



Hydrology Report

Newstead Flood Study and Mitigation Strategy (M1751-2023)

Mount Alexander Shire Council

25 October 2024



Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
V01	Draft	Lachlan Inglis	Lachlan Inglis	30/08/2024
V02	Final	Lachlan Inglis	Lachlan Inglis	25/10/2024

Project Details

Project Name	Newstead Flood Study and Mitigation Strategy (M1751-2023)
Client	Mount Alexander Shire Council
Client Project Manager	Rana Punam
Water Technology Project Manager	Elin Olsson
Water Technology Project Director	Lachlan Inglis
Authors	Elin Olsson, Jean Yong
Document Number	24010317_HydrologyReport_R02V02.docx



COPYRIGHT

Water Technology Pty Ltd has produced this document in accordance with instructions from Mount Alexander Shire Council for their use only. The concepts and information contained in this document are the copyright of Water Technology Pty Ltd. Use or copying of this document in whole or in part without written permission of Water Technology Pty Ltd constitutes an infringement of copyright.

Water Technology Pty Ltd does not warrant this document is definitive nor free from error and does not accept liability for any loss caused, or arising from, reliance upon the information provided herein.

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365
ACN 093 377 283
ABN 60 093 377 283





ACKNOWLEDGEMENT OF COUNTRY

The Board and employees of Water Technology acknowledge and respect the Aboriginal and Torres Strait Islander Peoples as the Traditional Custodians of Country throughout Australia. We specifically acknowledge the Traditional Custodians of the land on which our offices reside and where we undertake our work.

We respect the knowledge, skills and lived experiences of Aboriginal and Torres Strait Islander Peoples, who we continue to learn from and collaborate with. We also extend our respect to all First Nations Peoples, their cultures and to their Elders, past and present. In particular, we recognise the Dja Dja Wurrung People as the Traditional Custodians of the waters and lands on which this project is based.



Artwork by Maurice Goolagong 2023. This piece was commissioned by Water Technology and visualises the important connections we have to water, and the cultural significance of journeys taken by traditional custodians of our land to meeting places, where communities connect with each other around waterways.

The symbolism in the artwork includes:

- Seven circles representing each of the States and Territories in Australia where we do our work
- Blue dots between each circle representing the waterways that connect us
- The animals that rely on healthy waterways for their home
- Black and white dots representing all the different communities that we visit in our work
- Hands that are for the people we help on our journey



CONTENTS

GLOSSARY	6
1 INTRODUCTION	8
1.1 Overview	8
1.2 Objectives and outputs	8
1.3 Study area	9
2 MODELLING METHODOLOGY	11
3 FLOOD FREQUENCY ANALYSIS	12
4 RORB MODEL SETUP	17
4.1 Overview	17
4.2 Model setup	17
4.2.1 Subarea and reach delineation	17
4.2.2 Fraction impervious	19
5 RORB CALIBRATION/VALIDATION	21
5.1 Historic event rainfall	21
5.2 Streamflow	23
5.3 October 2022 calibration	25
5.3.1 Rainfall	25
5.3.2 Streamflow	27
5.4 September 2016 calibration	30
5.4.1 Rainfall	30
5.4.2 Streamflow	33
5.5 January 2011 calibration	36
5.5.1 Rainfall	36
5.5.2 Streamflow	39
5.6 November 2010 calibration	42
5.6.1 Rainfall	42
5.6.2 Streamflow	44
5.7 Calibration/Validation discussion	46
6 DESIGN HYDROLOGY	48
6.1 Overview	48
6.2 Design rainfall	48
6.2.1 Spatial variation of design rainfall	48
6.2.2 Pre-burst	51
6.2.3 Embedded bursts	51
6.3 Design losses	52
6.4 Design RORB routing parameters	53
6.5 Design flows	54
6.6 Near-term climate change considerations for 2030 (SSP5 – 8.5)	54
6.7 Long-term climate change consideration for 2100 (SSP5 – 8.5)	57



LIST OF FIGURES

Figure 1-1	Newstead Study Area	10
Figure 3-1	Annual maximum flows at the two Loddon River gauges at the two Loddon River gauges	14
Figure 3-2	FFA: Log Pearson III Distribution	16
Figure 3-3	FFA: Generalised Extreme Value Distribution	16
Figure 3-4	FFA: Log Natural Distribution	16
Figure 3-5	FFA: Generalised Pareto Distribution	16
Figure 4-1	RORB model layout	18
Figure 4-2	Adopted fraction impervious	20
Figure 5-1	Upper Loddon River Rainfall Gauges	21
Figure 5-2	Utilised streamflow gauges	24
Figure 5-3	Rainfall distribution and isopleths for October 2022 event	26
Figure 5-4	Hourly rainfall increments for the sub-daily rainfall stations from 7am 12 October 2022 to 6pm 14 October 2022	27
Figure 5-5	Modelled and recorded stream gauges, October 2022 event	29
Figure 5-6	Rainfall distribution and isopleths for September 2016 event	32
Figure 5-7	Hourly rainfall increments for the sub-daily rainfall stations from 9am 8 September 2016 to 9am 19 September 2016	33
Figure 5-8	Modelled and recorded stream gauges, September 2016 event	35
Figure 5-9	Rainfall distribution and isopleths for January 2011 event	38
Figure 5-10	Hourly rainfall increments for the sub-daily rainfall stations from 10am 10 January 2011 to 9am 15 January 2011	39
Figure 5-11	Modelled and recorded stream gauges, January 2011 event	41
Figure 5-12	Rainfall distribution and isopleths for November 2010 event	43
Figure 5-13	Hourly rainfall increments for the sub-daily rainfall stations from 10am 24 November 2010 to 10am 30 November 2010	44
Figure 5-14	Modelled and recorded stream gauges, November 2010 event	46
Figure 6-1	Example of Spatially Varied Rainfall, 1% AEP 24 Hour Event	50
Figure 6-2	Conceptualisation of storm vs burst rainfall and its interaction with Initial Loss	51
Figure 6-3	Modelled flows and FFA flows at Newstead	53

LIST OF TABLES

Table 3-1	Streamflow gauges information	12
Table 3-2	Adopted annual flow series (Ordered by flow magnitude)	12
Table 3-3	Major flood events at Newstead	13
Table 3-4	Adopted FFA quantiles for Loddon River at Newstead (407215)	15
Table 3-5	Approximate AEP of 5 largest recorded events (based on FFA)	15
Table 4-1	Land use zones and fraction impervious	19
Table 5-1	Daily rainfall stations	22
Table 5-2	Sub-daily Rainfall Stations	22
Table 5-3	October 2022 rainfall totals (arrows represent accumulated rainfall)	25
Table 5-4	October 2022 RORB calibration parameters	28



