemetery. The water started to come from this creek across the common, towards the school, to protect the school Jake Wilson and Bob Tassell threw up a delver bank. About this time the water just started to flow across Tualka Terrace into the triangle in front of the shire chambers when the flood started to recede. It had backed up the town gutter from the punt to Morago Street and alongside the Royal Hotel. I used to read the river heights for father each morning to send to the various papers for the shire. Our boat was tied to the roots of a tree a few yards downstream from the gauge. As the river rose we tied the boat to a higher root. I had a look about 20 years ago and the ring bolt he had put into the root to tie the boat was still there. It would be 20 feet or so downstream of the gauge. It is possibly still there. All the creeks and low lying land north of the town was flooded."*

The 1956 and 1974 flood event records consisted of photographs from various sources; shown in **Photo 4-13** to Photo 4-20.

Photo 4-13: 1956 Flood - Moulamein Railway Station

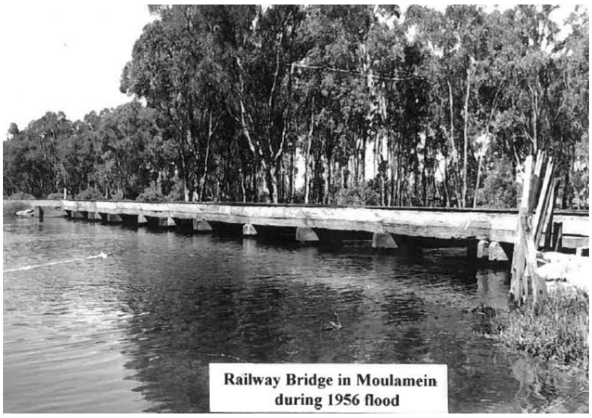


Photo 4-14: 1956 Flood - Railway Bridge in Moulamein

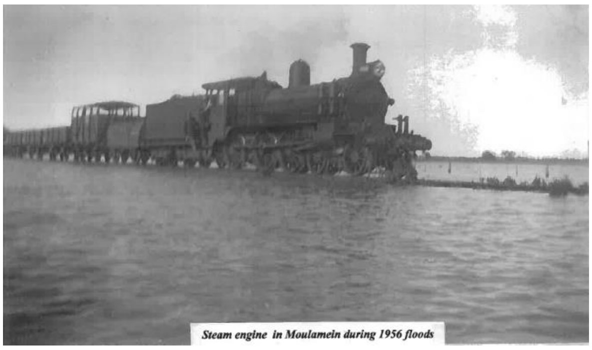


Photo 4-15: 1956 Flood - Steam engine in Moulamein

Photo 4-16: 1956 Flood - Football Oval

Photo 4-17: 1956 Flood - Moulamein Football Shed

Photo 4-18: 1956 Flood - Moulamein Township Surrounded by Floodwater

Photo 4-19: 1956 Flood - Isolated Farm near Moulamein

Photo 4-20: 1974 Flood - Old Court House Bridge

4.4.4 Landsat

The United States Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) developed Landsat 8. The Landsat 8 satellite consists of two scientific instruments; the Operational Land Imager (OLI) and the Thermal Infrared Sensors (TIRS). Landsat 8 is the most recent satellite launched as part of the Landsat Program which provides repetitive high resolution multispectral data of the surface of the Earth. From this, the study was able to acquire imagery of the October 2016 flood extent (as shown in Figure 4), which was used for model calibration (discussed in Section 7).

4.5 Historic Stream Data

4.5.1 Stream Gauges

Official stream gauges upstream of the Moulamein Town Centre were sourced from Water NSW, shown in Table 4-5.

Table 4-5: Stream Gauges Upstream and Downstream of Moulamein Town Centre

Station number	Station name	Distance (in a straight line)	First Record	Last Record	Zero Gauge
409014	Edward River at Moulamein	1.13	1/01/1905		64.324
409035	Edward River at Liewah	70.67	21/03/1957		55.348
410134	Billabong Creek at Darlot	38.21	24/04/1978		71.325
409023	Edward River Downstream of Stevens Weir	77.10	3/07/1935		79.773
409003	Edward River at Deniliquin	98.69	01/09/1896		82.43

4.6 Historic Rainfall Data

4.6.1 Rainfall Gauges

Official rainfall gauges within a 70 km radius of the Moulamein Town Centre were sourced from the Bureau of Meteorology (BoM) and Department of Primary Industries (DPI), shown in Table 4-6 and Figure 5.

Table 4-6: Rainfall Stations within 60 km of Moulamein Town Centre

Station	Station name	Distance from Moulamein Town Centre	First Record	Last Record	Type
75046	Moulamein Post Office	1.04	1888 Jul	2018 Jun	Daily
75020	Mallan (Niemur Valley)	16.84	1877 Jan	2011 Dec	Daily
75001	Balpool (Nyang)	17.22	1889 Jan	1950 Apr	Daily
75106	Mallan	17.32	1901 Nov	1918 Jul	Daily
75093	Mallan (Oakbank)	19	2012 Feb	2018 May	Daily
75036	Keri Keri	23.13	1936 Jan	1951 Jan	Daily
75138	Moulamein (Kildery)	24.28	1967 Mar	1968 Jul	Daily
75131	Windouran	28.96	1904 Jan	1925 Mar	Daily
75045	Moolpa	31.16	1866 Dec	1948 Dec	Daily
75062	Moulamein (Tchelery)	32.32	1936 Jan	2018 Jun	Daily
75098	Dry Lake 2	34.59	1911 Jul	1928 Apr	Daily
75136	Dry Lake Post Office	34.59	1906 Jun	1923 Feb	Daily
75176	Tullakool (Cheethams Salt)	35.32	1993 Jul	2008 Jul	Daily
75051	Noorong	35.49	1877 Jan	1939 Dec	Daily
75121	Royston	35.99	1897 Jul	1925 Jun	Daily
75083	Werai	38.56	1876 Jan	1925 Jan	Daily
75081	Wanganella (Bundyulumblah)	38.86	1900 Feb	2018 Jun	Daily
75061	Stoney Crossing	39.93	1932 Dec	1956 Sep	Daily
75164	Stony Crossing (Barwon)	41.64	1957 Jul	2018 May	Daily
75117	Poon Boon	41.93	1888 Jan	1910 Jun	Daily
75091	Cobwell	43.77	1901 Mar	1914 Dec	Daily
77066	Pental Island	46.27	1907 Feb	1923 Jul	Daily
75101	Gonn	46.52	1911 Jan	1935 Nov	Daily
75092	Colenso Park	48.06	1900 Jun	1910 May	Daily
75048	Swan Hill (Murray Downs)	49.39	1864 Aug	1998 Feb	Daily
76059	Tyntynder Station	49.73	1882 Jan	1970 Aug	Daily
75112	Lynwood 1	49.78	1901 Sep	1945 Aug	Daily
75004	Wakool (Barratta)	50.82	1891 Jan	2018 Jun	Daily
80001	Benjeroop (Davey)	51.02	1884 Jan	1990 Dec	Daily
80040	Murrabit R.W.C.	51.16	1926 Nov	1992 Oct	Daily
77043	Swan Hill High School	51.32	1949 Nov	1951 Apr	Daily
75082	Deniliquin (Kalawar)	51.4	1952 Jan	1978 Jun	Daily
75089	Kyalite Post Office	51.56	1965 Jan	1974 Oct	Daily
77042	Swan Hill Post Office	51.82	1884 Oct	1996 Dec	Daily
75095	Bookit Island	52.45	1912 Jun	1932 Jan	Daily

Station	Station name	Distance from Moulamein Town Centre	First Record	Last Record	Type
77084	Swan Hill Sr&wsc	52.65	1956 Oct	1982 Dec	Daily
76071	Woorineen	53.72	1919 Jun	1948 Apr	Daily
75086	Wakool (Murray Irrigation)	54.18	1962 Nov	2018 May	Daily
75070	Wakool Dampier St	54.28	1928 Mar	1990 Jun	Daily
77024	Lake Boga State Reservoir	54.38	1948 Jun	1956 Sep	Daily
77094	Swan Hill Aerodrome	54.97	1996 Dec	2018 Jul	Daily
77094	Swan Hill Aerodrome	54.97	2010 Jul	2018 Jul	Continuous
77045	Tresco	55.18	1916 Sep	1944 Nov	Daily
77046	Tresco Srwsc	55.18	1926 Jan	1949 Mar	Daily
77025	Lake Boga	55.57	1903 Sep	2018 Jul	Daily
77092	Kangaroo Lake	57.15	1977 Nov	1987 Jan	Daily
75077	Yanga	57.33	1889 Jan	1954 Oct	Daily
75002	Barham 2	57.85	1899 Jan	1963 Dec	Daily
409113	Barbers Creek at Barbers Pool	58.14	2014 Aug		Continuous
76060	Tyntynder West	58.5	1896 Nov	1950 Oct	Daily
77070	Ultima East	59.53	1897 Dec	1925 Sep	Daily

4.6.2 Analysis of Daily Rainfall Data

Daily rainfall gauges typically collect data for the 24 hours prior to 9:00 am on the day the data is recorded. For instance, the data recorded on the 2nd January 2018 covers the period from 9:00 am on the 1st January 2018 to 9:00 am on the 2nd January 2018.

Table 4-7 details the highest daily rainfall values recorded where a significant period of record was available and where the gauges were proximate to Moulamein. The gauge at Moulamein Post Office was the closest gauge to the town centre and had the second longest period of record of the proximate gauges.

There were some dates that appeared to have relatively large rainfall values across multiple gauges, such as January 1941, March 1983, and January 1974. The spatial distribution of the 4th January 1974 rainfall is shown on Figure 7.

Table 4-7: Top 15 Daily Records at Gauge 75046, 75020, 75062, and 75081

Moulamein Post Office (75046)			Mallan - Niemur Valley (75020)		
Jul 1888 - To Date			Jan 1877 - Dec 2011		
Rank	Date	Rainfall (mm)	Rank	Date	Rainfall (mm)
1	17/11/1889	130.8	1	21/03/1926	78.7
2	16/12/1930	111.8	2	26/02/1939	76.2
3	4/01/1941	97.3	3	22/03/1983	73.8
4	5/12/1933	89.4	4	12/11/1998	73.6
5	4/06/1923	79.2	5	4/01/1974	73
6	23/02/1934	76.2	6	14/12/1894	72.1

Moulamein Post Office (75046)		
Jul 1888 - To Date		
Rank	Date	Rainfall (mm)
7	28/11/2011 (3 days)	76
8	4/01/1974	75
9	15/08/1958	73.7
10	27/02/1939	73.4
11	28/12/1903	67.8
12	10/02/1969	67.3
13	26/02/1946	66.5
14	24/12/1921	65
15	4/01/1988 (4 days)	65

Mallan - Niemur Valley (75020)		
Jan 1877 - Dec 2011		
Rank	Date	Rainfall (mm)
7	18/01/1928	70.4
8	10/02/1969	69.3
9	6/03/1956	68.6
10	3/07/1936	66
11	28/11/1973	63
12	3/01/1941	62.5
13	31/03/1981	62.2
14	15/08/1958	59.9
15	24/10/1975	59.2

Moulamein - Tchelery (75062)		
Jan 1936 - To Date		
Rank	Date	Rainfall (mm)
1	4/01/1941	118.4
2	8/03/2010 (4 days)	109.4
3	19/12/2011	92.2
4	26/04/1973	83.8
5	26/11/2011	70.6
6	22/10/1939	66.5
7	21/04/1990	64
8	22/02/1973	62.7
9	22/03/1983	62.4
10	5/02/2011	60
11	17/02/1939	57.2
12	1/01/1988	57
13	6/12/1985	55.6
14	22/11/1986	55
15	30/12/1948	53.6

Wanganella - Bundyulumblah (75081)		
Feb 1900 - To Date		
Rank	Date	Rainfall (mm)
1	22/03/1983	113.4
2	21/02/1973	110.7
3	24/10/1975	92.2
4	3/12/1954	78.5
5	27/04/1973	76.2
6	4/01/1974	70.2
7	2/05/1956	58.4
8	10/02/1969	57.4
9	8/03/2010	57
10	31/10/2010 (2 days)	56.4
11	18/05/1978	55.2
12	6/11/1999	55
13	1/05/1960	54.6
14	9/02/1971	54.6
15	2/04/1959	53.6

4.6.3 Analysis of Pluviometer Rainfall Data

Pluviometer (or continuous) rainfall gauges typically collect data per increment of rainfall rather than per increment of time, thereby returning data at sub-daily intervals. In such a way, pluviometer gauges are ideal for analysing the short-duration, high-intensity storm bursts.

Table 4-8 details the highest hourly rainfall values for the two pluviometer gauges within a 70 km radius of the Moulamein. The gauge at Swan Hill Aerodrome was the closest gauge to the town centre and had the longest period of record.

Table 4-8: Top 15 Hourly Records at Gauge 77094 and 409113

Swan Hill Aerodrome (77094) Jul 2010 - To Date			Barbers Creek at Barbers Pool (409113) Aug 2014 - To Date		
Rank	Date	Rainfall (mm)	Rank	Date	Rainfall (mm)
1	15/11/2017 23:00	29.6	1	1/12/2017 23:00	16.8
2	10/01/2011 10:00	17.6	2	4/11/2015 21:00	16.4
3	20/04/2017 23:00	15.4	3	2/10/2016 23:00	14.8
4	27/11/2010 18:00	15.2	4	16/11/2017 5:00	14.4
5	1/12/2017 20:00	14	5	2/12/2017 0:00	14
6	10/04/2014 4:00	13.8	6	30/01/2016 17:00	13.8
7	9/11/2011 21:00	13.4	7	18/03/2016 1:00	12.4
8	10/01/2011 6:00	13.2	8	29/01/2018 18:00	10.4
9	24/05/2012 19:00	13	9	1/12/2017 14:00	9.8
10	27/02/2012 19:00	12	10	16/11/2014 0:00	8.4
11	12/06/2013 3:00	11.8	11	31/01/2016 17:00	8.4
12	27/01/2016 17:00	11.8	12	18/06/2015 9:00	7.4
13	14/09/2016 1:00	11.6	13	19/12/2017 18:00	6.6
14	21/04/2017 0:00	10.4	14	12/09/2016 23:00	6.4
15	9/03/2011 16:00	10.2	15	30/09/2016 16:00	6.4

From this data, it can be seen that high hourly rainfall totals tend to be highly localised, with high hourly rainfall totals at one location not necessarily occurring at another location. For this reason, the local rainfall validation process (undertaken in Section 7) identified the most recent highest daily total at the Moulamein Post Office (75046) gauge and scaled the pluviometer rainfall data from the Swan Hill Aerodrome (77094) gauge. This was necessary as there is no pluviometer rainfall data recorded at Moulamein.

5 Flood Frequency Analysis

5.1 Overview

Flood Frequency Analysis (FFA) has been undertaken as part of this study to determine the peak flow rates for the design flood analysis. The methodology undertaken is in accordance with ARR 2019 using the TUFLOW FLIKE software.

FFA is a process whereby historical flood peaks are "fitted" to a probability distribution, which can then be used to determine the flood peak for an event of a given probability, e.g. 1% AEP. In this analysis the annual peak flood distribution was used instead of the partial series (often referred to as peak over threshold series). The annual series was chosen as it is more widely used in the region.

There are two inputs of FFA:

- The time series of annual peak heights; and
- The rating table that converts those peak heights to discharge.

5.2 Annual Peak Heights

Annual heights were extracted for the Edward River at Moulamein (409014) gauge from the WaterNSW data. Data was extracted on a daily timestep and then analysed to ensure that each annual peak was independent (i.e. a flood did not occur in December/January and was counted for two years). The independent annual maximum daily value was then chosen for use in the flood frequency analysis.

The annual peak heights were then censored using the Grubbs-Beck test in FLIKE to remove the low, non-flood years. This procedure is recommended as part of ARR 2019. This resulted in 48 low flow years being censored while 49 years were included in the analysis.

Table 5-1 Annual Time Series in FFA

Included Flows			Censored Flows		
Rank	**Flow (m^3/s)**	**Year**	**Rank**	**Flow (m^3/s)**	**Year**
1	402.37	1956	50	67.76	1988
2	345.5	1931	51	67.03	1943
3	246.63	1974	52	63.09	1928
4	240.28	1952	53	62.69	1948
5	222.92	1975	54	58.99	1979
6	220.97	1981	55	58.21	1985
7	213.24	1939	56	54.97	1998
8	199.76	2016	57	53.15	2013
9	199.46	1955	58	52.06	1968
10	185.71	1973	59	52.05	1994
11	181.61	1993	60	51.35	1987
12	181.61	1990	61	49.31	1927
13	173.83	1992	62	48.34	1940
14	158.25	1958	63	47.95	1967
15	157.94	1960	64	46.3	1963

Included Flows			Censored Flows		
16	155.43	1964	65	45.68	1954
17	153.2	1970	66	45.13	2003
18	138	1934	67	42.14	1976
19	134.43	1932	68	42.13	1929
20	130.03	1923	69	40.41	2005
21	129.51	1996	70	37.73	1999
22	126.16	1936	71	36.44	2004
23	124.11	1951	72	36	1982
24	122.39	1946	73	36	1966
25	115.5	1989	74	35.01	2006
26	114.1	1995	75	34.74	2002
27	113.67	1924	76	33.5	2015
28	112.88	1926	77	33.42	1957
29	112.25	2000	78	33.25	2001
30	111.93	2011	79	33.09	2017
31	108.72	1991	80	33.09	2017
32	107.3	2010	81	32.95	1959
33	104.53	1953	82	31.99	1937
34	103.81	1942	83	31.61	1997
35	102.43	1950	84	31.53	2014
36	100.76	1984	85	30.18	1941
37	99.74	1983	86	28.31	1980
38	99.35	2012	87	27.84	2009
39	99.23	1930	88	26.96	1977
40	96.71	1935	89	26.37	1965
41	96.43	1978	90	25.39	1962
42	92.19	1986	91	23.15	2007
43	81.17	1925	92	22.54	1961
44	81.01	1949	93	22.53	1972
45	80.64	1971	94	21.57	1945
46	77.76	1933	95	14.51	1938
47	76.27	1969	96	14.38	2008
48	75.18	1922	97	11.5	1944
49	74.22	1947			

5.3 Probability Distribution

Four commonly used probability distributions were analysed as part of the FFA, these were:

- Log Pearson Type III (LP3)
- Log-Normal
- Gumbel
- Generalized Extreme Value (GEV)

The probability distributions were also tested with and without "censoring" whereby years with low flows are removed from the analysis to avoid the probability distribution becoming skewed by these results. Low flow years were removed using the Grubbs-Beck test available in FLIKE. The plotting position for each historic flood was then compared to the distribution to determine the best fit. Overall it was found that the LP3 with censored flows had the best fit.

5.4 Results

5.4.1 Estimates at Moulamein Gauge

The results of the FFA using the LP3 distribution with censored low flows is shown in Table 5-2, Table 5-3 and Chart 5-1.