Table 5-5	October 2022 calibration statistics	28
Table 5-6	September 2016 rainfall totals (arrows represent accumulated rainfall)	31
Table 5-7	September 2016 RORB calibration parameters	34
Table 5-8	September 2016 calibration statistics	34
Table 5-9	January 2011 rainfall totals (arrows represent accumulated rainfall)	36
Table 5-10	January 2011 RORB calibration parameters	40
Table 5-11	January 2011 calibration statistics	40
Table 5-12	November 2010 rainfall totals (arrows represent accumulated rainfall)	42
Table 5-13	November 2010 RORB calibration parameters	45
Table 5-14	November 2010 calibration statistics	45
Table 5-15	Summary of values for calibration events	46
Table 6-1	Catchment groups for ARF	48
Table 6-2	Upper Loddon River catchment IFD (weighted average) rainfall totals	49
Table 6-3	Design Loss Summary	52
Table 6-4	Design RORB kc values by interstation area	53
Table 6-5	Design flows, critical durations and representative temporal patterns	54
Table 6-6	Near-term climate change rainfall intensity increase per storm duration	54
Table 6-7	Near-term climate change rainfall loss increase	55
Table 6-8	Upper Loddon River catchment IFD (weighted average) rainfall totals with near-term climate change considerations for the year 2030	55
Table 6-9	Design flows, critical durations and representative temporal patterns for near-term (2030) climate change scenario	55
Table 6-10	Design flows, critical durations and representative temporal patterns for near-term (2030) climate change scenario at hydraulic model inflow locations	56
Table 6-11	Long-term climate change rainfall intensity increase per storm duration	57
Table 6-12	Long-term climate change rainfall loss increase	57
Table 6-13	Upper Loddon River catchment IFD (weighted average) rainfall totals with long-term climate change considerations for the year 2100	57
Table 6-14	Design flows, critical durations and representative temporal patterns for 2100 climate change scenario	58



GLOSSARY

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would likely be relatively small magnitude. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would likely be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life caused by flooding. Flood hazard combines the flood depth and velocity.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.



Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.
TUFLOW	A hydraulic modelling software package used to undertake modelling using hydrological modelling inputs.



1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by Mount Alexander Shire Council (MASC) to undertake the Newstead Flood Study and Mitigation Strategy. The project is funded by the Disaster Ready Fund and the Victorian Government. The investigation covers the study area presented in Figure 1-1.

Newstead is a small township in Victoria, located 15 km west of Castlemaine on the banks of the Loddon River. Located within MASC and the North Central Catchment Management Authority (NCCMA) management area. Newstead was established in the mid-19th century as a river crossing point and today hosts a population of approximately 800 people.

The Loddon River catchment upstream of Cairn Curran Reservoir was included in a RORB hydrology model prepared as part of the Cairn Curran Dam Hydrology report¹ prepared by SKM. This model was refined for the catchment upstream of Guildford during the NCCMA Rapid Flood Risk Assessment². The SKM model was calibrated to three events from 2010 and 2011. Given the age of the SKM model along with the Guildford model only covering part of the catchment upstream of Newstead, a new hydrology model was produced for the current study. However, parameters adopted for the previous models were considered for model validation. This study will produce flood intelligence information for use in emergency management, assess the current flood impact/exposure in terms of annual average damages caused by flooding in Newstead, investigate structural and non-structural mitigation options and make recommendations for establishing a flood warning system for the town.

This report is one of a series documenting the outcomes for the Newstead Flood Study. Each reporting stage is shown below:

R01 – Data Review and Validation Report – Draft published 26 June 2024

R02 – Hydrology Report – This report

R03 - Draft Hydraulic Modelling Report

R04 – Final Hydraulic Modelling Report

R05 - Design Modelling and Mapping Outputs

R06 – Municipal Flood Emergency Plan (MFEP) Documentation

R07 – Flood Damage and Structural Mitigation Options

R08 – Final Project Report

This report details the hydrologic modelling undertaken as part of the study. The report describes the hydrology model build, calibration process, and key modelling outputs for the existing conditions. It also details the Flood Frequency Analysis (FFA) undertaken for the Loddon River at Newstead gauge (Station ID: 407215).

1.2 Objectives and outputs

The Newstead Flood Study outputs are required to meet several floodplain management objectives as highlighted in the project brief prepared by MASC. The objectives of the investigation are described below:

¹ SKM, 2012 *Cairn Curran Dam: Flood Hydrology Update*

² HARC, 2020 *Guildford Rapid Flood Risk Assessment - North Central CMA Region*, prepared for North Central CMA



- Undertake hydrologic and hydraulic modelling to determine flood levels and flood extents for the full range of flood events up to and including the probable maximum flood.
- Calibrate models to historic flood events including the October 2022 flood event.
- Investigate modelling of climate change scenarios.
- Assess the feasibility of a range of potential mitigation options including understanding of the level of protection provided by the existing levee and information to inform necessary upgrades to this levee.
- Analyse the feasibility of establishing effective flood warning, accounting for time available between rainfall and the township flooding, in the context of a total flood warning system.
- Update flood intelligence to be incorporated into the Municipal Flood Emergency Plan.
- Provide recommendations to update the Planning Scheme and ensure it is informed by the best available flood information.

1.3 Study area

The main flood risk in Newstead is posed by the Loddon River, a levee was constructed in the 1920's that is still protecting the eastern portion of the township from Loddon River flooding. However, a number of smaller catchments generate runoff towards Newstead directly or indirectly, resulting in complex hydrologic and hydraulic conditions to address in planning and emergency response. These catchments include Mia Mia Creek, Muckleford Creek, Larni Barramal Yaluk, Green Gully and Green Gully Creek as shown in Figure 1-1. Additionally, there are several tributaries joining the Loddon River near Newstead further impacting river levels.

Newstead most recently experienced flooding in October 2022, causing flooding to the township located on the western side of the Loddon River. Flooding in Newstead has historically caused levee breaches which were mitigated by sandbagging. Flooding of the Loddon River also leads to the town being isolated when major traffic routes have been cut off. The Loddon River at Newstead has been subject to considerable physical and ecological modifications due to extensive historic mining activities and other anthropogenic influences since European settlement. In recent years, bank erosion has been an issue for landholders adjacent to the Loddon River.