Table 5-2: FFA Estimates - Historical Event Probabilities

Event	AEP (%)	ARI (1 in X Years)
1956	0.012	82
1973	0.195	5
1974	0.053	19
1975	0.094	10
1981	0.114	9
1993	0.215	5
2016	0.154	6

Table 5-3: FFA Estimates - Design Event Probabilities

ARI	Discharge (m^3/s)	Discharge (Ml/d)
1 in 5	179	15,447
1 in 10	225	19,474
1 in 20	279	24,064
1 in 50	362	31,242
1 in 100	436	37,695
1 in 200	523	45,200

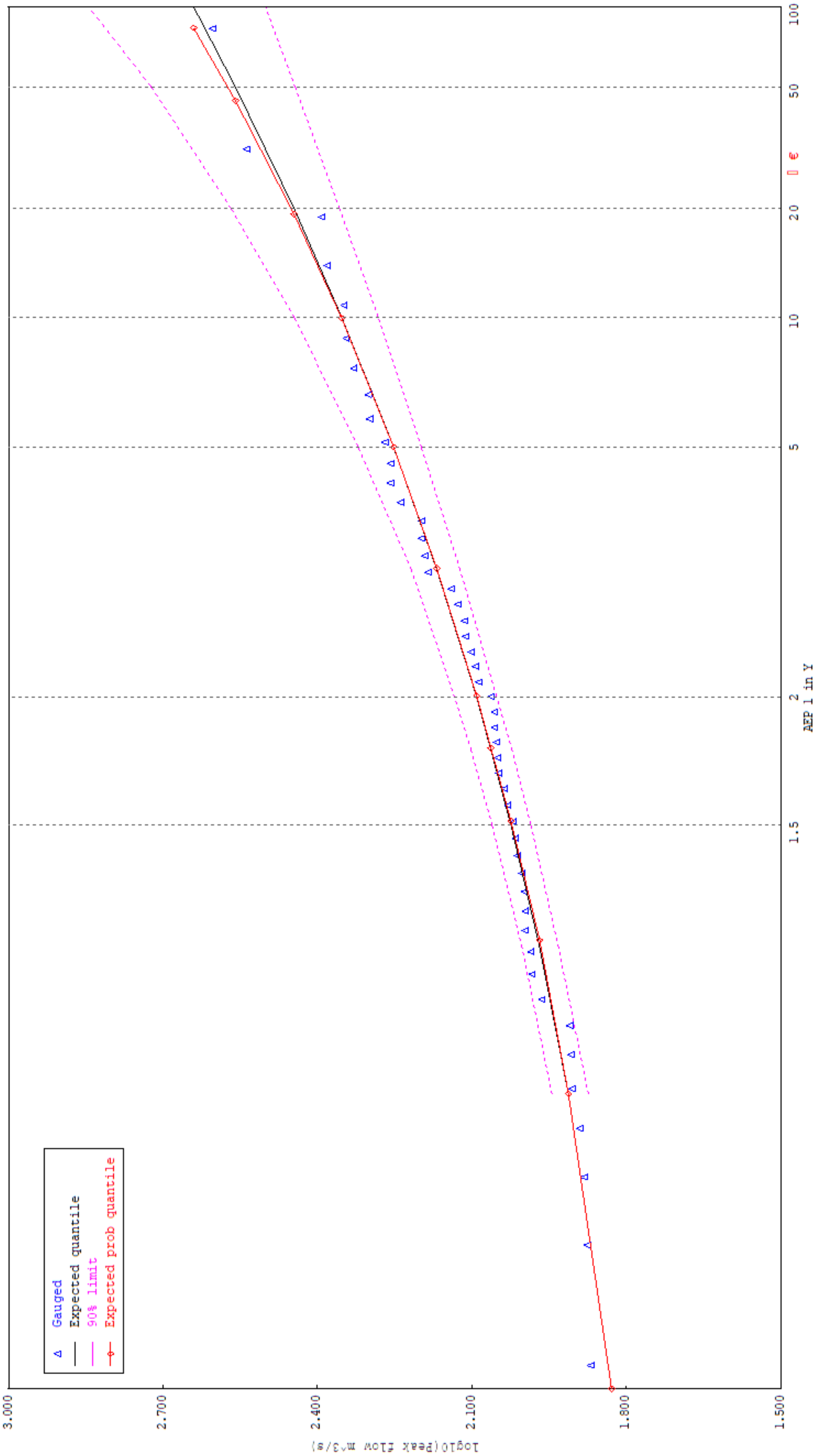


Chart 5-1: Flood Frequency Analysis Results (LP3, Censored)

5.4.2 Comparison to Previous Estimates at Moulamein Gauge

The FFA estimates calculated in this study have been compared to the FFA estimates from the previous study undertaken by Patterson Britton (2006); shown in Table 5-4 and Table 5-5. From this it was found that there was a relatively good correlation between the estimates; although the current estimates were found to decrease the probability of the historic events and increase the estimated flows of the design events. These differences were due to:

- The current study used an additional 14 years of record that was not available at the time of the Patterson Britton Study (2006). This included the 2016 event, which was estimated to be in the order of a 1 in 6 year ARI event.
- The current study used the Grubbs-Beck test to censor low flows, whereas the Patterson Britton Study (2006) used uncensored flows.
- The Patterson Britton Study (2006) identified minor independence issues, which have since been rectified prior to the commencement of the current study.

Table 5-4: FFA Comparison to Previous Moulamein Studies - Historical Estimates

Historic Event	Current Study ARI (1 in X Years)	Patterson Britton (2006) ARI (1 in X Years)
1956	82	100
1973	5	10
1974	19	20
1975	10	15
1981	9	14
1993	5	8
2016	6	N/A

Table 5-5: FFA Comparison to Previous Moulamein Studies - Design Estimates

Design Event	Current Study Flow (m^3/s)	Patterson Britton (2006) Flow (m^3/s)
1 in 20	279	253
1 in 50	362	335
1 in 100	436	401

5.4.3 Comparison to Estimates at Surrounding Gauges

The following gauges are located upstream of the Edward River at Moulamein (409014) gauge:

- The Billabong Creek at Darlot (410134) gauge; and
- The Edward River at Deniliquin (409003) gauge.

The Billabong Creek at Darlot (410134) gauge was established in 1978; therefore it has a limited period of record, i.e. 40 years of record. Due to this, the five largest events recorded at the Edward River at Moulamein (409014) gauge pre-dated the establishment of the Darlot gauge; namely the 1956, 1931, 1974, 1952 and 1975 event. For this reason, an FFA comparison was not undertaken on the Darlot gauge.

The Edward River at Deniliquin (409003) gauge was located more than 98 km upstream of the Edward River at Moulamein (409014) gauge. It is anecdotally understood that a significant portion of the flow recorded at Deniliquin escapes from the Edward River and diverts to the south through Wakool. This correlates with the comparison of the FFA estimates from the Deniliquin Flood Study (WMAwater,2014), shown in Table 5-6.

Table 5-6: FFA Comparison to Previous Adjacent Studies - Design Estimates

ARI	Current Study Discharge (m^3/s)	WMAwater Study (2014) Discharge (m^3/s)
1 in 5	179	600
1 in 10	225	998
1 in 20	279	1391
1 in 50	362	1861
1 in 100	436	2204
1 in 200	523	2425

5.4.4 Estimate of PMF Flow

The PMF flow at Moulamein was approximated to be double the 1% AEP flow estimate. This corresponded with the method used to estimate the PMF flow in the previous Patterson Britton Study (2006). This results in a PMF flow estimate of 873 m^3/s or 75,389 Ml/d.

6 Hydraulic Model Development

6.1 Overview

The hydraulic model developed for this study used the TUFLOW software (BMT WBM, 2016). The TUFLOW version used was 2018-03-AB with double precision.

6.2 Digital Elevation Model

The data used to generate the Digital Elevation Model (DEM) and the grid cell resolution are important components to the 2D domain definition used by TUFLOW.

The data used to generate the DEM is often dependent on:

- The degree of vertical accuracy;
- The horizontal resolution; and
- The date of collection (as older datasets may not entirely represent the current catchment conditions, if changes have occurred).

And the factors that influence the model grid cell resolution are:

- The purpose of the study;
- A balance between model resolution and model runtimes - with higher resolution models requiring longer computation runtimes; and
- The resolution of the available data - as very little is gained from modelling at a finer resolution than the input data.

Taking these factors into consideration, the LiDAR data (discussed in Section 4.3.1) was used to derive the DEM and establish a hydraulic model with a 24 m grid cell resolution across the rural catchment area and a 6 m grid resolution across the town catchment area.

6.3 Hydraulic Roughness

The hydraulic roughness (Manning's 'n') represents the hydraulic efficiency of the flow paths within the TUFLOW model. Various industry references provide guidelines for acceptable hydraulic roughness ranges for varying land use types including Chow (1959), Henderson (1966), and the ARR Revision Project 15. Field inspections were undertaken and the ARR Revision Project 15 guidelines were used to determine the Manning's 'n' values for varying land use types within the study area, detailed in Table 6-1.

Table 6-1: Roughness Values Adopted

Land Use Type	Adopted Manning's 'n' Value	Range of Acceptable Manning's 'n' Values
Roads	0.02	0.02 - 0.03
Dams	0.03	0.02 - 0.04
Urban	0.04	N/A *
Major River System (Vegetated Waterway)	0.045	0.04 - 0.10
Light Vegetation	0.03	0.03 - 0.05
Medium Vegetation	0.05	0.05 - 0.07
Heavy Vegetation	0.08	0.07 - 0.12
Crops	0.05	0.05 - 0.07

* Note: the Manning's 'n' values for residential and industrial/commercial areas within the guidelines are for use within the building extents not the urban area surrounding the building extents.

The Wakool Local Environmental Plan (LEP) 2013 Land Zoning Maps and aerial photography were used to delineate the spatial extents of the land use types (and thus the hydraulic roughness) throughout the study area, shown on Figure 6. The model's sensitivity to the hydraulic roughness factors applied were investigated, as discussed in Section 8.3.2.

6.4 Hydraulic Structures

6.4.1 Road and Railway Embankments

The road and railway embankments were identified through inspection of the aerial photography and the aerial-based survey (discussed in Section 4.3.1). From this, the embankments were overlaid in the 2D domain based upon the LiDAR levels at the crest. The location of the embankments are shown on Figure 6.

6.4.2 Rural Levees

The rural levees were identified through inspection of the aerial photography and the aerial-based survey (discussed in Section 4.3.1). From this, the rural levees were overlaid in the 2D domain based upon the LiDAR levels at the crest. The location of the rural levees are shown on Figure 6.

6.4.3 Town Levees

The town levees were identified and schematised as an overlay in the 2D domain based upon the ground-based survey (discussed in Section 4.3.2.1). The location of the rural levees are shown on Figure 6.

6.4.4 Edward River and Billabong Creek

The Edward River and Billabong Creek were modelled as an embedded 1D domain within the TUFLOW model. The river and creek schematisation was based upon a combination of the aerial-based survey (discussed in Section 4.3.1) and the ground-based survey commissioned by Council (discussed in Section 4.3.2). The location of the 1D river and creek schematisation is shown on Figure 6.

6.4.5 Tributaries and Divergences

There are a number of small tributaries and divergences that are connected to the Edward River and Billabong Creek. These have been modelled in the 2D domain, with the alignment based on the National Surface Hydrology Lines developed by Geoscience Australia (https://data.gov.au/dataset/surface-hydrology-lines-national) and the inverts carved into the 2D domain based on the LiDAR data (discussed in Section 4.3.1). The location of the 2D tributaries and divergences schematisation is shown on Figure 6.

6.4.6 Bridges and Culverts

The bridges along the Edward River and Billabong Creek were modelled as 1D features to maintain consistency with the 1D river and creek schematisation (discussed in Section 6.4.4) directly upstream and downstream of the bridge structures. The culverts under roads and through the levee were modelled as 1D features as the dimensions of the culverts were smaller than the 2D grid cell size. The bridge and culvert details were obtained from the ground-based survey commissioned by Council (discussed in Section 4.3.2). The locations of the bridge and culvert structures modelled are shown in Figure 6 with the details provided in Appendix D.

Based upon the data collection, community consultation and calibration process, a 25% blockage factor was applied to bridges along the Edward River and Billabong Creek, and a 50% blockage factor was applied to culverts under roads and through the levee. This blockage factor was applied to both the riverine flood model and the overland flood model. The sensitivity of the model's to blockage was investigated, as discussed in Section 8.3.3.

6.4.7 Buildings

Buildings were simulated in the hydraulic model for the town as an absolute flow obstructions within the 2D domain. The building extents were determined from analysis of the aerial imagery. This is shown in Figure 6.

6.5 Initial Water Level Conditions

The initial water level within the hydraulic model was specified to be the same as the downstream water level at the commencement of the event.

6.6 Hydraulic Inflow and Outflow Conditions

6.6.1 Riverine Model

The downstream outflow to the rural hydraulic model was applied to the Edward River at the western (downstream) edge of the 1D model domain. The downstream boundary was assigned a water level versus time curve based upon the event modelled.

The upstream inflows to the rural hydraulic model was applied to the Edward River at the south-eastern edge and Billabong Creek at the north-eastern edge of the 1D model domain. The upstream boundaries were assigned a flow versus time curve based upon the event modelled.

For the historic events the derivation of the inflow and outflow conditions is discussed in Section 7.3.2.

6.6.2 Overland Model

Given the short length of river within the overland model, the water level along the length of the Edward River and Billabong Creek was considered to be uniform from the western to the eastern edge of the model domain. Therefore, the downstream outflow to the overland hydraulic model was applied to the Edward River and Billabong Creek along the length of the 1D model domain.

The rainfall inflows were applied as "rain-on-grid" to the overland hydraulic model. This method applies the rainfall intensity to each individual grid cell within the model and allows the hydraulic model to calculate the runoff-routing between each of the individual grid cells.

The rainfall losses that represent the amount of rainfall that does not contribute to runoff (due to interception by vegetation, infiltration into the soil, retention on the surface, and transmission loss through stream beds and banks) was modelled using the initial loss - continuing loss (IL/CL) method. The IL/CL method was used for this study as per ARR 2019 and the latest NSW DPIE guidelines (NSW DPIE, 2018).

Furthermore, the NSW DPIE guidelines (NSW DPIE, 2018) recommend a hierarchical approach to loss estimation, provided in the table below in order of preference (with 1 being the most preferred).

Table 6-2: Hierarchical Approach to Rainfall Loss (Extracted from the NSW DPIE guidelines)

Approach	Storm initial loss	Pre-burst (transformational)	IL burst	Continuing loss
1	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
2	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
3	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
4	NSW FFA reconciled initial loss (see ARR Data Hub)	Not required or back calculated using IL_{storm} - IL_{burst}	Probability Neutral Burst Loss available through ARR Data Hub	NSW FFA reconciled continuing losses where available (see ARR Data Hub)
5	ARR Data Hub initial loss	Not required or back calculated using IL_{storm} - IL_{burst}	Probability Neutral Burst Loss available through ARR Data Hub	ARR Data Hub continuing losses multiplied x 0.4

For this study, approach 1 was adopted; with the calibration losses discussed in Section 7.3. The rainfall initial losses were applied by subtracting from the rainfall intensity prior to the rainfall intensity being applied to the hydraulic model's individual grid cells. The rainfall continuing losses were applied using the "rain-on-grid" method with negative values denoted. In such a way, the continuing losses were extracted from each of the individual grid cells within the model.

7 Historical Flood Simulations

7.1 Overview

It is important to calibrate and validate the model's performance in representing flood behaviour in historical flood events prior to investigating design flood events. However, the degree of calibration is dependent upon the amount and type of calibration data available, such as:

- Rainfall records, in either daily or sub-daily (pluviograph) intervals;
- Stream flow gauges;
- Water level gauges;
- Historical catchment conditions (records of any changes to structures, land-forms, etc.);
- Photographs or videos recording historical flood events;
- Records of flood mark levels or extents from debris marks or watermarks etc.; and/or
- Anecdotal evidence

Where data is available, the models would ideally be calibrated to one historical event and validated to two historical events. Model calibration involves running the model with initial parameter estimates, then adjusting these parameter estimates (within the industry acceptable range) to produce model results that more closely correspond to the observed flood information. Model validation follows model calibration and involves running the models with other historical rainfall events and no additional refinement of the parameter values.

7.2 Historic Event Selection

The October 2016 event was used for calibration of the rural hydraulic model. This event was selected due to:

- The recentness of the event; as such the catchment conditions are relatively unchanged between then and now, as well as anecdotal evidence being readily available in the community, Council and SES.
- Availability of data; including gauged water levels, stream flows, Landsat imagery of the flood extent, photographs of flood levels from Council and the community, and anecdotal evidence of flood behaviour.

However, it should be noted that the flood frequency analysis estimated the October 2016 event as being in the order of a 1 in 6 year ARI event (discussed in the Terminology Section), which is a relatively small magnitude flood event. Furthermore, very little rainfall fell within the urban area, and so the October 2016 event was only able to be used as a validation event for the overland hydraulic model.

The July 1956 event was used to validate the rural hydraulic model as the flood frequency analysis estimated the event as being in the order of a 1 in 82 year ARI event. However due to the amount of time that has elapsed since this event, the exact catchment conditions that contributed to the flood levels and behaviour in this event could not be fully substantiated; hence this event was only used for model validation not calibration.

The March 2011 rainfall event was used for an indicative calibration of the overland hydraulic model. This event was selected due to the recentness of the event and the relatively high daily rainfall total recorded at Moulamein Post Office (75046) gauge for the 24 hours to 9:00 am on the 10/03/2011.

However, no flooding of property within Moulamein was reported to occur due to this rainfall event. Therefore a "reverse-calibration" method was used, whereby model results showing no flooding of property was considered to be a qualitative validation of the model. It was necessary to employ this reverse-calibration method due to the lack of flood data available to verify the overland flood behaviour within the urban area of Moulamein.

7.3 Historic Parameters

7.3.1 Riverine Model

7.3.1.1 October 2016 Event

The rural hydraulic model simulated the period from the 1:00am on the 12 October 2016 to 1:00am on the 16 November 2016.

The downstream water level versus time curve applied to the model boundary was developed from the interpolation of the water levels recorded on the Edward River upstream and downstream of the boundary. In this case, the Edward River at Liewah (409035) gauge was approximately 72,000 m downstream of the boundary and the Edward River at Moulamein (409014) gauge was approximately 19,400 m upstream of the boundary, as measured along the river length. This is shown in Chart 7-1.

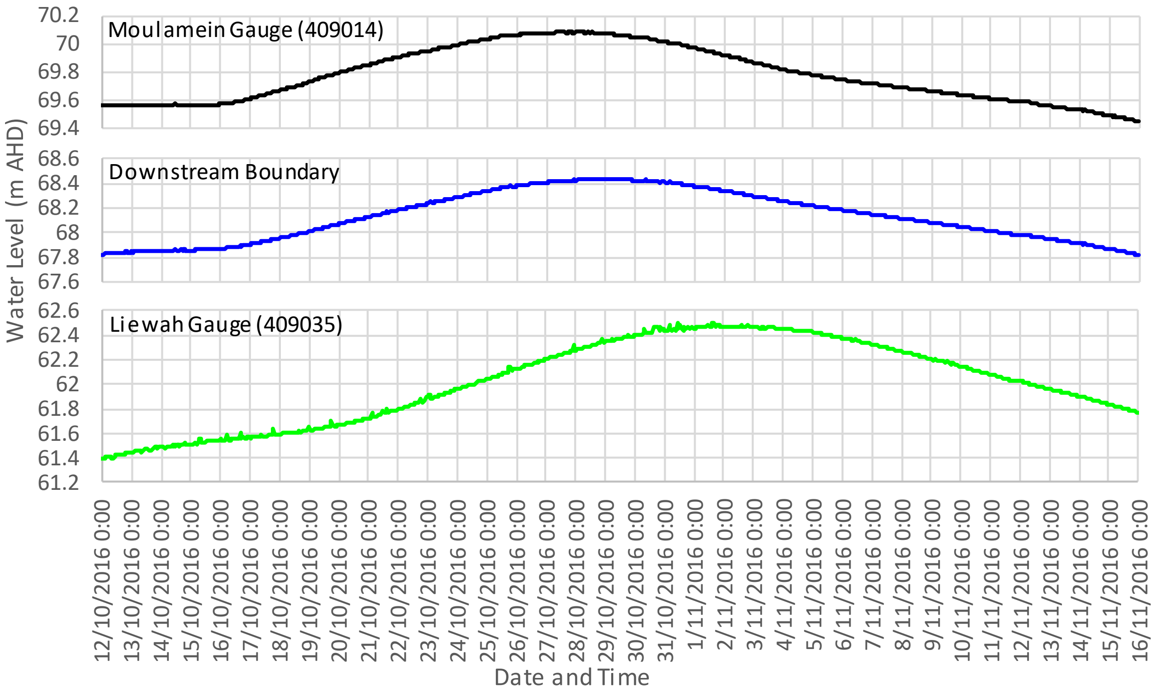


Chart 7-1: Downstream Boundary - 2016 Event

The upstream inflows along the Edward River and Billabong Creek were a ratio of the flows recorded at the Edward River at Moulamein (409014) gauge for the event modelled. The ratio was based upon the volume of flow recorded at the Edward River at Moulamein (409014) gauge compared to the volume of flow recorded at the Billabong Creek at Darlot (409035) gauge. For the October 2016 event, it was estimated that the flow along the Billabong Creek accounted for approximately 40% of the flow through Moulamein. However, due to floodrunners breaking out of the Edward River to the south and bypassing the Moulamein gauge, the inflows into the Edward River were scaled up to account for this. In this way, the flow applied to the Edward River was 70% of the flow recorded at Moulamein. The hydraulic model inflow values resulting from this analysis are detailed in Table 7-1. Furthermore, to account for the floodwater travel time from the upstream boundary to Moulamein, the upstream inflow hydrographs were offset by 16 hours. This is shown in Chart 7-2.

Table 7-1: Peak Inflows for the October 2016 Event

	Peak October 2016 Flows (m^3/s)
Edward River at Moulamein Gauge	199.1
Billabong Creek Inflows	79.6
Edward River Inflows	139.4

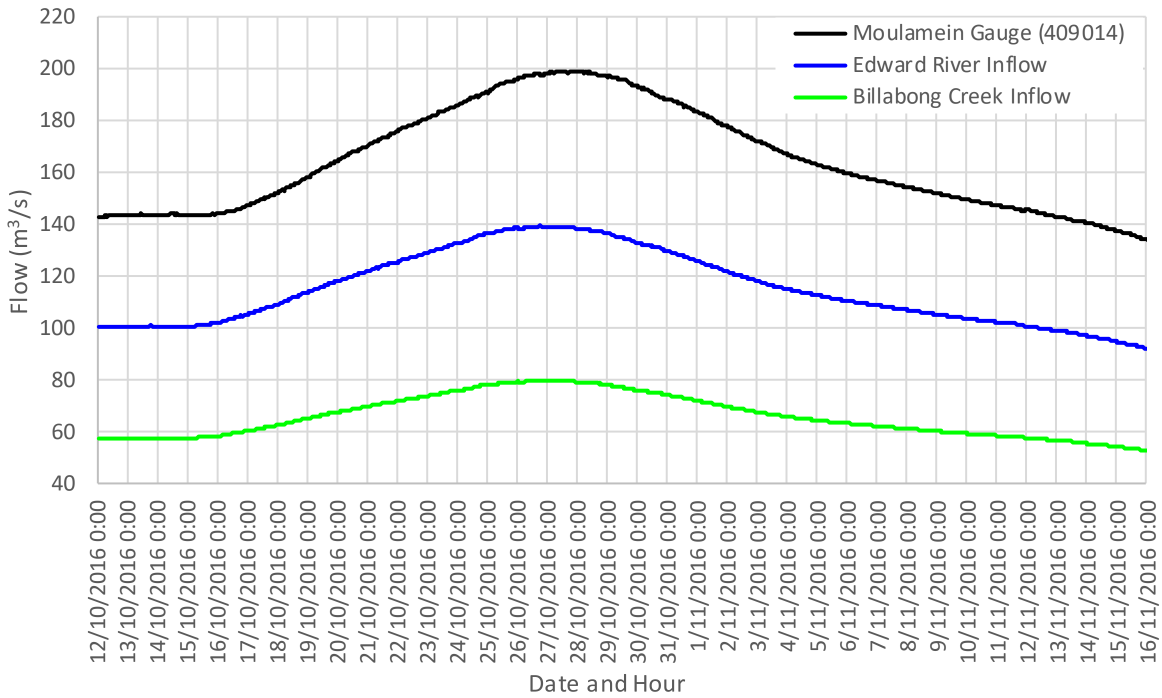


Chart 7-2: Upstream Boundaries - 2016 Event

7.3.1.2 July 1956 Event

The July 1956 event pre-dated the establishment of the Edward River at Liewah (409035) gauge, therefore the method used to develop the downstream water level versus time curve that was used for the October 2016 event could not be directly applied to the July 1956 event. Therefore, the downstream water level versus time curve used the water level recorded at the Edward River at Moulamein (409014) gauge, scaled down using the proportional difference approximated from the October 2016 event. This is shown in Chart 7-3.

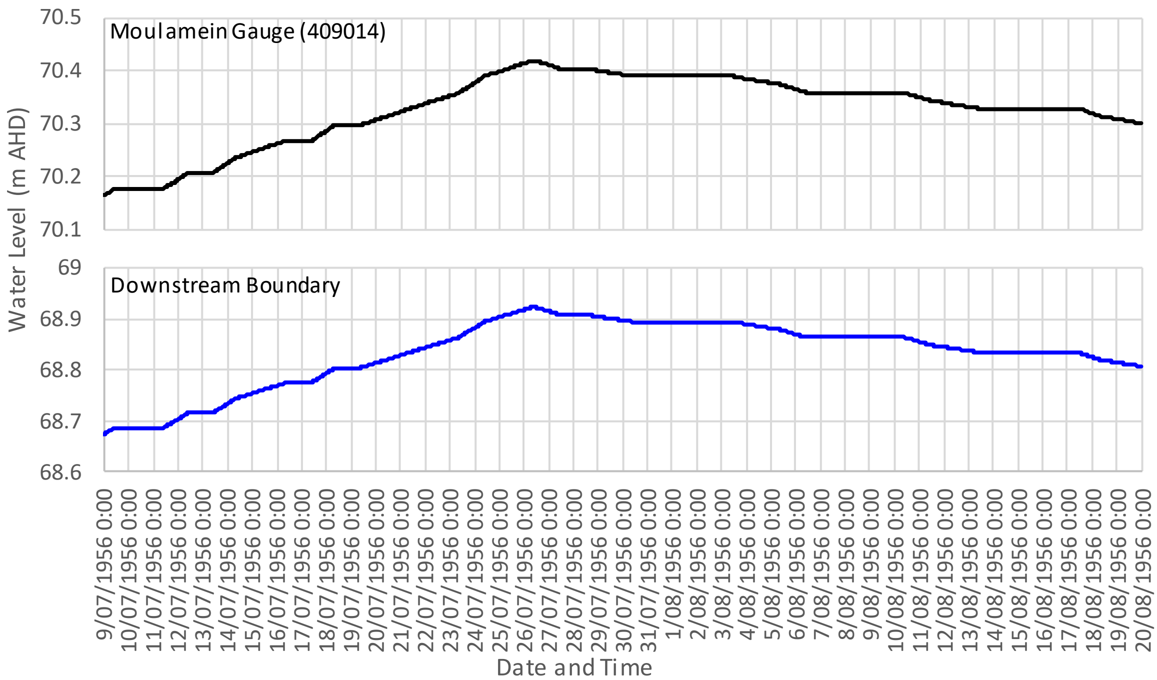


Chart 7-3: Downstream Boundary - 1956 Event

The July 1956 event also pre-dated the establishment of the Billabong Creek at Darlot (409035) gauge, therefore the method used to determine the proportion of the flow arriving at Moulamein from the Billabong Creek could not be estimated using the same methods employed for the October 2016 event. However, it was noted that the previous Moulamein Levee Upgrade Flood Study (PBP, 2006) estimated the floodrunners bypassing the Edward River at Moulamein (409014) gauge to be almost 50% of the flows through the Moulamein gauge, with the proportion attributed almost equally between the Billabong Creek inflows and the Edward River inflows. This data was used as the basis for the hydraulic model inflow values used in this study, detailed in Table 7-2. Furthermore, to account for the floodwater travel time from the upstream boundary to Moulamein, the upstream inflow hydrographs were offset by 16 hours. This is shown in Chart 7-4.

Table 7-2: Peak Inflows for the July 1956 Event

	Peak July 1956 Flows (m^3/s)
Edward River at Moulamein Gauge	402.2
Billabong Creek Inflows	301.6
Edward River Inflows	301.6

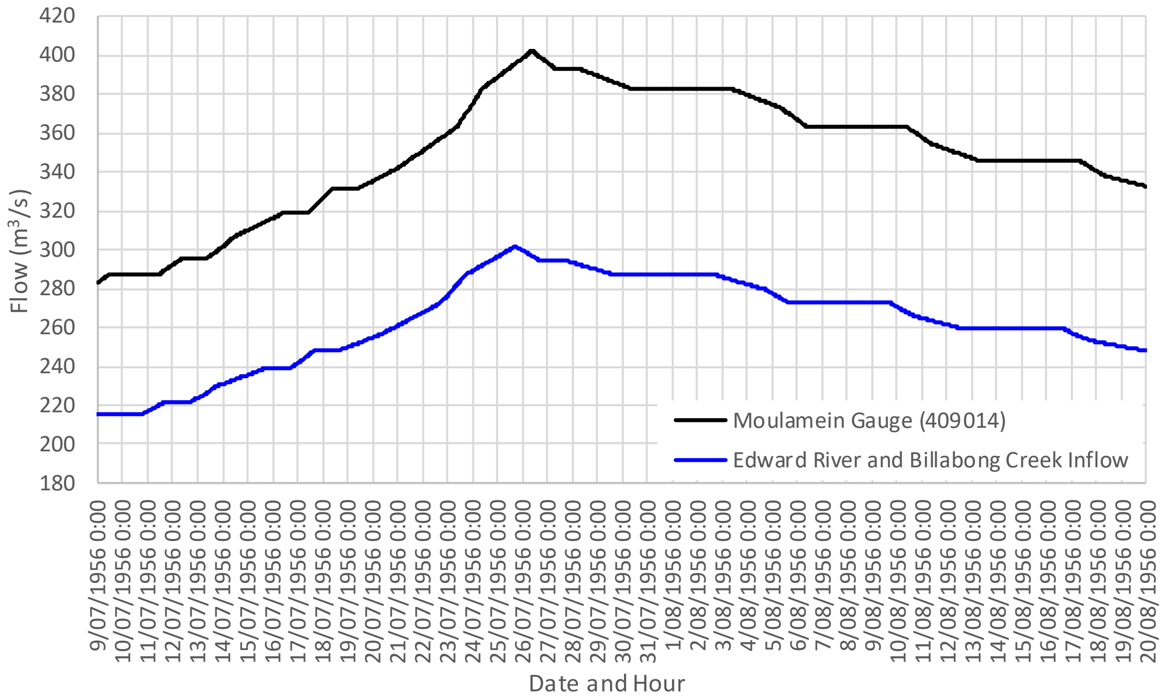


Chart 7-4: Upstream Boundaries - 1956 Event

7.3.2 Overland Model

7.3.2.1 March 2011 Event

The downstream water level versus time curve applied to the overland hydraulic model boundary was extracted from the Edward River at Moulamein (409014) gauge for the time period corresponding to the 2011 event modelled.

The local rainfall inflows used the temporal pattern from the Swan Hill Aerodrome (77094) pluviometer gauge, as shown in Chart 7-5. However, as the Swan Hill Aerodrome (77094) gauge recorded a daily total of 23.6 mm and the Moulamein Post Office (75046) gauge recorded a daily total of 64.8 mm, the temporal pattern recorded at the Swan Hill Aerodrome (77094) pluviometer gauge was scaled up accordingly.

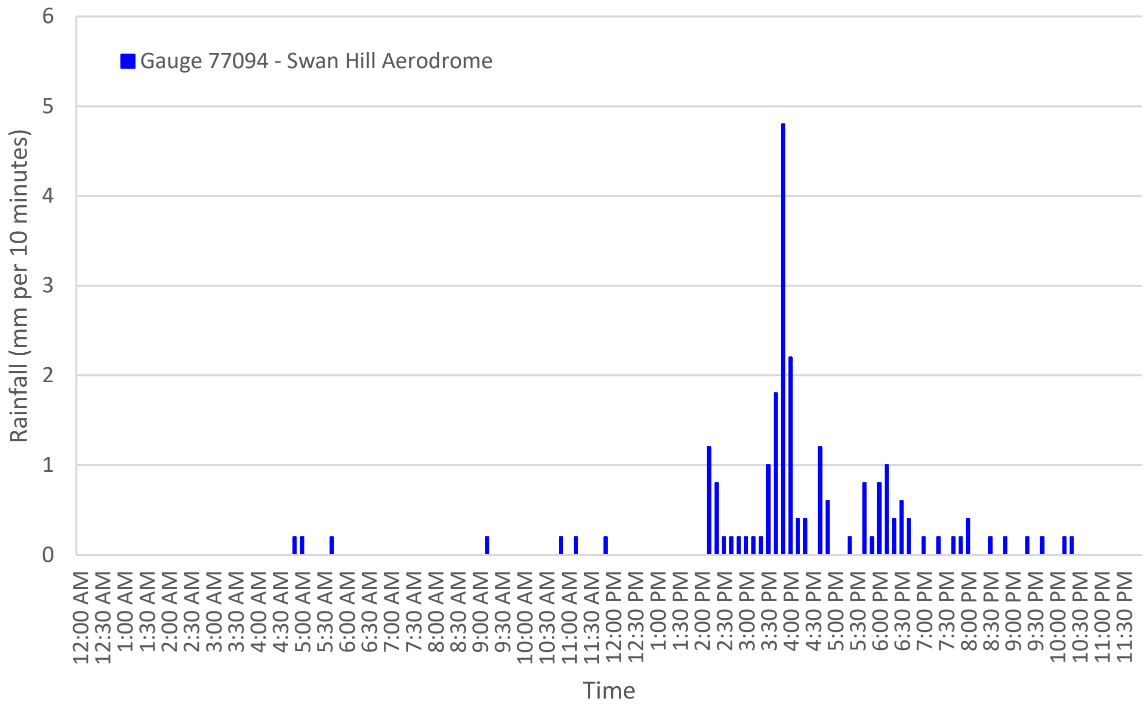


Chart 7-5: Rainfall Pattern for the 09/03/2011

The March 2011 event was approximated to be in the range of a 10% AEP event for a 3 hour storm burst, based upon the Swan Hill Aerodrome (77094) gauge temporal pattern scaled up to the Moulamein Post Office (75046) gauge daily rainfall total. As such, the probability neutral burst initial losses extracted from the ARR Data Hub (shown in Appendix B) for this equivalent design event was applied to the hydraulic model for the 2011 event. However, although the ARR Data Hub suggested a continuing loss value of 0 mm/hr for the study area, this was deemed to be an underestimation and a 2.5 mm/hr continuing rainfall loss was applied to the hydraulic model for the 2011 event.

7.4 Historic Flood Simulation Results

7.4.1 October 2016 Event

For the October 2016 event, there were four key pieces of calibration data to compare against:

a) The flood extent shown in photographic and anecdotal evidence;
b) The flood extent recorded by the Landsat imagery;
c) The hydrograph shape recorded at the Edward River at Moulamein (409014) gauge; and
d) The peak flood level recorded at the Edward River at Moulamein (409014) gauge.

Figure 8A and Figure 8B shows the hydraulic model's peak flood depth compared to photographs of flooding for the October 2016 event. From this, the hydraulic model's peak flood extent was found to correspond to the photographic flood extent. Along Moulamein Road (south of the bridge) the hydraulic model showed a shallow depth of flooding along the edge of the roadway, which corresponded to the photograph. Along the northern banks of Billabong Creek and Edward River the hydraulic model showed flooding up to the edge of the levee, which corresponded to photographs of flooding around the court house, the wharf and near the picnic park bench.

Figure 8C and Figure 8D shows the hydraulic model's peak flood depth against the Landsat imagery for the October 2016 event. From this the hydraulic model's flood extent was found to correlate relatively well with the Landsat imagery.

Chart 7-6 shows the hydraulic model flood level results against the recorded flood level at the Edward River at Moulamein (409014) gauge. The recorded level was obtained by adding the gauged water level to the gauge zero level for the Edward River at Moulamein (409014) gauge, with gauge zero given as 64.324 m AHD. From this, the gauge recorded a peak flood level of 70.089 m AHD during the 2016 flood event. By comparison the hydraulic model produced a peak flood level of 69.962 m AHD, which was approximately 0.127 m below the recorded peak flood level.

In summary, the hydraulic model's hydrograph shape was found to correspond to the recorded hydrograph shape relatively well, and the hydraulic model's peak flood level was found to be within a reasonable range to the recorded peak flood level. Furthermore, the flood extent was found to correspond relatively well to the Landsat imagery as well as the photographs taken from ground level during the flood event.

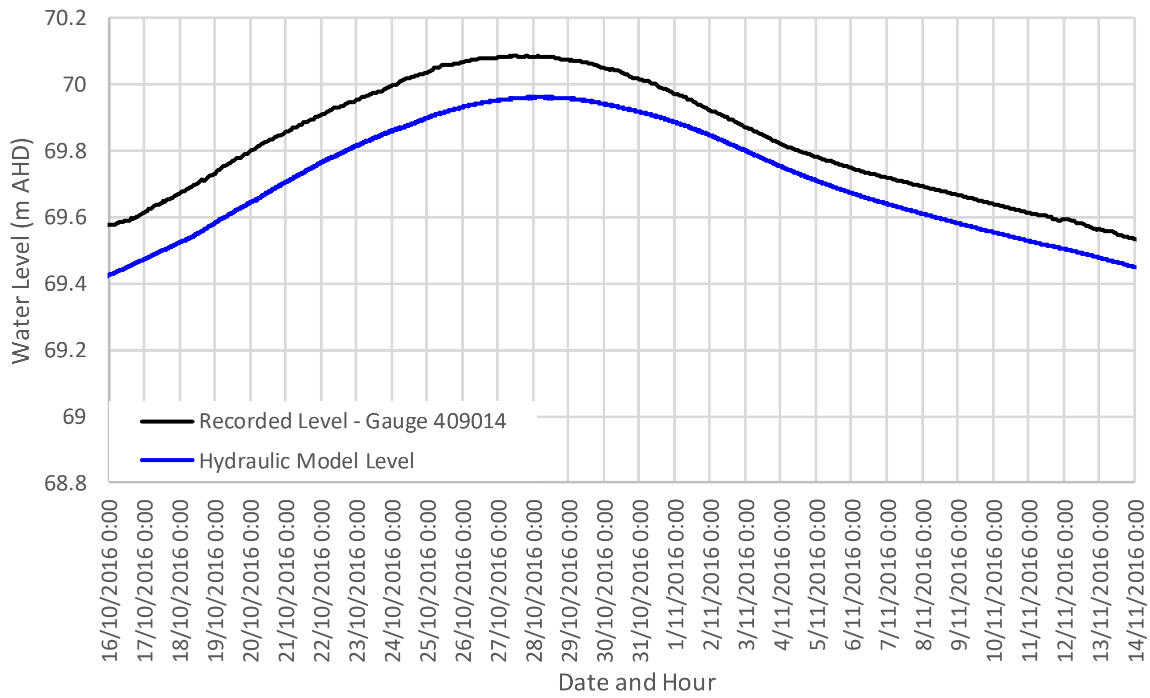


Chart 7-6: Water Level Comparison - October 2016 Event

7.4.2 July 1956 Event

Figure 9 shows the hydraulic model's peak flood depth and Chart 7-7 shows the hydraulic model flood level results against the recorded flood level at the Edward River at Moulamein (409014) gauge. The recorded level was obtained by adding the gauged water level to the gauge zero level for the Edward River at Moulamein (409014) gauge, with gauge zero given as 64.324 m AHD. From this, the gauge recorded a peak flood level of 70.42 m AHD during the 1956 flood event. By comparison the hydraulic model produced a peak flood level of 70.318 m AHD, which was approximately 0.102 m below the recorded peak flood level.