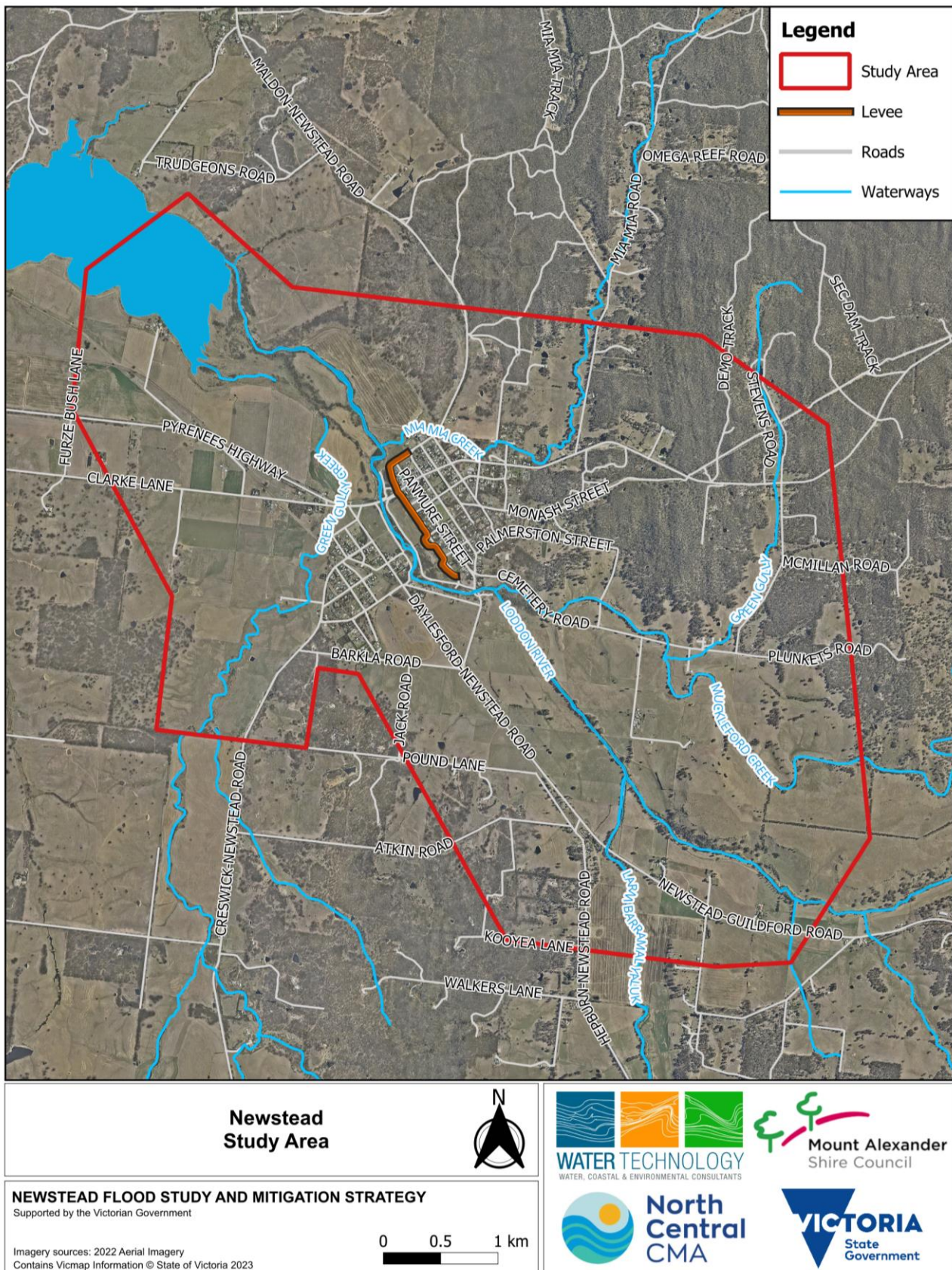


Figure 1-1 Newstead Study Area



2 MODELLING METHODOLOGY

A hydrologic/hydraulic modelling approach has been adopted to investigate flood risk in Newstead, utilising RORB and TUFLOW software modelling packages. Catchment hydrology has been simulated in a hydrologic (RORB) model with hydrographs extracted from the RORB model and will be applied to the hydraulic (TUFLOW) model to simulate flows through the study area and determine the resultant flood levels, depths, velocities and hazard associated with various historic and design event magnitudes including climate change scenarios.

The catchment has multiple historic and active stream gauges which have been utilised in hydrology model calibration. A number of rain gauges, both daily and sub-daily, exist within and around the catchment which provide historic rainfall distribution. A separate hydrologic calibration and validation approach was adopted for the study, whereby the hydrologic model was primarily calibrated to recorded flows at the most relevant gauge (Loddon River at Newstead), and secondarily to other streamflow gauges. Flows produced by the hydrologic model will then be applied to the hydraulic model and model parameters adjusted until agreement between surveyed and modelled flood levels is achieved.

The October 2022 flood event is the largest recorded event on the Loddon River within the period of continuous recording of river heights, with the Loddon River at Newstead gauge recording a peak height of 6.12 metres (214.06 mAHD). The rating table of the Loddon River at Newstead gauge was compared to results of hydraulic modelling of the gauge site, indicating a close match for high flows above gaugings (within the extrapolated region of the rating table). Therefore, given the close alignment, further investigation into the rating table was not required this project and the rating table information was considered suitable to use in the establishment of design flows. The rating curve review is detailed in the Data Review and Validation Report³

A Flood Frequency Analysis (FFA) was completed for the Loddon River at Newstead gauge in line with the method recommended by ARR2019⁴, utilising the series of annual maximum flows.

Design flood flows were modelled in the RORB hydrological model, taking into account the temporal and spatial patterns of design rainfall provided by ARR2019 and design depths provided by the Bureau of Meteorology. Model parameters were adjusted to reconcile flows with the FFA results to ensure unbiased flows were produced for the design scenarios.

Based on the most recent climate change recommendations provided in ARR Book 1 Chapter 6⁴, the Intensity-Frequency-Duration (IFD) data provided by the Bureau of Meteorology were adjusted to represent near-term climate change rainfall for the year 2030.

³ Water Technology, 2024 *Data Review and Validation Report - Newstead Flood Study and Mitigation Strategy*, prepared for Mount Alexander Shire Council

⁴ Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni, 2019 *Australian Rainfall and Runoff: A Guide to Flood Estimation*, prepared for the Commonwealth of Australia



3 FLOOD FREQUENCY ANALYSIS

Table 3-1 lists the streamflow gauges within the Upper Loddon River catchment. The Loddon River at Vaughan gauge has the longest record from the current gauging system, and an even longer record from the Victorian surface water information records to 1987⁶ (Blue Books) – which extends the period of record back to 1947. However, this gauge is located 15 km upstream of Newstead and several main tributaries that influence flooding in Newstead enter the Loddon River downstream of it. Therefore, a flood frequency analysis (FFA) was completed for the Loddon River at Newstead (407215).

Table 3-1 Streamflow gauges information

Station Name	Station No.	Start	End
Loddon River @ Newstead	407215	1973	Current
Larni Barramal Yaluk @ Yandoit	407221	1973	
Loddon River @ Vaughan D/S Fryers Creek	407217	1967	
Muckleford Creek @ Muckleford North	407300	1993	

The analysis took into account of all available complete calendar years of data, from 1976 to 2023. The annual flow series utilised the annual maximum flow (ML/day) for each of the 48 years of data, see Table 3-2. The analysis was completed in the FLIKE software package as recommended by ARR2019. The annual series used data as published by DEECA on Victoria's Water Measurement Information System⁷ (WMIS). The raw data was considered fit for purpose based on the rating curve review undertaken during the data review phase of the Newstead Flood Study.