In summary and given the relatively high degree of uncertainty regarding the 1956 catchment conditions, the hydraulic model's hydrograph shape was found to correspond to the recorded hydrograph shape moderately well. Furthermore, the differences in peak flood level were found to be reasonable and correlated with the peak flood level difference found in the 2016 event (for which there was greater certainty on the relevant catchment conditions).

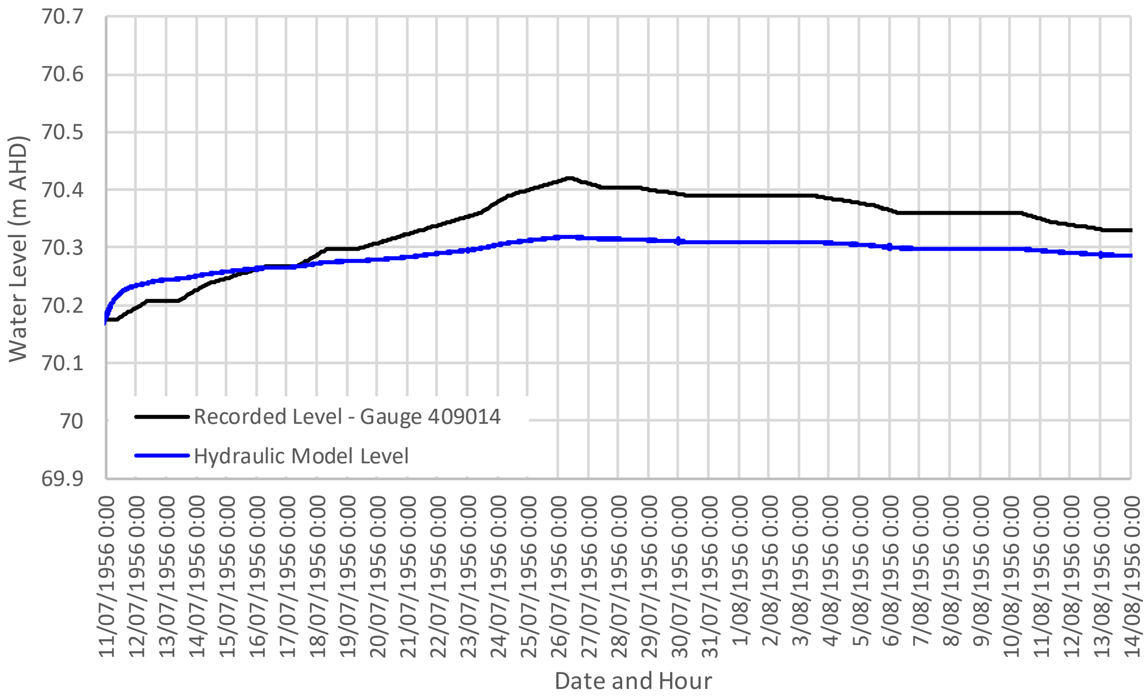


Chart 7-7: Water Level Comparison - July 1956 Event

7.4.3 March 2011 Event

Figure 10 shows the hydraulic model's peak flood depth for the March 2011 event. From this, the peak flood depth was found to be less than 0.15 m across the majority of the Moulamein township area. As such, the results were considered to approximately validate the overland hydraulic model.

8 Design Flood Simulations

8.1 Overview

A design event is a statistically-based estimate of the probability of a certain rainfall depth being recorded at a certain location over a defined duration. The various magnitudes of these statistically-based estimates are usually discussed in terms of the Annual Exceedance Probability (AEP); such as the 1% AEP event, which is an event that has a 1% chance of occurring in any given year. The terminology for design events is discussed in the Forward.

8.2 Design Parameters

8.2.1 Riverine Model

8.2.1.1 Proportioning Flow Between Billabong Creek and Edward River

The proportion of the flow attributed to the Edward River and Billabong Creek in the design events was estimated through investigation of the stream flow historical data. Specifically, the historical discharge proportions at the Edward River at Moulamein (409014) gauge versus the Billabong Creek at Darlot (409035) gauge, shown in Chart 8-1. From this, it was found that Billabong Creek accounted for between 25% and 75% of the flow through the Moulamein gauge.

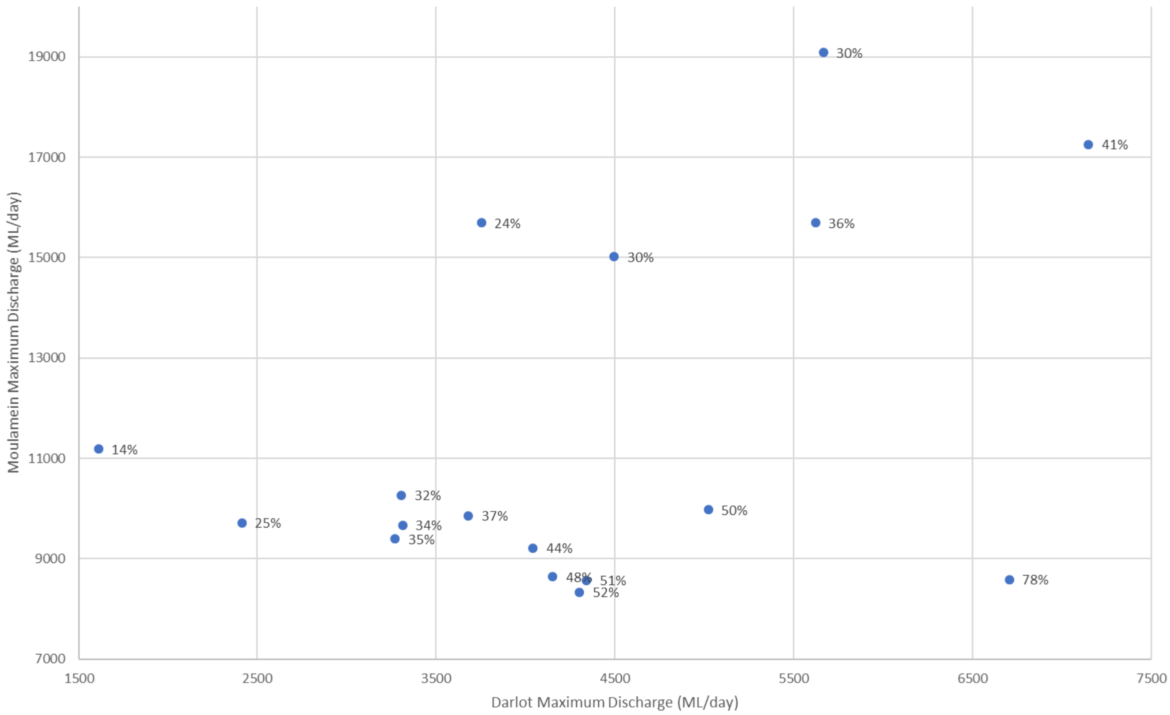


Chart 8-1: Percentage of Discharge Recorded at the Moulamein Gauge versus the Darlot Gauge

8.2.1.2 Estimating the Bypass Flows

Through the data collection, community consultation and calibration process it was established that events with greater flows resulted in floodrunners that bypass Moulamein and the Moulamein gauge. To account for the bypass flows, the design event flows applied to the upstream inflows in the hydraulic model were proportionally increased from the flood frequency analysis estimates, such that:

- The 20% AEP event was increased by 10%, based upon the proportional increase established through the 2016 calibration event (which was approximately equivalent to a 1 in 6 year ARI event).
- The 10% AEP event and 5% AEP event were increased by 30%.
- The 2% AEP, 1% AEP and PMF event were increased by 50%, based upon the proportional increase established through the 1956 calibration event (which was approximately equivalent to a 1 in 82 year ARI event).

8.2.1.3 Critical Inflows

To account for the variations in the proportion of the flow attributed to the Edward River and Billabong Creek, a number of different scenarios were investigated for proportions varying from 25% to 75% of flows applied to Billabong Creek. From this investigation, it was determined that the proportions at each end of the extremes (i.e. the 25% and 75% proportions) governed the peak flood levels along each of the systems. In such a way, the scenario with 75% of flows applied to Billabong Creek produced the highest peak flood level to the north of the Edward River; and conversely the scenario with 25% of flows applied to Billabong Creek produced the highest peak flood level to the south of the Edward River. Therefore, the design event results were an envelope of the 25% and 75% flow distribution scenarios.

8.2.1.4 Applied Hydrographs

The hydrograph recorded at Edward River at Moulamein (409014) gauge during the 2016 event was used for the 20% AEP, 10% AEP, and 5% AEP event. The 2% AEP, 1% AEP, 0.5% AEP and PMF event used the hydrograph recorded at Edward River at Moulamein (409014) gauge during the 1956 event. Chart 8-2 shows the hydrographs used for each event, including the proportional increase in flows (discussed in Section 8.2.1.2).

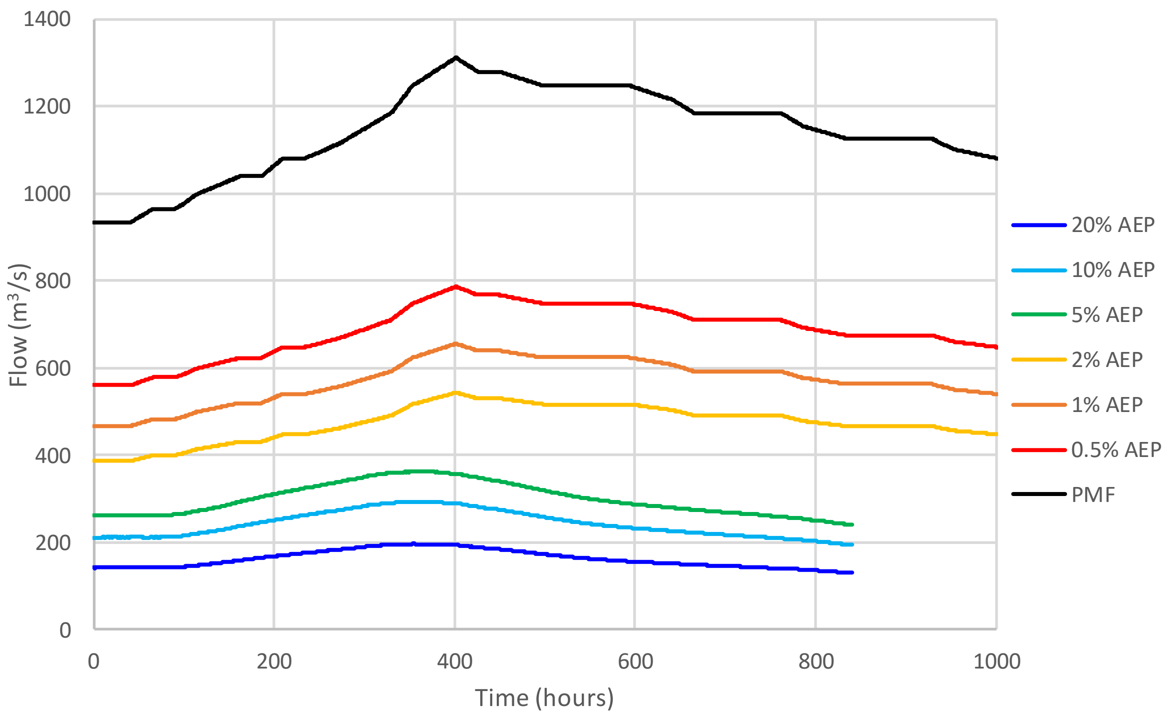


Chart 8-2: Applied Hydrographs

8.2.2 Overland Model

8.2.2.1 Rainfall Losses

Based upon the calibration process, a continuing loss of 2.5 mm/hr was applied and the probability neutral burst initial losses extracted from the ARR Data Hub (shown in Appendix B) was applied to the design flood simulations. For storm durations less than 60 minutes, for which the ARR Data Hub does not provide data, the 60 minute probability neutral burst initial loss was applied.

8.2.2.2 Rainfall Depths

The design rainfall depths were extracted from the BoM's 2019 Rainfall IFD Data System for the study area. This data is shown in Appendix C.

8.2.2.3 Rainfall Temporal Patterns

As the study area is less than 75 km^2, the point temporal patterns were applied to design storm durations.

8.2.2.4 Critical Storm Duration and Temporal Patterns

In urban overland flow areas where flooding is less directionally constrained, the "ensemble" approach from ARR 2019 determines the critical duration and critical pattern as being that which produced the peak flood level one higher than the highest average peak flood level (via the hydraulic modelling).

To determine this, box and whisker plots were analysed for the 20% AEP, 5% AEP and the 1% AEP peak flood levels at Moulamein Bowling Club (Location ID H001, shown in Figure 11); so as to represent each of the temporal pattern ranges i.e. the frequent temporal pattern range (events that are more frequent than the 14.4% AEP event), the intermediate temporal pattern range (events that are between a 3.2% AEP event and a 14.4% AEP event), and the rare temporal pattern range (events that are rarer than a 3.2% AEP event). These box and whisker plots are shown in Chart 8-3 to Chart 8-5.

Overall, the peak flood level variation across the range of storm durations and temporal patterns were minimal. From this, the storm durations and temporal patterns adopted were:

- The 720 minute storm duration with temporal pattern 5 for the 20% AEP event; and
- The 720 minute storm duration with temporal pattern 2 for the 10% AEP and greater.