Table 3-2 Adopted annual flow series (Ordered by flow magnitude)

Year	Flow (ML/day)	Year	Flow (ML/day)	Year	Flow (ML/day)	Year	Flow (ML/day)
2022	74,986	1979	19,492	1989	4,344	1994	1,326
2011	62,251	1988	17,871	1976	3,886	2018	1,247
2016	52,836	1986	17,840	1997	3,798	2019	1,222
2010	49,759	1981	16,784	2020	3,212	2004	1,168
2000	49,335	1987	13,139	2021	2,663	2017	1,028
1993	26,846	1984	9,685	2013	2,378	2009	930
1995	25,135	1991	8,595	2005	2,281	2014	925
1990	23,759	1999	7,949	2003	2,227	1982	323
1996	23,710	2012	7,628	2007	2,146	2002	154
1983	21,490	1985	7,156	1998	1,800	2015	106
1978	21,194	1977	7,084	2023	1,756	2008	102
1992	20,475	1980	6,905	2001	1,344	2006	100

A number of data sources were used to identify major flood events at Newstead outside of the gauge record, including:

⁶ Rural Water Commission of Victoria, 1990 *Victorian surface water information to 1987*

⁷ <https://data.water.vic.gov.au/>



- The extended record for Loddon River at Vaughan D/S Fryers Creek
- Historic flood events described in the Newstead Local Flood Guides (SES)
- Historic newspaper articles and gazettes found on Trove

Table 3-3 summarises notable flood events in Newstead with non-gauged event flood heights estimated based on topography data and location.

Table 3-3 Major flood events at Newstead

Year	Source/stated levels	Gauge height at Newstead gauge (m)
1890	900 mm depth at old Post Office (22 Lyons Street) (SES)	~6.4
1909	Flooding was 1.2 metres high for two blocks on both sides of the main street and reached the steps of the bank building (27 Lyons Street) (SES)	~5.9
1934	The water of the Loddon River at Newstead was within 300mm of the top of the levee bank. (SES)	~5.6
1942	Loddon at Newstead was the highest it's been for 12 years (Trove)	
2000	WMIS	5.64
2010 (Sept)	WMIS	4.91
2010 (Nov)	WMIS	5.63
2011	WMIS	5.89
2016	WMIS	5.70
2022	WMIS	6.12

** Estimated heights in italics*

The available information presented in Table 3-3 indicates that no major flood event occurred in Newstead between 1942 and 2000. This was further supported by analysing annual maximum flows for the extended record for Loddon River at Vaughan and comparing to the annual series at Newstead, see Figure 3-1. Whilst there are several major tributaries of the Loddon River downstream of Vaughan, Figure 3-1 shows that the major flood events in 2000, 2010, 2011, 2016 and 2022 were also the largest recorded at Vaughan since 1947.

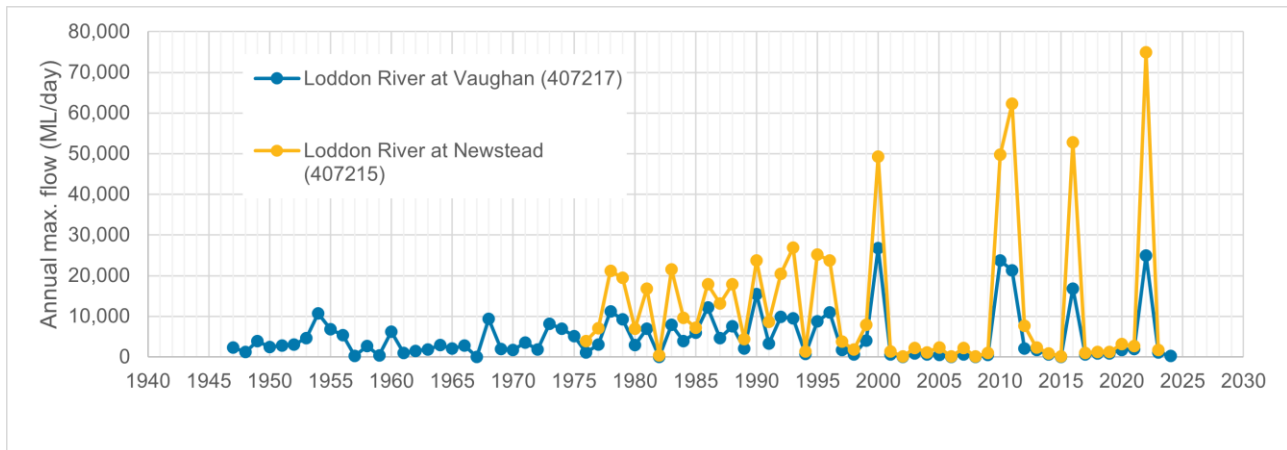


Figure 3-1 Annual maximum flows at the two Loddon River gauges at the two Loddon River gauges

The following assumptions were made for the purpose of the FFA:

- 1934 had a flood event of a similar magnitude to the event in 2010 (~50,000 ML/day).
- No events larger than the 1942 flood event occurred in the 12 years prior. Therefore the 1942 flood referred to in the news articles can be assumed to be:
 - Larger than the 1934 flood but could not have overtopped the levee as that would have likely generated greater media attention.
 - A peak flow of at least 50,000 ML/day.
- This means two events larger than 50,000 ML/day occurred between 1930 and 1942.
- No events above 50,000 ML/day occurred between 1947 and 1974.
- No assumptions can be made for the years between 1942 and 1947.
- Years prior to the construction of the Newstead Levee in the 1920s were excluded since this would have altered the flow-height relationship at the gauge location.

The above assumptions were incorporated into FLIKE as years above and below threshold.

Utilising FLIKE's built in multiple Grubbs Beck test did not identify any low flow years for censoring. Sensitivity testing of low flow thresholds was undertaken to achieve a better fit in the low-flow region. However, this showed limited improvement to the low flow match while causing large increases to the 1% AEP flows and events of greater magnitude. Hence, no low flows were censored. The following distributions were tested, with the Log Pearson III distribution providing the best fit to the observed data:

- Log Pearson III
- Generalised Extreme Value
- Log Natural
- Generalised Pareto

A graph of each distribution and the observed values is shown in Figure 3-2 to Figure 3-5 below. The adopted FFA quantiles are shown in Table 3-4. The five largest flood events since records began were compared against the design FFA distribution to assign an approximate AEP (as defined by the FFA) to each event in Table 3-5 below.