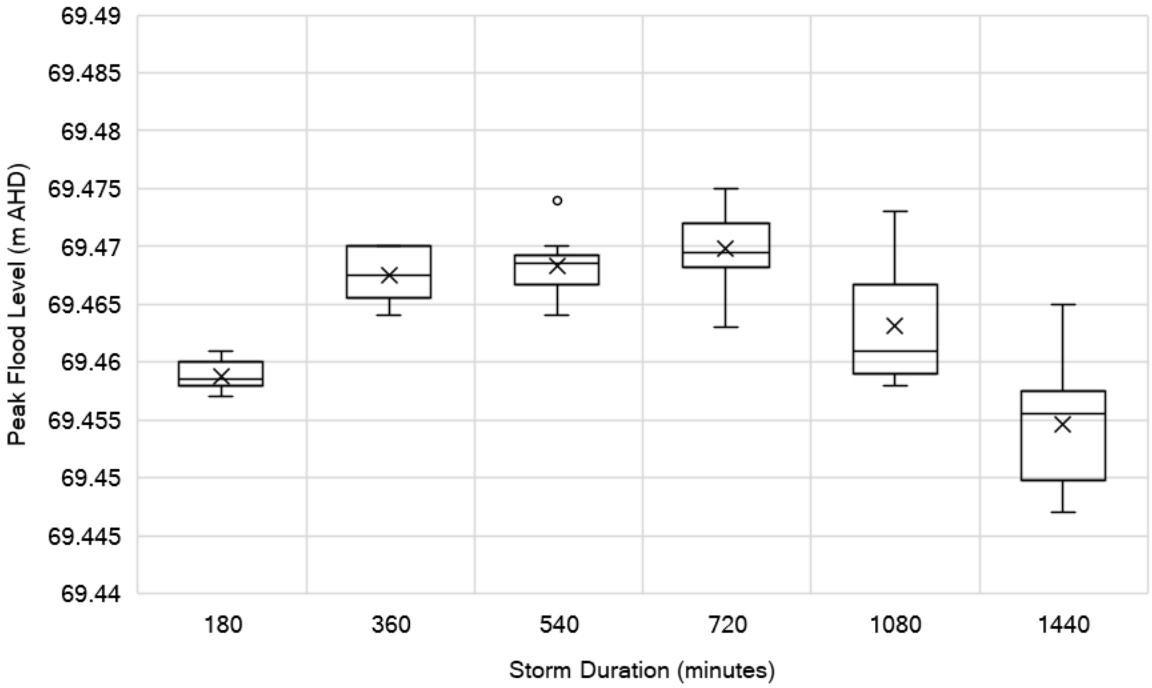


Chart 8-3: Box and Whisker Plot for the 1% AEP Event

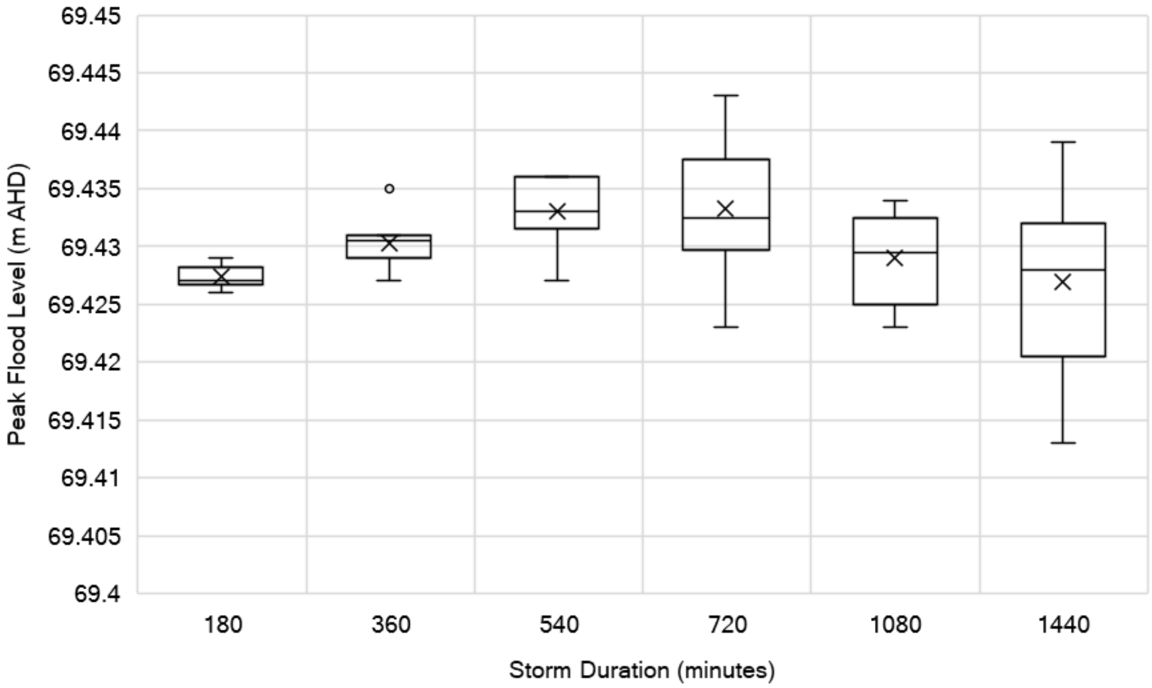


Chart 8-4: Box and Whisker Plot for the 5% AEP Event

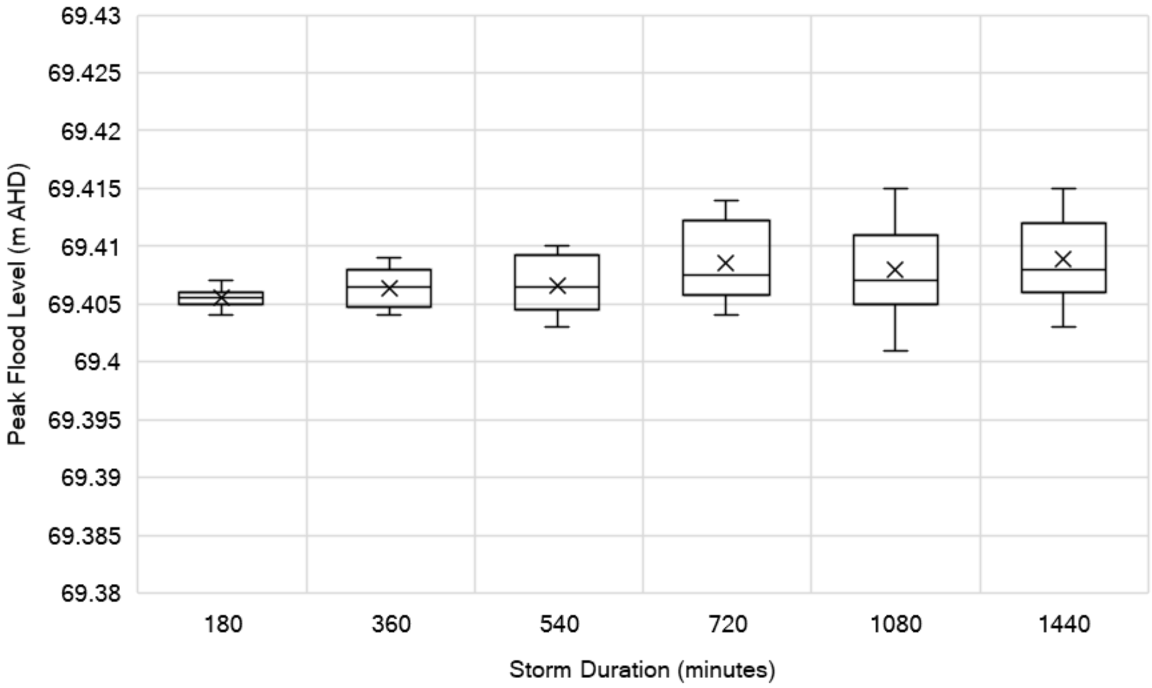


Chart 8-5: Box and Whisker Plot for the 20% AEP Event

8.3 Design Parameter Sensitivity Analysis - Overland Model

A sensitivity analysis process was undertaken on the parameters selected for the design events to estimate the variation in peak flood levels possible under an alternate parameter scenario. The following sections detail the method and results from this sensitivity analysis. Note: The tabulated locations discussed in the following sections are shown spatially in Figure 11.

8.3.1 Rainfall Losses

As discussed in Section 8.2.2.1, the rainfall losses were determined based upon the continuing loss values determined in the calibration and validation process and the probability neutral burst initial losses extracted from the ARR Data Hub. To assess the sensitivity of the peak flood levels to the rainfall losses, a continuing loss of 0 mm/hr was applied in one scenario and an initial loss of 0 mm was applied in another scenario, with the results provided in Table 8-1. From this, it was found that the models were relatively sensitive to variations in continuing and initial losses, particularly in topographical low points.

Table 8-1: 1% AEP Peak Flood Level Difference (m) - Rainfall Loss Sensitivity

ID	Location	Continuing Loss of 0 mm/hr	Initial Loss of 0 mm
H001	Moulamein Bowling Club	0.02	0.03
H002	West of the Flood Bridge under Moulamein Road	0.00	0.00
H003	Within the Southern Town Levee	0.07	0.09

ID	Location	Continuing Loss of 0 mm/hr	Initial Loss of 0 mm
H004	West of the Intersection of Nyang Street and Old Court House Street	0.00	0.00
H005	West of the Intersection of Brougham Street and Turora Street	0.01	0.01
H006	North-East of the Intersection of Brougham Street and Young Street	0.09	0.10

8.3.2 Hydraulic Roughness

As discussed in Section 6.3, a range of hydraulic roughness values are acceptable for various land use types. The sensitivity of the peak flood levels to the hydraulic roughness parameters selected was analysed by varying the hydraulic roughness parameters by ± 20% of the adopted values, with the results detailed in Table 8-2. From this, the models were determined to be relatively insensitive to variations in hydraulic roughness values.

Table 8-2: 1% AEP Peak Flood Level Difference (m) - Hydraulic Roughness Sensitivity

ID	Location	Hydraulic Roughness Decreased by 20%	Hydraulic Roughness Increased by 20%
H001	Moulamein Bowling Club	0.00	0.00
H002	West of the Flood Bridge under Moulamein Road	0.00	0.00
H003	Within the Southern Town Levee	0.00	0.00
H004	West of the Intersection of Nyang Street and Old Court House Street	0.00	0.00
H005	West of the Intersection of Brougham Street and Turora Street	0.00	0.00
H006	North-East of the Intersection of Brougham Street and Young Street	0.00	0.00

8.3.3 Blockage of Hydraulic Structures

As discussed in Section 6.4.6, various blockage factors were applied to the bridges along the Edward River and Billabong Creek, and culverts under roads and through the levee. The sensitivity of the peak flood levels to these blockage factors was analysed by comparing the peak flood levels to a 0% blockage scenario, with the results provided in Table 8-3. From this, the urban area of Moulamein was found to be marginally sensitive to blockage of structures.

Table 8-3: 1% AEP Peak Flood Level Difference (m) - Blockage of Structures Sensitivity

ID	Location	No Blockage of Bridges or Culverts
H001	Moulamein Bowling Club	0.00
H002	West of the Flood Bridge under Moulamein Road	0.00
H003	Within the Southern Town Levee	0.02
H004	West of the Intersection of Nyang Street and Old Court House Street	0.00
H005	West of the Intersection of Brougham Street and Turora Street	0.00
H006	North-East of the Intersection of Brougham Street and Young Street	0.02

8.4 Design Flood Simulation Results

8.4.1 Flood Behaviour

The peak flood depths for events ranging from the 20% AEP event to the PMF event are shown in Figure 12 to Figure 18.

Within the overland model, the area within the Northern Town Levee was shown to be subject to relatively low peak flood depths, between 0.1 m and 0.5 m in events up to and including the 1% AEP event. However, the area within the Southern Town Levee and the Western Town Levee was shown to be subject to moderately higher depths, between 0.5 m and 1.2 m in events up to and including the1% AEP event. The peak flood depths are shown in Table 8-4 and the peak flood levels are shown in Table 8-5 for various events, corresponding to the locations detailed in Figure 11.

Table 8-4: Peak Flood Depths (m) - Overland Model

ID	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H001	Moulamein Bowling Club	1.1	1.1	1.1	1.2	1.2	1.2	2.1
H002	West of the Flood Bridge under Moulamein Road	1.7	1.7	1.7	1.7	1.7	1.7	1.7
H003	Within the Southern Town Levee	0.7	0.8	0.8	0.9	0.9	1.0	1.6

ID	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H004	West of the Intersection of Nyang Street and Old Court House Street	0.1	0.2	0.2	0.3	0.3	0.3	0.4
H005	West of the Intersection of Brougham Street and Turora Street	0.2	0.3	0.3	0.4	0.4	0.4	0.7
H006	North-East of the Intersection of Brougham Street and Young Street	0.0	0.0	0.1	0.1	0.1	0.2	0.7

Table 8-5: Peak Flood Levels (m AHD) - Overland Model

ID	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H001	Moulamein Bowling Club	69.4	69.4	69.4	69.5	69.5	69.5	70.4
H002	West of the Flood Bridge under Moulamein Road	69.4	69.4	69.4	69.4	69.4	69.4	69.4
H003	Within the Southern Town Levee	69.4	69.5	69.5	69.6	69.6	69.7	70.3
H004	West of the Intersection of Nyang Street and Old Court House Street	69.8	69.9	69.9	70.0	70.0	70.0	70.1
H005	West of the Intersection of Brougham Street and Turora Street	69.9	70.0	70.1	70.1	70.1	70.1	70.4
H006	North-East of the Intersection of Brougham Street and Young Street	69.7	69.8	69.8	69.8	69.8	69.9	70.4

Within the riverine model, the Southern Town Levee was found to be overtopped in events as small as the 20% AEP event; the Northern Town Levee was found to be overtopped in the 2% AEP event; and the Western Town Levee was protected from inundation up to and including the PMF event. The peak flood levels are shown in Table 8-6 for various events, corresponding to the locations detailed in Figure 11.

Table 8-6: Peak Flood Levels (m AHD) - Riverine Model

ID	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H001	Moulamein Bowling Club	N/I	N/I	N/I	68.6	68.7	68.7	68.7
H002	West of the Flood Bridge under Moulamein Road	70.0	70.0	70.1	70.2	70.2	70.3	70.4
H003	Within the Southern Town Levee	70.3	70.3	70.3	70.4	70.5	70.5	70.6
H004	West of the Intersection of Nyang Street and Old Court House Street	70.2	70.2	70.3	70.4	70.4	70.5	70.6
H005	West of the Intersection of Brougham Street and Turora Street	N/I	N/I	N/I	70.3	70.4	70.5	70.6
H006	North-East of the Intersection of Brougham Street and Young Street	N/I	N/I	N/I	70.3	70.4	70.5	70.6
H007	Edward River (Upstream of the Moulamein Road Bridge)	70.2	70.2	70.2	70.3	70.4	70.4	70.5
H008	Edward River (Adjacent to the Flood Bridge under Moulamein Road)	70.2	70.2	70.3	70.4	70.5	70.5	70.6
H009	Edward River (Between the Confluence with Billabong Creek and the Railway Bridge)	70.3	70.3	70.3	70.4	70.5	70.5	70.6
H010	Edward River (Upstream of the Railway Bridge)	70.4	70.4	70.5	70.7	70.8	70.8	70.8
H011	Edward River (Upstream of township)	70.5	70.5	70.6	70.8	70.9	70.9	71.0

ID	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H012	Edward River (Upstream of township)	70.9	70.9	71.1	71.5	71.7	71.8	72.0
H013	Edward River (Upstream of township)	71.5	71.5	71.7	72.3	72.4	72.5	72.8
H014	Billabong Creek (Upstream of the Old Court House Pedestrian Bridge)	70.2	70.2	70.3	70.4	70.5	70.5	70.6
H015	Billabong Creek (Upstream of the Baratta Street Bridge)	70.3	70.3	70.4	70.5	70.6	70.6	70.7
H016	Billabong Creek (Upstream of the Railway Bridge)	70.4	70.4	70.5	70.6	70.7	70.8	70.9
H017	Billabong Creek (Upstream of township)	70.7	70.7	70.8	70.8	70.9	71.0	71.1
H018	Billabong Creek (Upstream of township)	70.9	70.9	71.0	71.0	71.1	71.1	71.3
H019	Billabong Creek (Upstream of township)	71.5	71.5	71.6	71.6	71.6	71.7	71.9
H020	Edward River (Downstream of township)	69.7	69.7	69.8	70.0	70.0	70.1	70.2
H021	Edward River (Downstream of township)	69.6	69.6	69.8	70.0	70.0	70.1	70.2
H022	Edward River (Downstream of township)	69.3	69.3	69.5	69.8	69.8	69.9	70.1
H023	Edward River (Downstream of township)	69.0	69.0	69.2	69.5	69.5	69.6	69.8
H024	Edward River (Downstream of township)	68.7	68.7	68.8	69.1	69.2	69.2	69.3

* Note: N/I is Not Inundated

Figure 19 to Figure 21 shows the peak flood velocity across the study area for the 5% AEP, 1% AEP and PMF events. In events of a smaller magnitude (such as the 5% AEP event), the flows throughout the town were of a consistently low velocity, with medium velocity flows of 0.25 to 1.0 m/s being confined primarily to Edward River and Billabong Creek. However, in events of a larger magnitude (such as the PMF event), the high velocity flows also occurred in the kerb and gutter system of the roadways through town.

8.4.2 Post-Processing Results

8.4.2.1 Flood Hazard Categories

There are two standard industry methods for determining flood hazard categories as defined by the Floodplain Development Manual (2005) and Australian Rainfall and Runoff (2019). Both methods use the depth and velocity product, however they differ in the thresholds applied and the categories denoted.

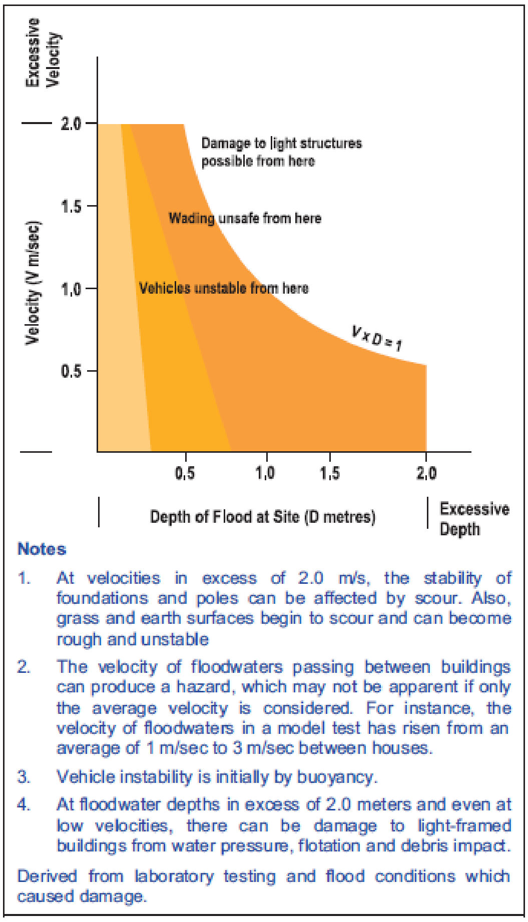


FIGURE L1 - Velocity & Depth Relationships

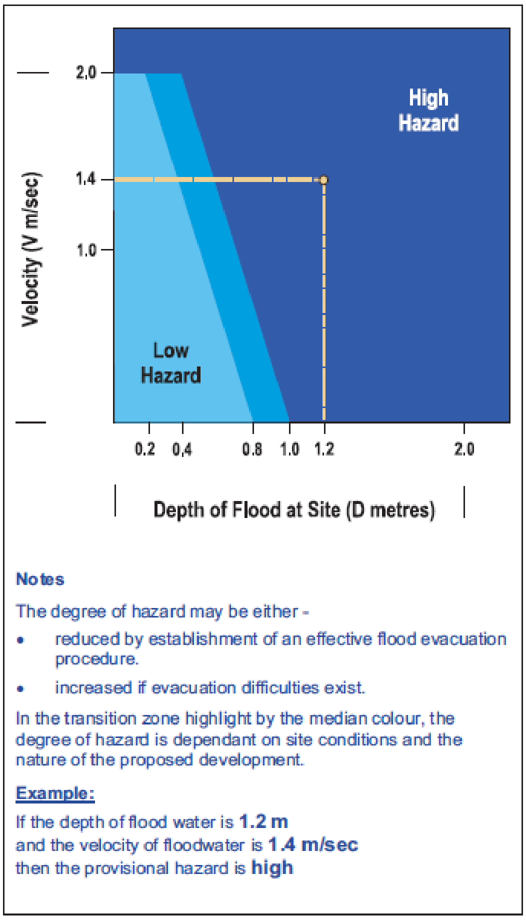


FIGURE L2 - Provisional Hydraulic Hazard Categories

Chart 8-6: Flood Hazard Thresholds (FDM, 2005)

The FDM (2005) method denotes hazard categories as low hazard or high hazard based upon the thresholds, shown in Chart 8-6. The high hazard category is particularly significant as it is a criterion in regulating complying development as per the State Environmental Planning Policy (SEPP) (Exempt and Complying Development Codes) 2008. Until such a time as the SEPP Codes are updated to correspond to ARR (2019) method it remains important to define flood hazard as per the FDM (2005) method.

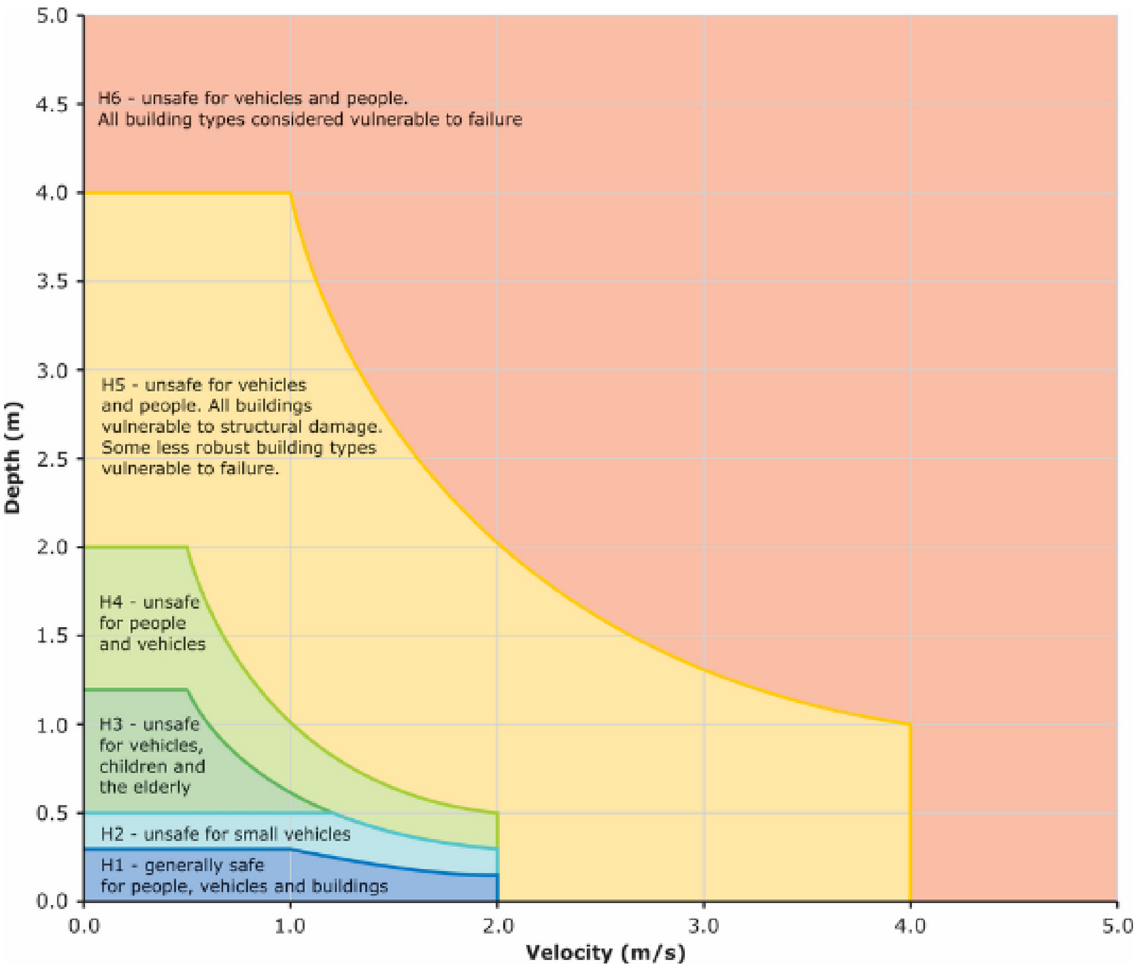


Chart 8-7: Flood Hazard Curves (ARR, 2019)

The ARR (2019) method is defined in both the ARR 2019 Guidelines (Ball, 2019) and also in the AEMI Handbook 7 Guidelines (AEMI, 2017). This method denotes hazard categories as H1, H2, H3, H4, H5 and H6; with the greater risk attributed to the highest category (i.e. H6), shown in Chart 8-7. These hazard categories are described as follows:

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for vehicles, children and the elderly.
- H4 - Unsafe for vehicles and people.
- H5 - Unsafe for vehicles and people. All building types 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.

Figure 22 to Figure 24 shows the flood hazard categories for the 5% AEP, 1% AEP and PMF events using the ARR 2019 methodology. In events of a smaller magnitude (such as the 5% AEP event), the H1 category covered the majority of the town, however the hazard categories were more severe in the open channels (up to the H6 category), which would likely be influenced by the relatively high velocity through the open channels. In events of a larger magnitude (such as the PMF event), somewhat more severe hazard categories occurred through some properties and roadways through town (up to the H4 category).

8.4.2.2 Flood Function Categories (formerly Flood Hydraulic Categories)

The Floodplain Development Manual (2005) identifies three hydraulic categories: floodways, flood storage, and flood fringe. Floodway is described as those areas where a significant portion of the flood flow is conveyed and where partial blockage will negatively affect flood behaviour to a substantial extent. Flood storage is described as those areas where the temporary storage of floodwaters during the passage of a flood is important. Flood fringe is described as the remaining area affected by flooding, excluding the floodway and flood storage areas.

Although a description is given for each, a technical method to define these hydraulic categories is not provided by the Manual. A number of different methods are available for use, including the Howells et al (2003) method, the Thomas et al (2012) method, and the 5% AEP extent coupled with the encroachment method. The latter two methods are best suited to estimating hydraulic categories where mainstream flood behaviour is being investigated, however the methods are less suited to overland flood behaviour. As such, the Howells et al (2003) method was used as it is well suited to both the mainstream and the overland flood behaviour being investigated in the study area.

From the Howells et al (2003) method, the hydraulic categories were defined as follows:

- Floodway where:
  - the peak velocity-depth product (V x D) > 0.25 m2/s AND the peak velocity > 0.25 m/s; OR
  - the peak velocity > 1.0 m/s AND the peak depth > 0.15 m.
- Flood Storage where:
  - the area is outside of the Floodway; AND
  - the peak flood depth > 0.5 m.
- Flood Fringe where:
  - the area is outside the Floodway; AND
  - the peak flood depth < 0.5 m.

Figure 25 to Figure 27 shows the flood hydraulic categories for the 5% AEP, 1% AEP and PMF events. Generally, floodways corresponded to Edward River and Billabong Creek, whereas the flood storage areas corresponded with the dam as well as areas upstream of flow constrictions such as bridges and culverts, and topographical low points.

9 Interim Flood Planning Area and Levels

9.1 Overview

To assist Council in assessing proposed developments within the study area, preliminary Flood Planning Areas (FPA) and Flood Planning Levels (FPL) need to be determined. The FPA identifies parcels of land that are subject to Section 10.7 flood-related development controls. The FPL identifies the minimum floor level required for proposed developments on parcels of land classified as within the FPA.

The Floodplain Development Manual recommends that the FPL be based upon the 1% AEP peak flood level plus a freeboard. Typically, a 0.5 m freeboard is applied; although the Manual does allow for a lower freeboard to be applied if local conditions justify doing so. Of further consideration is also the difference between mainstream flood behaviour and local overland flood behaviour, with the former typically being the basis on which FPA and FPL methodologies have been developed and applied. Often these differences are seen in how great the difference in peak flood levels are between different magnitude events, whereby mainstream flood levels vary drastically between events whereas overland flood levels vary to a much smaller degree. As such, applying the typical freeboard of 0.5 m to overland flood levels can result in an FPL that is greater than the PMF level and areas outside the PMF extent being identified within the FPA.

9.2 Methodology

Given the focus of the current flood study is the township of Moulamein, the FPA and FPL has focused on the overland flooding behaviour. In this case, the overland flooding was defined as flooding where the 1% AEP peak flood depth was greater than 0.15 m. The overland FPA extent was classified as areas where overland flooding affected 10% or more of the area of a property. The overland FPL was defined as the 1% AEP peak flood level plus a freeboard of 300 mm.

Where a property was affected by both the mainstream and overland FPA, the mainstream FPA and FPL prevailed.

9.3 Summary

Figure 28 shows the properties affected by the overland FPA. The total number of properties affected by the overland FPA was 117.

10 References

Ref 1: Australian Emergency Management Institute (2017), *Australian Emergency Management Handbook 7: Managing the Floodplain Best Practice in Flood Risk Management in Australia*, AEMI, Canberra

Ref 2: Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) (2019), *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia

Ref 3: BMT WBM (2016), *TUFLOW User Manual*

Ref 4: Boyd, M., Rigby, E., VanDrie, R. (2017), *Watershed Bounded Network Model (WBNM) User Guide*

Ref 5: Chow, V.T. (1959), *Open Channel Hydraulics*, McGraw-Hill, New York

Ref 6: Henderson, F.M. (1966), *Open Channel Flow*, MacMillan, New York

Ref 7: Institute of Engineers, Australia (1987), *Australian Rainfall and Runoff: A Guide to Flood Estimation, Vol. 1*, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted 1998), Barton, ACT

Ref 8: NSW Government (2005), *Floodplain Development Manual: The management of flood liable land*, Department of Infrastructure, Planning and Natural Resources, NSW Government, Sydney

Ref 9: NSW Office of Environment and Heritage (now the Department of Planning, Industry and Environment) (2018), Floodplain Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in Studies, NSW Government

Ref 10: Patterson Britton & Partners Pty Ltd (2006), *Moulamein Levee Upgrade Flood Study*, Wakool Shire Council

Ref 11: SMEC Australia Pty Ltd (2004), *Edward/Wakool Rivers Rural Floodplain Management Plan*, Department of Infrastructure, Planning and Natural Resources

Ref 12: WMAwater Pty Ltd (2014), *Edward River at Deniliquin Flood Study*, Deniliquin City Council

APPENDIX A
GLOSSARY

The following glossary has been extracted from the Australian Emergency Management Institute Handbook 7 (AEMI, 2017).

Annual Exceedance Probability (AEP)	The likelihood of the occurrence of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood flow of 500 m3/s has an AEP of 5%, it means that there is a 5% chance (that is, a one-in-20 chance) of a flow of 500 m3/s or larger occurring in any one year (see also average recurrence interval, flood risk, likelihood of occurrence, probability).
Australian Height Datum (AHD)	A common national survey height datum as a reference level for defining reduced levels; 0.0 m AHD corresponds approximately to sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood-prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time. If the damage associated with various annual events is plotted against their probability of occurrence, the AAD is equal to the area under the consequence-probability curve. AAD provides a basis for comparing the economic effectiveness of different management measures (i.e. their ability to reduce the AAD).
Average Recurrence Interval (ARI)	A statistical estimate of the average number of years between the occurrence of a flood of a given size or larger than the selected event. For example, floods with a flow as great as or greater than the 20-year ARI (5% AEP) flood event will occur, on average, once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event (see also annual exceedance probability).
Catchment	The area of land draining to a particular site. It is related to a specific location, and includes the catchment of the main waterway as well as any tributary streams.
Catchment flooding	Flooding due to prolonged or intense rainfall (e.g. severe thunderstorms, monsoonal rains in the tropics, tropical cyclones). Types of catchment flooding include riverine, local overland and groundwater flooding.
Chance	The likelihood of something happening that will have beneficial consequences (e.g. the chance of a win in a lottery). Chance is often thought of as the ‘upside of a gamble’ (Rowe 1990) (see also risk).
Consent authority	The authority or agency with the legislative power to determine the outcome of development and building applications.
Consequence	The outcome of an event or situation affecting objectives, expressed qualitatively or quantitatively. Consequences can be adverse (e.g. death or injury to people, damage to property and disruption of the community) or beneficial.

Defined Flood Event (DFE)	The flood event selected for the management of flood hazard to new development. This is generally determined in floodplain management studies and incorporated in floodplain management plans. Selection of DFEs should be based on an understanding of flood behaviour, and the associated likelihood and consequences of flooding. It should also take into account the social, economic, environmental and cultural consequences associated with floods of different severities. Different DFEs may be chosen for the basis for reducing flood risk to different types of development. DFEs do not define the extent of the floodplain, which is defined by the PMF (see also design flood, floodplain and probable maximum flood).
Design flood	The flood event selected for the treatment of existing risk through the implementation of structural mitigation works such as levees. It is the flood event for which the impacts on the community are designed to be limited by the mitigation work. For example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breech the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping (see also annual exceedance probability, defined flood event, floodplain, freeboard and probable maximum flood).
Development	Development may be defined in jurisdictional legislation or regulation. This may include erecting a building or carrying out of work, including the placement of fill; the use of land, or a building or work; or the subdivision of land. Infill development refers to the development of vacant blocks of land within an existing subdivision that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. New development is intensification of use with development of a completely different nature to that associated with the former land use or zoning (e.g. the urban subdivision of an area previously used for rural purposes). New developments generally involve rezoning, and associated consents and approvals. It may require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment refers to rebuilding in an existing developed area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

Effective warning time	The effective warning time available to a floodprone community is equal to the time between the delivery of an official warning to prepare for imminent flooding and the loss of evacuation routes due to flooding. The effective warning time is typically used for people to self-evacuate, to move farm equipment, move stock, raise furniture, and transport their possessions.
Existing flood risk	The risk a community is exposed to as a result of its location on the floodplain.
Flood	Flooding is a natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal or catchment flooding, or a combination of both (see also catchment flooding and coastal flooding).
Flood awareness	An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures. In communities with a high degree of flood awareness, the response to flood warnings is prompt and effective. In communities with a low degree of flood awareness, flood warnings are liable to be ignored or misunderstood, and residents are often confused about what they should do, when to evacuate, what to take with them and where it should be taken.
Flood damage	The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding. Tangible costs are quantified in monetary terms (e.g. damage to goods and possessions, loss of income or services in the flood aftermath). Intangible damages are difficult to quantify in monetary terms and include the increased levels of physical, emotional and psychological health problems suffered by flood-affected people that are attributed to a flooding episode.
Flood education	Education that raises awareness of the flood problem, to help individuals understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
Flood emergency response plan	A step-by-step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations. The objective is to ensure a coordinated response by all agencies having responsibilities and functions in emergencies.
Flood emergency management	Emergency management is a range of measures to manage risks to communities and the environment. In the flood context, it may include measures to prevent, prepare for, respond to and recover from flooding.
Flood fringe areas	The part of the floodplain where development could be permitted, provided the development is compatible with flood hazard and appropriate building measures to provide an adequate level of flood protection to the development. This is the remaining area affected by flooding after flow

	conveyance paths and flood storage areas have been defined for a particular event (see also flow conveyance areas and flood storage areas).
Flood hazard	Potential loss of life, injury and economic loss caused by future flood events. The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, rate of rise of floodwaters, duration), topography and emergency management.
Floodplain	An area of land that is subject to inundation by floods up to and including the probable maximum flood event - that is, flood-prone land.
Floodplain management entity (FME)	The authority or agency with the primary responsibility for directly managing flood risk at a local level.
Floodplain management plan	A management plan developed in accordance with the principles and guidelines in this handbook, usually includes both written and diagrammatic information describing how particular areas of flood-prone land are to be used and managed to achieve defined objectives. It outlines the recommended ways to manage the flood risk associated with the use of the floodplain for various purposes. It represents the considered opinion of the local community and the floodplain management entity on how best to manage the floodplain, including consideration of flood risk in strategic land-use planning to facilitate development of the community. It fosters flood warning, response, evacuation, clean-up and recovery in the onset and aftermath of a flood, and suggests an organisational structure for the integrated management for existing, future and residual flood risks. Plans need to be reviewed regularly to assess progress and to consider the consequences of any changed circumstances that have arisen since the last review.
Flood Planning Area (FPA)	The area of land below the flood planning level, and is thus subject to flood-related development controls.
Flood Planning Level (FPL)	The FPL is a combination of the defined flood levels (derived from significant historical flood events or floods of specific annual exceedance probabilities) and freeboards selected for floodplain management purposes, as determined in management studies and incorporated in management plans.
Flood-prone land	Land susceptible to flooding by the probably maximum flood event. Flood-prone land is synonymous with the floodplain. Floodplain management plans should encompass all flood-prone land rather than being restricted to areas affected by defined flood events.
Flood proofing of buildings	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures that are subject to flooding, to reduce structural

	damage and potentially, in some cases, reduce contents damage.
Flood readiness	An ability to react within the effective warning time (see also flood awareness and flood education).
Flood risk	The potential risk of flooding to people, their social setting, and their built and natural environment. The degree of risk varies with circumstances across the full range of floods. Flood risk is divided into three types - existing, future and residual.
Flood severity	A qualitative indication of the 'size' of a flood and its hazard potential. Severity varies inversely with likelihood of occurrence (i.e. the greater the likelihood of occurrence, the more frequently an event will occur, but the less severe it will be). Reference is often made to major, moderate and minor flooding (see also minor, moderate and major flooding).
Flood storage areas	The parts of the floodplain that are important for temporary storage of floodwaters during a flood passage. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas (see also flow conveyance areas and flood fringe areas).
Flood study	A comprehensive technical investigation of flood behaviour. It defines the nature of flood hazard across the floodplain by providing information on the extent, level and velocity of floodwaters, and on the distribution of flood flows. The flood study forms the basis for subsequent management studies and needs to take into account a full range of flood events up to and including the probable maximum flood.
Flow	The rate of flow of water measured in volume per unit time - for example, cubic metres per second (m3/s). Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Flow conveyance areas	Those areas of the floodplain where a significant flow of water occurs during floods. They are often aligned with naturally defined channels. Flow conveyance paths are areas that, even if only partially blocked, would cause a significant redistribution of flood flow or a significant increase in flood levels. They are often, but not necessarily, areas of deeper flow or areas where higher velocities occur, and can also include areas where significant storage of floodwater occurs. Each flood has a flow conveyance area, and the extent and flood behaviour within flow conveyance areas may change with flood severity. This is because areas that are benign for small floods may experience much greater and more

	hazardous flows during larger floods (see also flood fringe areas and flood storage areas).
Freeboard	The height above the DFE or design flood used, in consideration of local and design factors, to provide reasonable certainty that the risk exposure selected in deciding on a particular DFE or design flood is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels and so on. Freeboard compensates for a range of factors, including wave action, localised hydraulic behaviour and levee settlement, all of which increase water levels or reduce the level of protection provided by levees. Freeboard should not be relied upon to provide protection for flood events larger than the relevant defined flood event of a design flood. Freeboard is included in the flood planning level and therefore used in the derivation of the flood planning area (see also defined flood event, design flood, flood planning area and flood planning level).
Frequency	The measure of likelihood expressed as the number of occurrences of a specified event in a given time. For example, the frequency of occurrence of a 20% annual exceedance probability or five-year average recurrence interval flood event is once every five years on average (see also annual exceedance probability, annual recurrence interval, likelihood and probability).
Future flood risk	The risk that new development within a community is exposed to as a result of developing on the floodplain.
Gauge height	The height of a flood level at a particular gauge site related to a specified datum. The datum may or may not be the AHD (see also Australian height datum).
Hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this handbook, the hazard is flooding, which has the potential to cause damage to the community.
Hydraulics	The study of water flow in waterways; in particular, the evaluation of flow parameters such as water level, extent and velocity.
Hydrograph	A graph that shows how the flow or stage (flood level) at any particular location varies with time during a flood.
Hydrologic analysis	The study of the rainfall and runoff process, including the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Intolerable risk	A risk that, following understanding of the likelihood and consequences of flooding, is so high that it requires consideration of implementation of treatments or actions to improve understanding, avoid, transfer or reduce the risk.
Life-cycle costing	All of the costs associated with the project from the cradle to the grave. This usually includes investigation, design,

	construction, monitoring, maintenance, asset and performance management and, in some cases, decommissioning of a management measure.
Likelihood	A qualitative description of probability and frequency (see also frequency and probability).
Likelihood of occurrence	The likelihood that a specified event will occur. (With respect to flooding, see also annual exceedance probability and average recurrence interval).
Local overland flooding	Inundation by local runoff on its way to a waterway, rather than overbank flow from a stream, river, estuary, lake or dam. Can be considered synonymous with stormwater flooding.
Loss	Any negative consequence or adverse effect, financial or otherwise.
Mathematical and computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land-use options for different flood-prone areas, together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of rivers and floodplains. This approach operates at two levels. At the strategic level, it allows for the consideration of flood hazard and associated social, economic, ecological and cultural issues in formulating statutory planning instruments, and development control plans and policies. At a site specific level, it involves consideration of the best way of developing land in consideration of the zonings in a statutory planning instruments, and development control plans and policies.
Minor, moderate and major flooding	These terms are often used in flood warnings to give a general indication of the types of problems expected with a flood.
Probability	A statistical measure of the expected chance of flooding. It is the likelihood of a specific outcome, as measured by the ratio of specific outcomes to the total number of possible outcomes. Probability is expressed as a number between zero and unity, zero indicating an impossible outcome and unity indicating an outcome that is certain. Probabilities are commonly expressed in terms of percentage. For example, the probability of 'throwing a six' on a single roll of a die is one in six, or 0.167 or 16.7% (see also annual exceedance probability).
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from PMP and, where applicable, snow melt, coupled with the worst flood-

	producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood-prone land - that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event, should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (WMO 1986). It is the primary input to probable maximum flood estimation.
Rainfall intensity	The rate at which rain falls, typically measured in millimetres per hour (mm/h). Rainfall intensity varies throughout a storm in accordance with the temporal pattern of the storm (see also temporal pattern).
Residual flood risk	The risk a community is exposed to that is not being remedied through established risk treatment processes. In simple terms, for a community, it is the total risk to that community, less any measure in place to reduce that risk. The risk a community is exposed to after treatment measures have been implemented. For a town protected by a levee, the residual flood risk is the consequences of the levee being overtopped by floods larger than the design flood. For an area where flood risk is managed by land-use planning controls, the residual flood risk is the risk associated with the consequences of floods larger than the DFE on the community.
Risk	'The effect of uncertainty on objectives' (ISO31000:2009). NOTE 4 of the definition in ISO31000:2009 also states that 'risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence'. Risk is based upon the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment (see also likelihood and consequence).
Risk analysis	The systematic use of available information to determine how often specified (flood) events occur and the magnitude of their likely consequences. Flood risk analysis is normally undertaken as part of a floodplain management study, and involves an assessment of flood levels and hazard associated with a range of flood events (see also flood study).
Risk management	The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring flood risk.