Table 3-4 Adopted FFA quantiles for Loddon River at Newstead (407215)

AEP	Peak Design Flow (ML/day)		
	Log Pearson III	LPIII 5% Limit	LPIII 95% Limit
20%	20,638	14,452	29,102
10%	36,025	26,191	49,919
5%	53,705	39,186	79,116
2%	79,173	55,276	137,209
1%	99,160	65,095	201,266
0.5%	119,188	72,681	283,411
0.2%	145,076	79,561	419,829
0.1%	163,859	83,142	552,890
0.05%	181,745	85,822	717,537

Table 3-5 Approximate AEP of 5 largest recorded events (based on FFA)

Year	Gauge Height (m)	Flow (ML/day)	Approximate AEP
October 2022	6.12	74,986	Between 2% and 5%
January 2011	5.89	62,251	Between 2% and 5%
September 2016	5.70	52,836	Between 5% and 10%
November 2010	5.63	49,759	Between 5% and 10%
October 2000	5.64	49,335	Between 5% and 10%

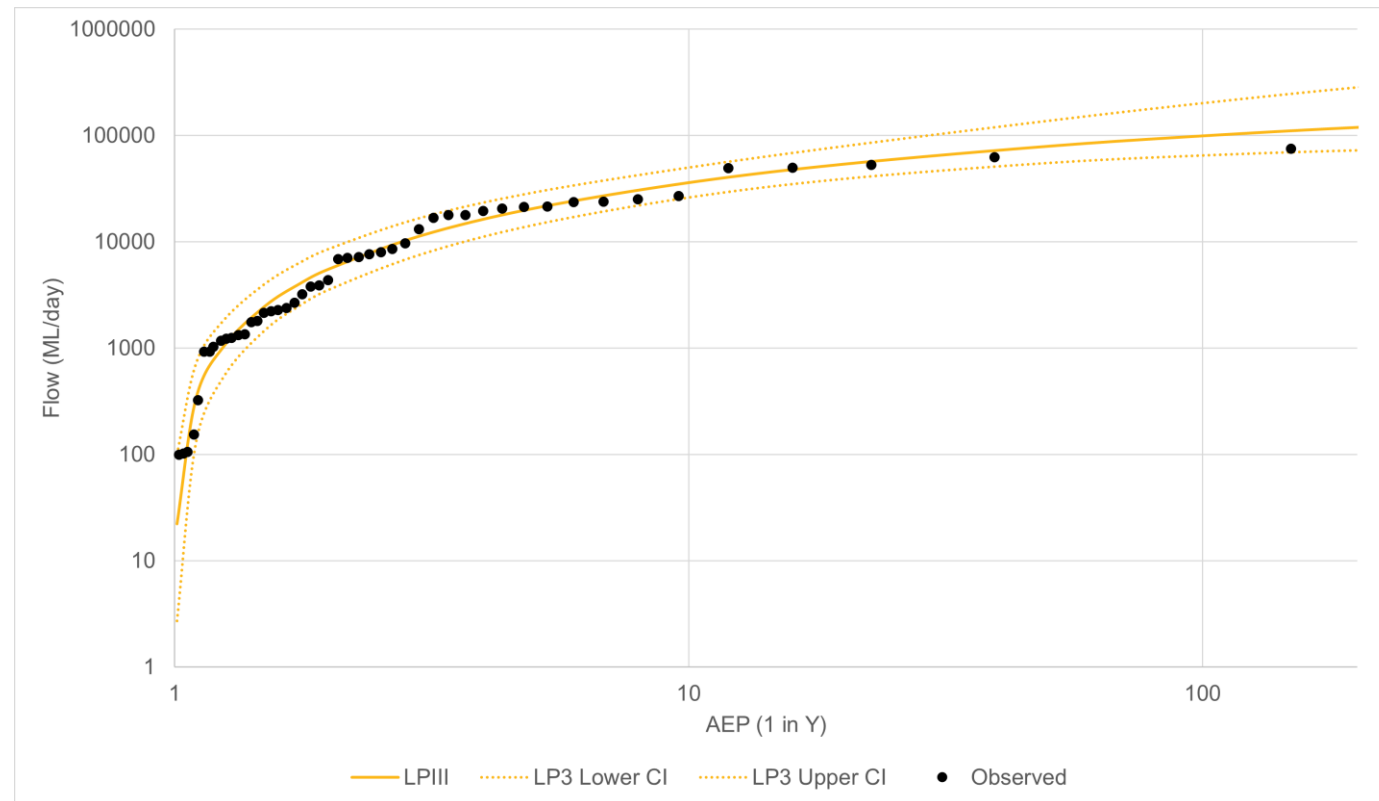


Figure 3-2 FFA: Log Pearson III Distribution

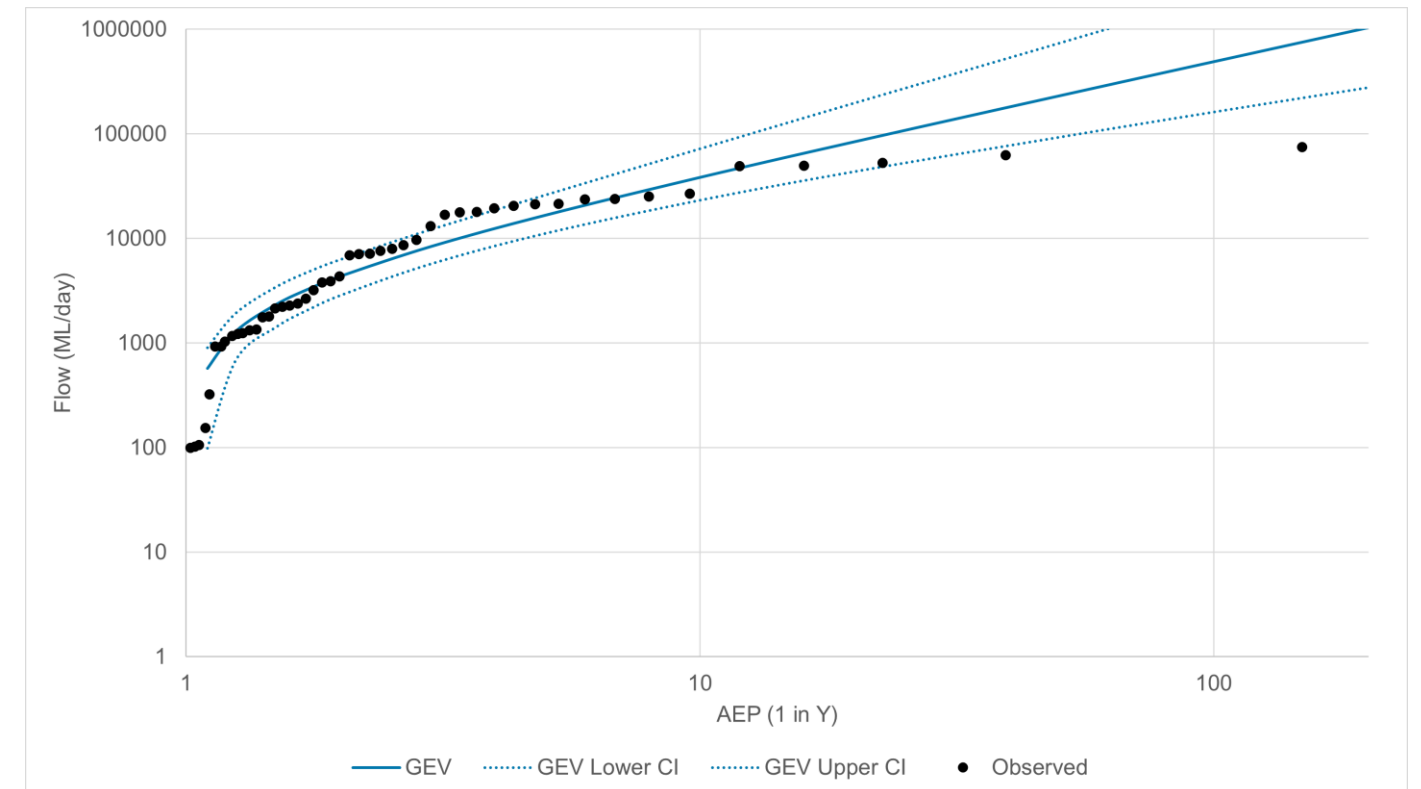


Figure 3-3 FFA: Generalised Extreme Value Distribution

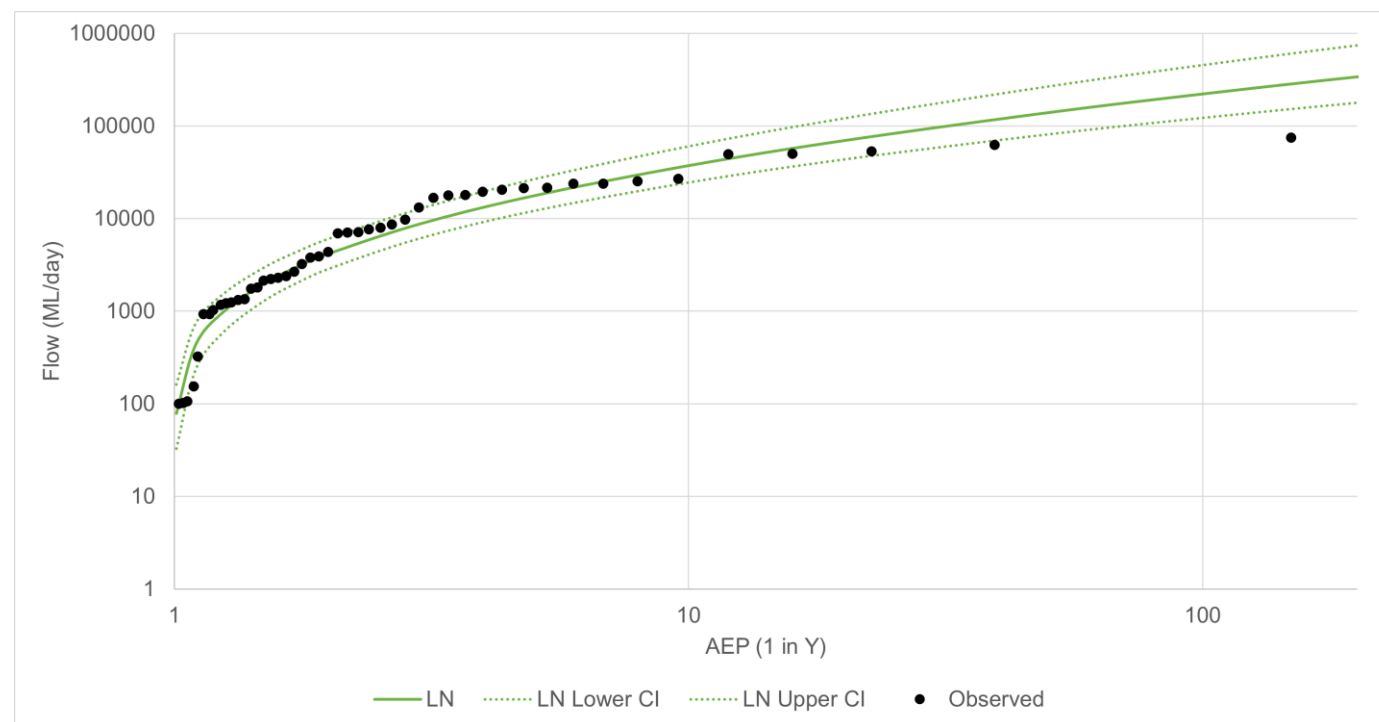


Figure 3-4 FFA: Log Natural Distribution

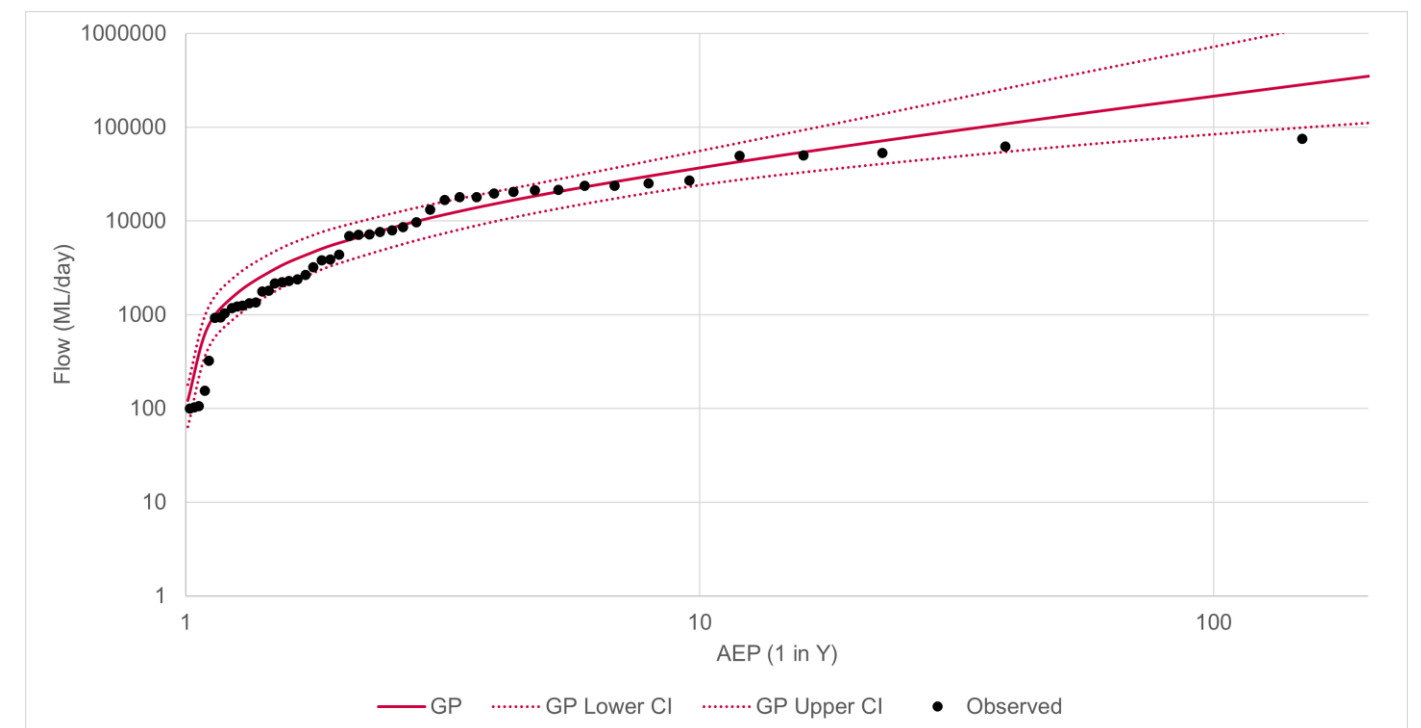


Figure 3-5 FFA: Generalised Pareto Distribution



4 RORB MODEL SETUP

4.1 Overview