	Flood risk management is undertaken as part of a floodplain management plan. The floodplain management plan reflects the adopted means of managing flood risk (see also floodplain management plan).
Riverine flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. Riverine flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Runoff	The amount of rainfall that drains into the surface drainage network to become stream flow; also known as rainfall excess.
Stage	Equivalent to water level. Both stage and water level are measured with reference to a specified datum (e.g. the Australian height datum).
Stormwater flooding	Is inundation by local runoff caused by heavier than usual rainfall. It can be caused by local runoff exceeding the capacity of an urban stormwater drainage systems, flow overland on the way to waterways or by the backwater effects of mainstream flooding causing urban stormwater drainage systems to overflow (see also local overland flooding).
Temporal pattern	The variation of rainfall intensity with time during a rainfall event.
Treatment options	The measures that might be feasible for the treatment of existing, future and residual flood risk at particular locations within the floodplain. Preparation of a treatment plan requires a detailed evaluation of floodplain management options (see also floodplain management plan).
Velocity of floodwater	The speed of floodwaters, measured in metres per second (m/s).
Vulnerability	The degree of susceptibility and resilience of a community, its social setting, and the natural and built environments to flood hazards. Vulnerability is assessed in terms of ability of the community and environment to anticipate, cope and recover from flood events. Flood awareness is an important indicator of vulnerability (see also flood awareness).

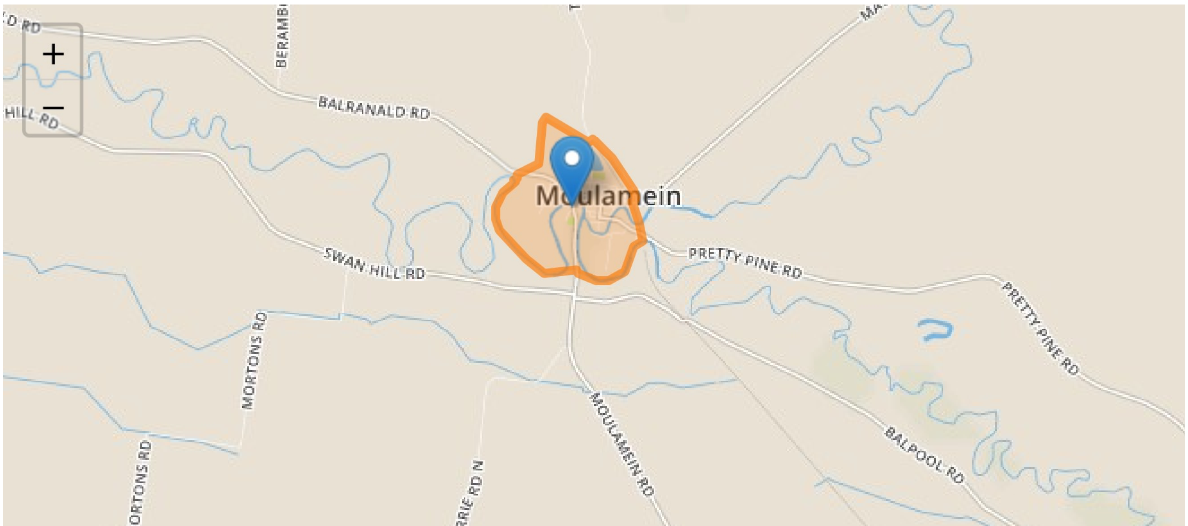
APPENDIX B
ARR DATA HUB

ATTENTION: This site was updated recently, changing some of the functionality. Please see the changelog (./changelog) for further information

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	144.031
Latitude	-35.091
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	10
River Name	Murray Riverina
Shape Intersection (%)	81.3

Layer Info

Time Accessed	21 September 2019 11:44AM
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	Shape Intersection (%)
Southern Semi-arid	0.254	0.247	0.403	0.351	0.0013	0.302	0.058	0.0	0.0	100.0

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	21 September 2019 11:44AM

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.

Storm Initial Losses (mm)	56.0
Storm Continuing Losses (mm/h)	0.0

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2016_v1

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

code	MB
Label	Murray Basin
Shape Intersection (%)	100.0

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2016_v2

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

code	MB
arealabel	Murray Basin
Shape Intersection (%)	100.0

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-35.0908102064&longitude=144.030832412&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	21 September 2019 11:44AM

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)	1.4 (0.091)	1.1 (0.047)	0.9 (0.031)	0.7 (0.020)	1.1 (0.024)	1.4 (0.025)
90 (1.5)	1.1 (0.061)	0.9 (0.033)	0.8 (0.023)	0.7 (0.016)	0.7 (0.014)	0.8 (0.013)
120 (2.0)	1.5 (0.077)	1.8 (0.058)	1.9 (0.050)	2.0 (0.045)	1.2 (0.021)	0.5 (0.008)
180 (3.0)	1.3 (0.058)	3.1 (0.093)	4.3 (0.103)	5.5 (0.109)	3.7 (0.059)	2.4 (0.033)
360 (6.0)	0.7 (0.024)	1.1 (0.026)	1.3 (0.026)	1.5 (0.025)	3.1 (0.042)	4.3 (0.050)
720 (12.0)	0.0 (0.000)	0.5 (0.010)	0.8 (0.013)	1.1 (0.015)	1.6 (0.018)	1.9 (0.019)
1080 (18.0)	0.0 (0.000)	0.5 (0.008)	0.8 (0.011)	1.1 (0.013)	0.8 (0.008)	0.6 (0.006)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.1 (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	21 September 2019 11:44AM
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	21 September 2019 11:44AM
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

Time Accessed	21 September 2019 11:44AM
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)	7.4 (0.470)	10.7 (0.442)	12.9 (0.421)	14.9 (0.400)	13.6 (0.287)	12.5 (0.226)
90 (1.5)	8.9 (0.491)	11.9 (0.432)	13.8 (0.401)	15.7 (0.374)	16.8 (0.319)	17.7 (0.285)
120 (2.0)	9.6 (0.483)	12.5 (0.418)	14.5 (0.386)	16.3 (0.358)	15.9 (0.279)	15.6 (0.234)
180 (3.0)	11.8 (0.517)	13.8 (0.408)	15.1 (0.360)	16.4 (0.324)	20.5 (0.325)	23.6 (0.320)
360 (6.0)	3.5 (0.123)	8.7 (0.211)	12.2 (0.240)	15.5 (0.255)	19.5 (0.260)	22.4 (0.259)
720 (12.0)	1.0 (0.030)	6.2 (0.123)	9.6 (0.157)	12.8 (0.177)	15.4 (0.175)	17.4 (0.173)
1080 (18.0)	0.0 (0.001)	4.5 (0.080)	7.4 (0.109)	10.2 (0.128)	11.0 (0.114)	11.6 (0.106)
1440 (24.0)	0.0 (0.000)	2.6 (0.044)	4.4 (0.061)	6.1 (0.072)	6.6 (0.065)	7.1 (0.061)
2160 (36.0)	0.0 (0.000)	0.4 (0.005)	0.6 (0.008)	0.8 (0.009)	0.6 (0.005)	0.4 (0.003)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.3 (0.002)	0.4 (0.003)
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	21 September 2019 11:44AM
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)	16.5 (1.040)	22.0 (0.910)	25.7 (0.842)	29.3 (0.784)	29.9 (0.634)	30.4 (0.548)
90 (1.5)	21.9 (1.205)	24.6 (0.895)	26.4 (0.765)	28.1 (0.670)	32.6 (0.617)	36.0 (0.580)
120 (2.0)	23.9 (1.197)	27.4 (0.915)	29.8 (0.794)	32.0 (0.704)	36.7 (0.643)	40.2 (0.602)
180 (3.0)	25.3 (1.111)	27.6 (0.816)	29.1 (0.693)	30.6 (0.603)	40.4 (0.638)	47.7 (0.647)
360 (6.0)	14.9 (0.526)	20.4 (0.493)	24.0 (0.472)	27.5 (0.452)	37.4 (0.499)	44.8 (0.518)
720 (12.0)	10.8 (0.310)	18.4 (0.367)	23.4 (0.383)	28.2 (0.390)	33.2 (0.378)	37.0 (0.368)
1080 (18.0)	4.6 (0.119)	11.8 (0.211)	16.5 (0.244)	21.0 (0.263)	23.0 (0.239)	24.4 (0.224)
1440 (24.0)	2.1 (0.050)	8.0 (0.134)	11.9 (0.164)	15.6 (0.184)	17.1 (0.168)	18.2 (0.158)
2160 (36.0)	0.1 (0.002)	4.5 (0.070)	7.5 (0.095)	10.3 (0.112)	12.9 (0.118)	14.9 (0.121)
2880 (48.0)	0.0 (0.000)	0.9 (0.014)	1.6 (0.019)	2.2 (0.023)	3.7 (0.032)	4.8 (0.038)
4320 (72.0)	0.0 (0.000)	0.4 (0.005)	0.6 (0.007)	0.8 (0.008)	4.1 (0.034)	6.5 (0.049)

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

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

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2019_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	15.8	24.0	24.3	24.3	22.7	22.4
90 (1.5)	18.1	27.3	24.1	24.6	23.8	22.0
120 (2.0)	19.9	27.9	24.3	24.8	24.3	22.8
180 (3.0)	22.7	28.0	24.7	25.1	23.6	23.0
360 (6.0)	28.3	32.6	30.1	29.7	27.1	24.2
720 (12.0)	34.8	35.7	33.0	32.7	30.4	27.7
1080 (18.0)	38.8	38.9	36.6	36.5	32.3	31.6
1440 (24.0)	41.5	40.8	38.3	39.1	35.2	34.9
2160 (36.0)	45.1	42.3	40.4	41.4	37.9	38.1
2880 (48.0)	47.3	43.4	42.5	43.4	40.5	40.3
4320 (72.0)	50.0	44.2	43.6	44.1	41.3	40.0

Layer Info

Time Accessed	21 September 2019 11:44AM

Version	2018_v1
Note	As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. Probability neutral burst initial loss values for NSW are to be used in place of the standard initial loss and pre-burst as per the losses hierarchy.

Baseflow Factors

Downstream	10687
Area (km2)	2073.8818
Catchment Number	10745
Volume Factor	0.034754
Peak Factor	0.020491
Shape Intersection (%)	60.3

Layer Info

Time Accessed	21 September 2019 11:44AM
Version	2016_v1

Download TXT (downloads/8c96d2ae-ea92-43db-b030-21383cb67fc6.txt)

Download JSON (downloads/1cb7185f-79f4-4d54-b4fe-2e3c7e4b8360.json)

Generating PDF... (downloads/3474eff6-4b1a-4a62-9f02-d4632594570f.pdf)

APPENDIX C
BOM IFD DATA

Australian Government
Bureau of Meteorology

Location

Label: Not provided

Latitude: -35.0885 [Nearest grid cell: 35.0875 (S)]

Longitude:144.0349 [Nearest grid cell: 144.0375 (E)]

IFD Design Rainfall Depth (mm)

Issued: 08 January 2019

Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).
FAQ for New ARR probability terminology

	Annual Exceedance Probability (AEP)						
Duration	**63.2%**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**
1 min	1.29	1.54	2.38	3.02	3.69	4.68	5.51
2 min	2.24	2.65	4.06	5.13	6.26	7.90	9.28
3 min	3.04	3.60	5.52	6.96	8.50	10.7	12.6
4 min	3.71	4.40	6.77	8.55	10.4	13.2	15.5
5 min	4.30	5.10	7.86	9.93	12.1	15.4	18.1
10 min	6.39	7.61	11.8	15.0	18.3	23.2	27.3
15 min	7.78	9.27	14.4	18.3	22.4	28.4	33.5
20 min	8.82	10.5	16.3	20.7	25.4	32.2	38.0
25 min	9.67	11.5	17.8	22.6	27.8	35.2	41.5
30 min	10.4	12.4	19.1	24.2	29.7	37.7	44.4
45 min	12.1	14.3	22.0	27.9	34.1	43.2	50.9
1 hour	13.4	15.8	24.2	30.6	37.3	47.2	55.5
1.5 hour	15.4	18.1	27.5	34.5	42.0	52.9	62.0
2 hour	17.0	19.9	30.0	37.5	45.5	57.1	66.8
3 hour	19.5	22.8	33.8	42.0	50.7	63.2	73.7
4.5 hour	22.3	25.9	38.0	47.0	56.4	69.9	81.0
6 hour	24.5	28.4	41.4	50.9	60.8	74.9	86.4
9 hour	27.9	32.1	46.4	56.7	67.4	82.4	94.5
12 hour	30.3	35.0	50.2	61.1	72.4	87.9	100
18 hour	33.9	39.0	55.7	67.6	79.6	96.0	109
24 hour	36.3	41.8	59.6	72.1	84.8	102	115
30 hour	38.1	43.8	62.5	75.6	88.7	106	119
36 hour	39.4	45.4	64.8	78.3	91.8	109	123
48 hour	41.4	47.7	68.1	82.2	96.3	114	128
72 hour	43.7	50.5	72.0	86.8	102	120	134
96 hour	45.2	52.2	74.3	89.4	104	123	137
120 hour	46.3	53.4	75.7	90.9	106	125	139

144 hour	47.3	54.4	76.7	91.9	107	126	141
168 hour	48.2	55.3	77.6	92.7	107	127	142

Note:
The 50% AEP IFD **does not** correspond to the 2 year Average Recurrence Interval (ARI) IFD. Rather it corresponds to the 1.44 ARI.
* The 20% AEP IFD **does not** correspond to the 5 year Average Recurrence Interval (ARI) IFD. Rather it corresponds to the 4.48 ARI.

This page was created at **10:49 on Tuesday 08 January 2019 (AEDT)**

Australian Government
Bureau of Meteorology

Location

Label: Not provided

Latitude: -35.0885 [Nearest grid cell: 35.0875 (S)]

Longitude: 144.0349 [Nearest grid cell: 144.0375 (E)]

Rare Design Rainfall Depth (mm)

Issued: 08 January 2019

Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).
FAQ for New ARR probability terminology

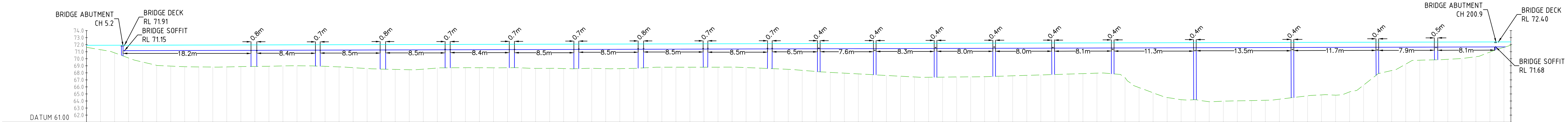
	Annual Exceedance Probability (1 in x)				
Duration	**1 in 100**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	5.51	6.23	7.19	7.96	8.76
2 min	9.28	10.4	11.8	13.0	14.2
3 min	12.6	14.2	16.2	17.8	19.5
4 min	15.5	17.5	20.1	22.1	24.3
5 min	18.1	20.4	23.5	25.9	28.5
10 min	27.3	31.0	35.9	39.8	43.8
15 min	33.5	38.0	43.9	48.6	53.6
20 min	38.0	43.0	49.7	55.0	60.6
25 min	41.5	47.0	54.2	60.0	66.0
30 min	44.4	50.2	57.9	64.0	70.4
45 min	50.9	57.4	66.1	73.0	80.2
1 hour	55.5	62.6	72.0	79.4	87.3
1.5 hour	62.0	70.0	80.5	88.9	97.6
2 hour	66.8	75.4	86.8	96.0	105
3 hour	73.7	83.5	96.3	107	117
4.5 hour	81.0	92.0	107	118	130
6 hour	86.4	98.4	114	127	140
9 hour	94.5	108	125	139	154
12 hour	100	115	133	148	164
18 hour	109	124	143	159	176
24 hour	115	130	150	166	183
30 hour	119	132	151	165	180
36 hour	123	135	153	166	180
48 hour	128	140	157	170	183
72 hour	134	147	165	179	193
96 hour	137	152	171	186	201

120 hour	139	155	176	191	207
144 hour	141	157	178	194	211
168 hour	142	157	180	196	212

This page was created at **14:11 on Tuesday 08 January 2019 (AEDT)**

APPENDIX D
GROUND-BASED SURVEY DATA

RAIL BRIDGE - SOUTH OF PRETTY PINE ROAD - LOOKING WEST



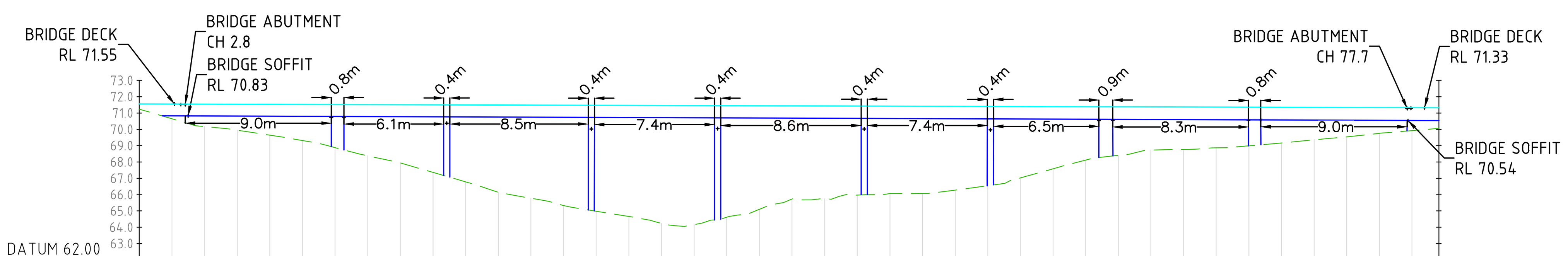
CHAINAGE	NATURAL SURFACE	BRIDGE DECK
0.0	71.62	
2.0	71.29	
4.0	70.84	
6.0	70.11	71.91
8.0	69.54	71.91
10.0	69.06	71.92
12.0	68.96	71.92
14.0	68.87	71.93
16.0	68.84	71.93
18.0	68.82	71.94
20.0	68.83	71.94
22.0	68.88	71.95
24.0	68.91	71.95
26.0	68.93	71.96
28.0	68.98	71.96
30.0	69.00	71.97
32.0	68.99	71.97
34.0	68.92	71.98
36.0	68.85	71.98
38.0	68.74	71.99
40.0	68.61	71.99
42.0	68.54	72.00
44.0	68.49	72.00
46.0	68.44	72.01
48.0	68.52	72.01
50.0	68.68	72.02
52.0	68.72	72.02
54.0	68.73	72.03
56.0	68.72	72.03
58.0	68.71	72.04
60.0	68.72	72.04
62.0	68.70	72.05
64.0	68.63	72.05
66.0	68.64	72.06
68.0	68.61	72.06
70.0	68.60	72.07
72.0	68.63	72.07
74.0	68.59	72.08
76.0	68.60	72.08
78.0	68.63	72.09
80.0	68.73	72.09
82.0	68.80	72.10
84.0	68.80	72.10
86.0	68.80	72.11
88.0	68.80	72.11
90.0	68.80	72.12
92.0	68.81	72.12
94.0	68.75	72.13
96.0	68.66	72.13
98.0	68.58	72.14
100.0	68.50	72.14
102.0	68.35	72.15
104.0	68.19	72.15
106.0	68.06	72.16
108.0	67.95	72.16
110.0	67.85	72.17
112.0	67.74	72.17
114.0	67.63	72.18
116.0	67.52	72.18
118.0	67.41	72.19
120.0	67.37	72.19
122.0	67.39	72.20
124.0	67.41	72.20
126.0	67.43	72.21
128.0	67.45	72.21
130.0	67.51	72.22
132.0	67.58	72.22
134.0	67.64	72.23
136.0	67.70	72.23
138.0	67.76	72.24
140.0	67.83	72.24
142.0	67.89	72.25
144.0	67.95	72.25
146.0	67.88	72.26
148.0	67.32	72.26
150.0	65.90	72.27
152.0	65.16	72.27
154.0	64.49	72.28
156.0	64.19	72.28
158.0	64.19	72.29
160.0	63.90	72.29
162.0	63.97	72.30
164.0	64.02	72.30
166.0	64.06	72.31
168.0	64.10	72.31
170.0	64.25	72.32
172.0	64.49	72.32
174.0	64.73	72.33
176.0	64.87	72.33
178.0	64.83	72.34
180.0	65.29	72.34
182.0	66.26	72.35
184.0	67.82	72.35
186.0	68.33	72.36
188.0	69.24	72.36
190.0	69.79	72.37
192.0	69.84	72.37
194.0	69.92	72.38
196.0	70.03	72.38
198.0	70.29	72.39
200.0	70.95	72.39
202.0	71.62	
203.0	71.92	

SOUTH

NORTH

CROSS SECTION
SCALES: HORIZONTAL 1:300 VERTICAL 1:300

RAIL BRIDGE - NORTH OF PRETTY PINE ROAD - LOOKING WEST



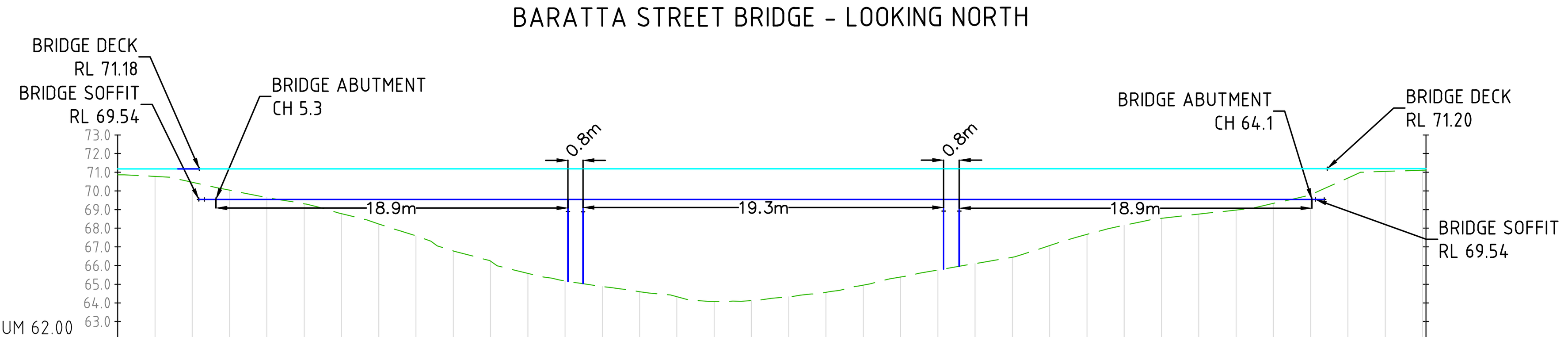
CHAINAGE	NATURAL SURFACE	BRIDGE DECK
0.0	71.24	
2.0	70.65	
4.0	70.17	71.55
6.0	69.95	71.54
8.0	69.65	71.54
10.0	69.32	71.53
12.0	68.88	71.52
14.0	68.38	71.52
16.0	67.94	71.51
18.0	67.36	71.51
20.0	66.79	71.50
22.0	66.15	71.49
24.0	65.78	71.49
26.0	65.33	71.48
28.0	64.98	71.48
30.0	64.66	71.47
32.0	64.24	71.47
34.0	64.16	71.46
36.0	64.61	71.45
38.0	65.10	71.45
40.0	65.73	71.44
42.0	65.74	71.44
44.0	65.97	71.43
46.0	66.06	71.42
48.0	66.07	71.42
50.0	66.27	71.41
52.0	66.55	71.41
54.0	67.03	71.40
56.0	67.59	71.39
58.0	68.12	71.39
60.0	68.40	71.38
62.0	68.73	71.38
64.0	68.77	71.37
66.0	68.87	71.36
68.0	68.99	71.36
70.0	69.17	71.35
72.0	69.37	71.35
74.0	69.54	71.34
76.0	69.76	71.33
78.0	69.92	71.33
79.6	70.04	

SOUTH

NORTH

CROSS SECTION
SCALES: HORIZONTAL 1:300 VERTICAL 1:300

BARATTA STREET BRIDGE - LOOKING NORTH



CHAINAGE	NATURAL SURFACE	BRIDGE DECK
0.0	70.87	
2.0	70.78	
4.0	70.47	
6.0	70.04	71.18
8.0	69.65	71.18
10.0	69.31	71.18
12.0	68.78	71.18
14.0	68.22	71.18
16.0	67.59	71.18
18.0	66.79	71.18
20.0	66.24	71.18
22.0	65.58	71.18
24.0	65.18	71.18
26.0	64.87	71.18
28.0	64.60	71.19
30.0	64.33	71.19
32.0	64.07	71.19
34.0	64.13	71.19
36.0	64.32	71.19
38.0	64.57	71.19
40.0	64.95	71.19
42.0	65.39	71.19
44.0	65.76	71.19
46.0	66.10	71.19
48.0	66.45	71.19
50.0	67.08	71.19
52.0	67.67	71.19
54.0	68.16	71.19
56.0	68.53	71.19
58.0	68.76	71.19
60.0	68.98	71.20
62.0	69.33	71.20
64.0	69.79	71.20
66.0	70.70	
68.0	71.05	
70.0	71.11	
70.2	71.12	

WEST

EAST

CROSS SECTION
SCALES: HORIZONTAL 1:300 VERTICAL 1:300

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DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 Bridges and X-sections.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	18/11/18	ORIGINAL CREATED	SMB	--	NSW	--

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SCALE OF METRES
3 0 6 12
ORIGINAL DRAWING SCALE 1 : 300

DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM22467
SURVEY DATE: 12/11/18
AREA: N/A

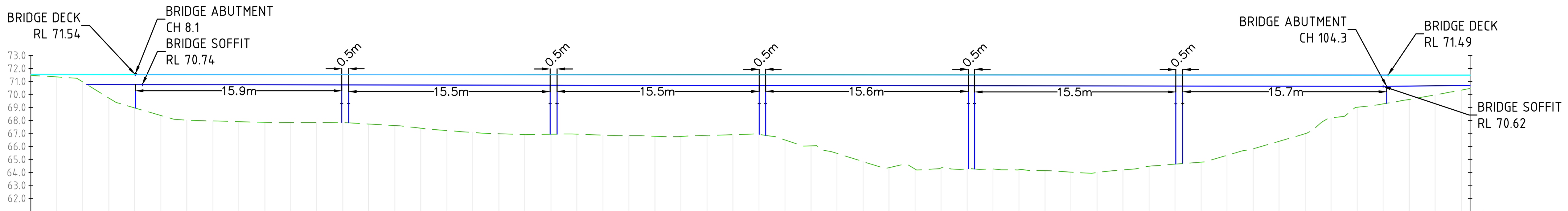
CLIENT:
MURRAY RIVER COUNCIL

DRAWING CREATED: 16 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: BRIDGE CROSS SECTIONS
CROWN DESCRIPTION:

FILE NUMBER: F8472
DRAWING NUMBER: 6016
SHEET NUMBER: 6 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1

MOULAMEIN ROAD EDWARD RIVER BRIDGE - LOOKING WEST



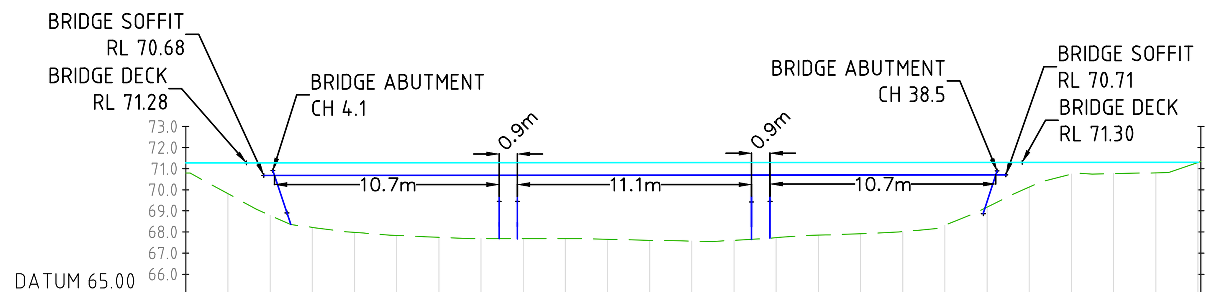
NATURAL SURFACE	71.47	71.34	70.96	69.72	68.96	68.38	68.01	67.96	67.90	67.85	67.84	67.85	67.84	67.72	67.60	67.40	67.22	67.07	66.97	66.91	66.94	66.95	66.87	66.82	66.78	66.76	66.83	66.91	66.93	66.50	66.04	65.47	64.83	64.36	64.25	64.34	64.28	64.27	64.20	64.14	64.02	64.00	64.20	64.47	64.64	64.79	65.31	65.81	66.39	66.98	68.20	69.01	69.27	69.62	69.97	70.33	70.46
BRIDGE DECK						71.54	71.54	71.54	71.54	71.54	71.53	71.53	71.53	71.53	71.53	71.53	71.53	71.53	71.53	71.52	71.52	71.52	71.52	71.52	71.52	71.52	71.52	71.52	71.51	71.51	71.51	71.51	71.51	71.51	71.51	71.51	71.51	71.50	71.50	71.50	71.50	71.50	71.50	71.50	71.50	71.50	71.49	71.49	71.49	71.49	71.49	71.49	71.49				
CHAINAGE	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0	110.0	110.7

SOUTH

CROSS SECTION
SCALES: HORIZONTAL 1:300 VERTICAL 1:300

NORTH

MOULAMEIN ROAD FLOOD BRIDGE - LOOKING WEST



NATURAL SURFACE	70.79	69.81	68.79	68.22	67.98	67.84	67.75	67.69	67.68	67.69	67.66	67.60	67.57	67.60	67.73	67.85	67.92	68.01	68.32	69.18	70.13	70.74	70.77	70.80	71.30	71.35
BRIDGE DECK			71.28	71.28	71.28	71.29	71.29	71.29	71.29	71.29	71.29	71.29	71.29	71.29	71.29	71.29	71.30	71.30	71.30	71.30						
CHAINAGE	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	48.1

SOUTH

CROSS SECTION
SCALES: HORIZONTAL 1:300 VERTICAL 1:300

NORTH

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DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 Bridges and X-sections.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	18/11/18	ORIGINAL CREATED	SMB	--	NSW	--

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SCALE OF METRES
3 0 6 12
ORIGINAL DRAWING SCALE 1 : 300

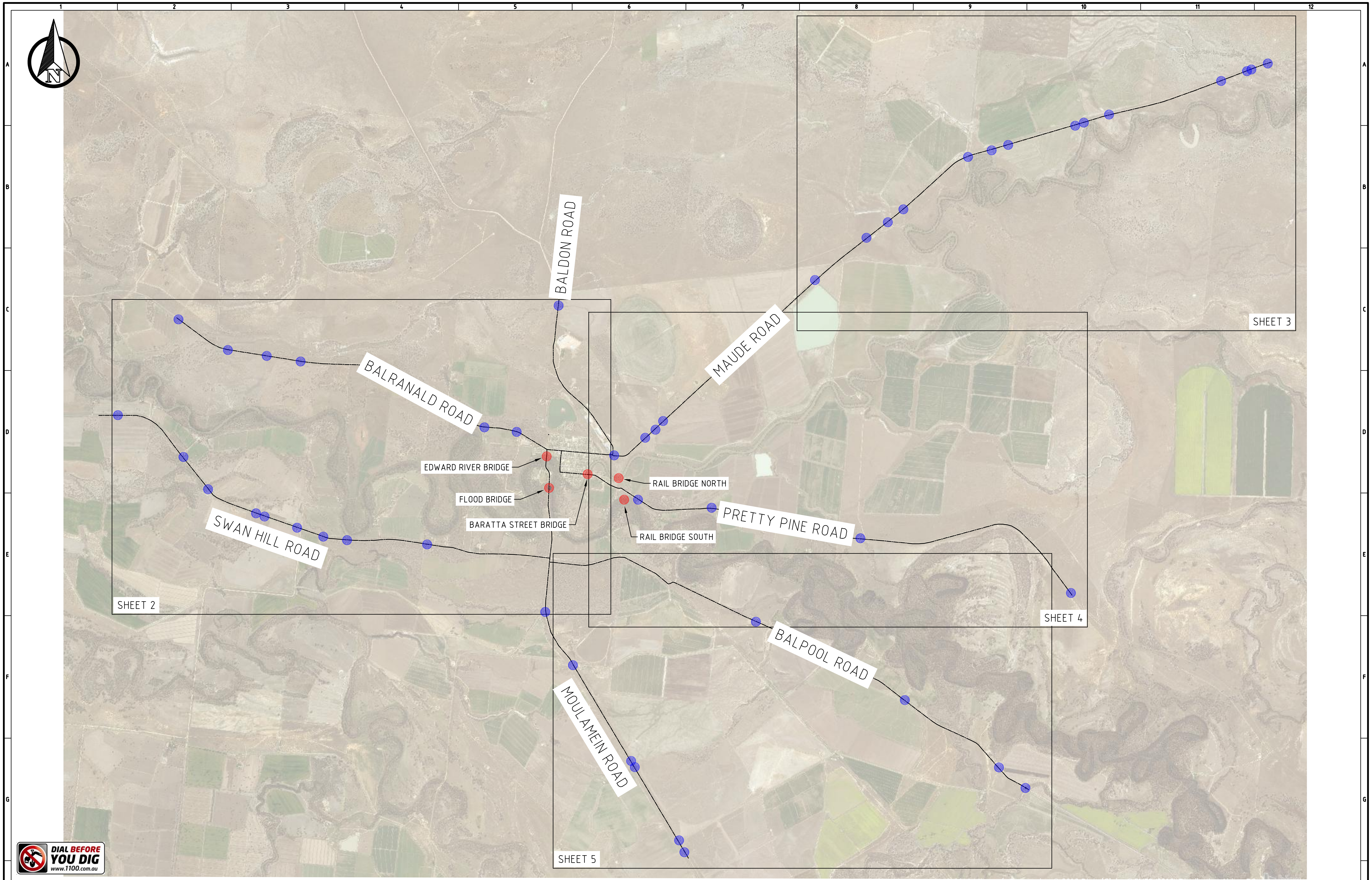
DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM22467
SURVEY DATE: 12/11/18
AREA: N/A

CLIENT:
MURRAY RIVER COUNCIL

DRAWING CREATED: 16 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: BRIDGE CROSS SECTIONS
CROWN DESCRIPTION:

FILE NUMBER: F8472
DRAWING NUMBER: 6016
SHEET NUMBER: 7 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1



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DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 culverts.dwg

REV	DATE	AMENDMENT	DRN	DES	CHK	APPD
0	20/11/18	ORIGINAL CREATED	JG	--	PM	--

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SCALE OF METRES
275.00 0 550.0 1100.0
ORIGINAL DRAWING SCALE 1 : 55000
DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM 22467
SURVEY DATE: 13/11/18
AREA: N/A

CLIENT: MURRAY RIVER COUNCIL
DRAWING CREATED: 13 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: LOCALITY PLAN
CROWN DESCRIPTION: ...

FILE NO: F8472
DRAWING NO: 6013
SHEET NO: 1 OF 7
REVISION: 0
SHEET SIZE: A3

DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 culverts.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	19/11/18	ORIGINAL CREATED	JG	--	PM	--

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SCALE OF METRES
100.0 0 200 400
ORIGINAL DRAWING SCALE 1 : 10000

DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM 22467
SURVEY DATE: 13/11/18
AREA: N/A

CLIENT:
MURRAY RIVER COUNCIL

DRAWING CREATED: 13 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: CULVERT DETAIL PLAN
CROWN DESCRIPTION: ...

FILE NUMBER: F8472
DRAWING NUMBER: 6013
SHEET NUMBER: 2 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1

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DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 culverts.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	19/11/18	ORIGINAL CREATED	JG	--	PM	--

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SCALE OF METRES

100.0 0 200 400

ORIGINAL DRAWING SCALE 1 : 10000

DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM 22467
SURVEY DATE: 13/11/18
AREA: N/A

CLIENT:

MURRAY RIVER COUNCIL

DRAWING CREATED: 13 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY

LOCATION: MOULAMEIN

SHEET TITLE: CULVERT DETAIL PLAN

CROWN DESCRIPTION: ...

FILE NUMBER: F8472
DRAWING NUMBER: 6013
SHEET NUMBER: 3 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1

DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 culverts.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	19/11/18	ORIGINAL CREATED	JG	--	PM	--

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SCALE OF METRES
100.0 0 200 400
ORIGINAL DRAWING SCALE 1 : 10000

DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM 22467
SURVEY DATE: 13/11/18
AREA: N/A

CLIENT: MURRAY RIVER COUNCIL

DRAWING CREATED: 13 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: CULVERT DETAIL PLAN
CROWN DESCRIPTION: ...

FILE NUMBER: F8472
DRAWING NUMBER: 6013
SHEET NUMBER: 4 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1

DRAWING LOCATION: P:\F8472\Drawings\Autocad\F8472 culverts.dwg

REV	DATE	AMENDMENT	DRAWN	DESIGNED	CHECKED	APP'D
0	19/11/18	ORIGINAL CREATED	JG	--	PM	--

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Swan Hill: pmash@pricemerrett.com.au

SCALE OF METRES

100.0 0 200 400

ORIGINAL DRAWING SCALE 1 : 10000

DATUM HORIZONTAL: APPROX. MGA-55
DATUM VERTICAL: AHD
LEVEL DATUM ORIGIN: PM 22467
SURVEY DATE: 13/11/18
AREA: N/A

CLIENT: MURRAY RIVER COUNCIL

DRAWING CREATED: 13 November 2018
LAST PLOTTED: 27 November 2018

PROJECT: MOULAMEIN FLOOD STUDY
LOCATION: MOULAMEIN
SHEET TITLE: CULVERT DETAIL PLAN

CROWN DESCRIPTION: ...

FILE NUMBER: F8472
DRAWING NUMBER: 6013
SHEET NUMBER: 5 OF 7
REVISION: 0
ORIGINAL SHEET SIZE: A1

FIGURES