A hydrologic model of the Upper Loddon River catchment to the outfall in Cairn Curran Reservoir was developed for this study. Modelling utilised RORB, a rainfall-runoff modelling software package to determine flow hydrographs at specific locations within the catchment (i.e. gauges) and at the upstream extent of the hydraulic model.

RORB is a non-linear rainfall-runoff and streamflow routing model used for the calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reaches and storage areas. Observed or design storm rainfall is input to each subarea. Initial and continuing losses are then deducted, and the excess runoff is routed through the reach and storage network to produce streamflow hydrographs at selected locations within the model (referred to as “print” locations).

4.2 Model setup

4.2.1 Subarea and reach delineation

Topographic data which was utilised in the RORB model construction came from the VicMap 10m resolution Digital Elevation Model (DEM). The DEM has a stated horizontal accuracy of 12.5 metres and a vertical accuracy of 5 metres. While the 10m resolution DEM is not suitable for 2-dimensional hydraulic modelling at the level of resolution and accuracy required for this study, it is suitable for use in subarea and reach delineation for the hydrologic RORB model. In order to make the topographic data “hydrologically correct”, sinks (i.e. local depressions) were filled to allow a continuous flow path to form along the terrain.

Catchment and subarea delineation was produced using the SAGA GIS topographic processing capabilities in QGIS software. The overall delineation was deemed accurate and suitable after comparison against existing waterways and drainage paths. Manual subarea manipulation was undertaken to ensure print nodes were placed at gauge locations where required and subareas adjusted to maintain a similar subarea size across the catchment. Interstation areas were placed at the gauge locations throughout the catchment.

Reach lengths were determined using GIS software, following the hydrologically corrected topography in a continuous flow path to the outlet. Reaches were assigned as Type 1 (Natural) for overland flows and waterways. No storages were identified within the catchment. Type 2 (Excavated/Unlined), Type 3 (Lined/Piped) and Type 4 (Drowned) reaches were not used. The shapefiles were then imported to ArcRORB where the final data manipulations occurred and the RORB .catg file was produced. The model layout is shown in Figure 4-1.

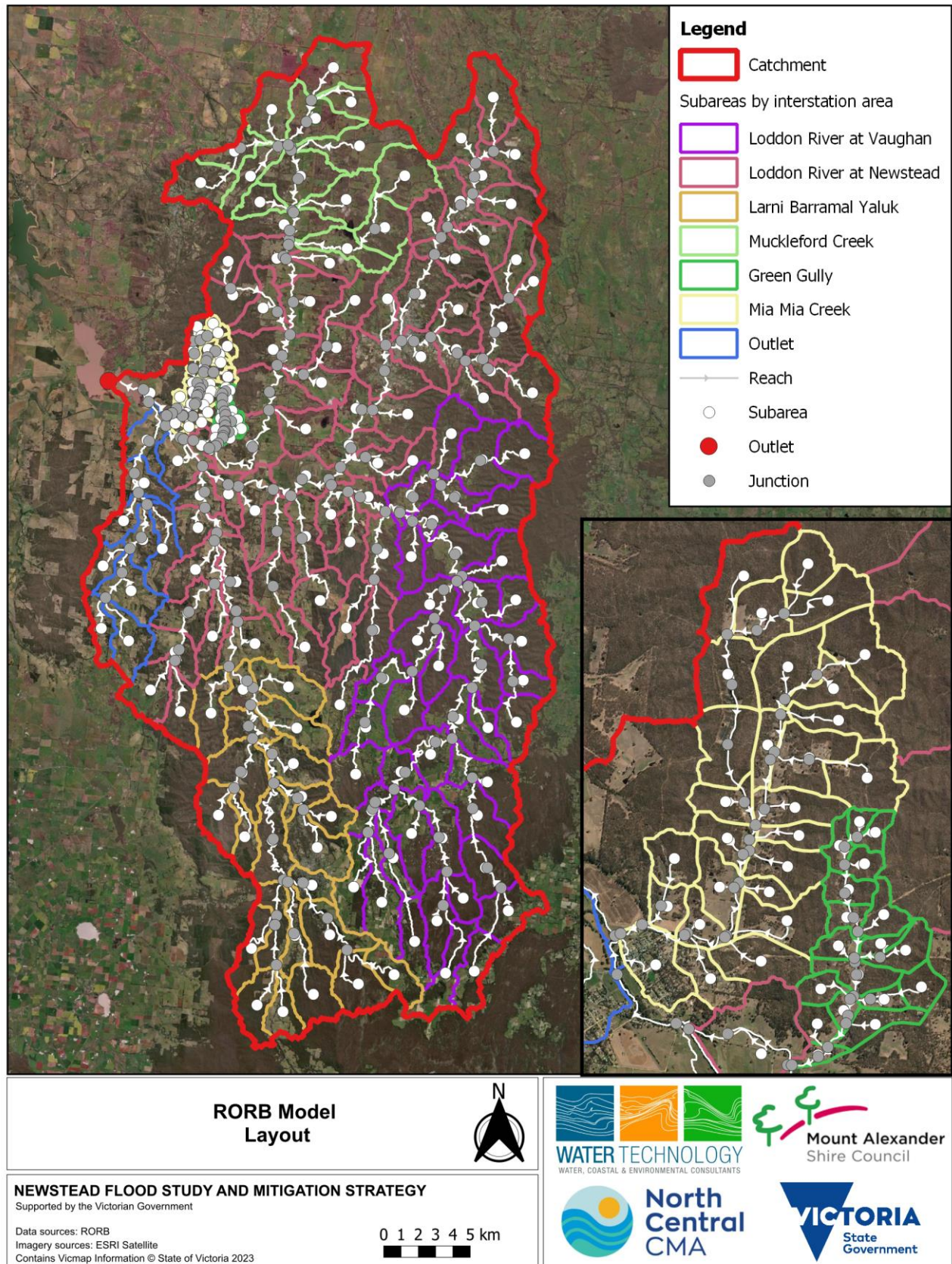


Figure 4-1 RORB model layout



4.2.2 Fraction impervious

A Fraction Imperviousness (FI) was added to each subarea using ArcRORB based on a GIS layer produced from the MASC planning scheme zoning. Inspection of aerial photography also informed some required changes where a typical FI value was inappropriate for the area. The catchment is predominately pervious surface with agricultural the main land use and a large portion of the upper catchment forested area. ARR2019 recommends the adoption of three types of imperviousness for urban areas: Directly Connected Impervious Areas (DCIA), Indirectly Connected Impervious Areas (ICIA) and Pervious Areas (PA). Given the majority of the catchment is pervious, the application of DCIA/ICIA was not adopted for the RORB modelling. Adoption of DCIA/ICIA would not be expected to influence results given the low impervious fractions throughout the catchment.

The adopted FI value for each land use type is shown in Table 4-1 and the FI spatial distribution is shown in Figure 4-2.

Table 4-1 Land use zones and fraction impervious

Zone	Fraction Impervious
Commercial Zone	0.5
Farming Zone	0.05
General Residential Zone	0.3
Industrial	0.5
Low Density Residential Zone	0.2
Neighbourhood Residential Zone - Schedule 1	0.3
Public Conservation and Resource Zone	0
Public Park and Recreation Zone	0.1
Public Use Zone - Service and Utility	0.05
Public Use Zone - Education	0.7
Public Use Zone - Health and Community	0.7
Public Use Zone - Cemetery/Crematorium	0.1
Public Use Zone - Local Government	0.6
Public Use Zone - Other Public Use	0.1
Rural Conservation Zone	0.05
Rural Living Zone	0.2
Special Use Zone - Various Schedules	0.1
Transport Zone – State transport infrastructure and Principal Road network	0.7
Transport Zone – Significant municipal road	0.6
Township Zone	0.3

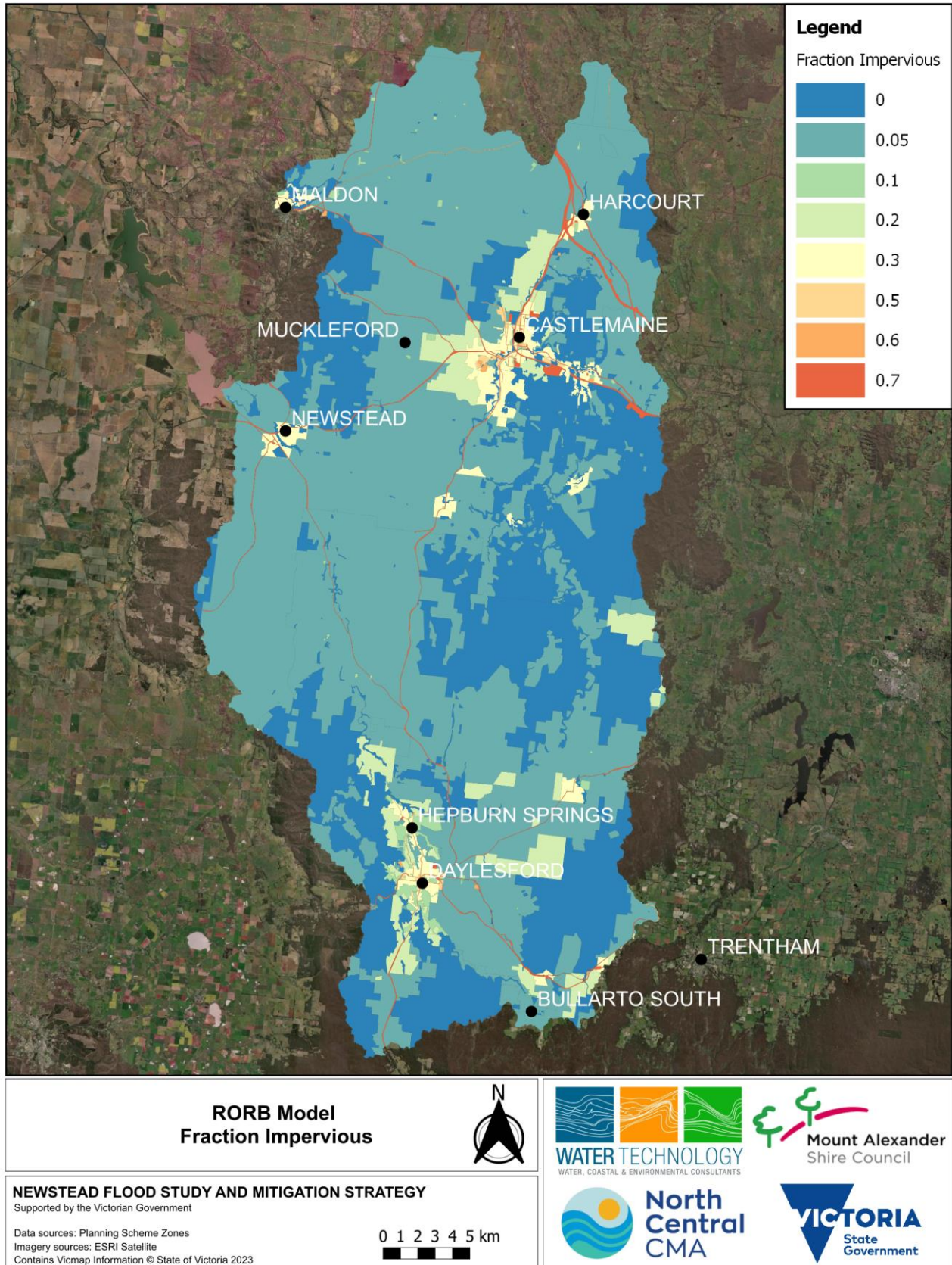


Figure 4-2 Adopted fraction impervious

5 RORB CALIBRATION/VALIDATION

5.1 Historic event rainfall

Daily and sub-daily rainfall stations within or near the catchment that had suitable records for modelling of historic events are shown in Figure 5-1. Table 5-1 details the daily rainfall stations utilised while Table 5-2 details the sub-daily rainfall stations utilised for modelling of the 2010, 2011, 2016 and 2022 events.

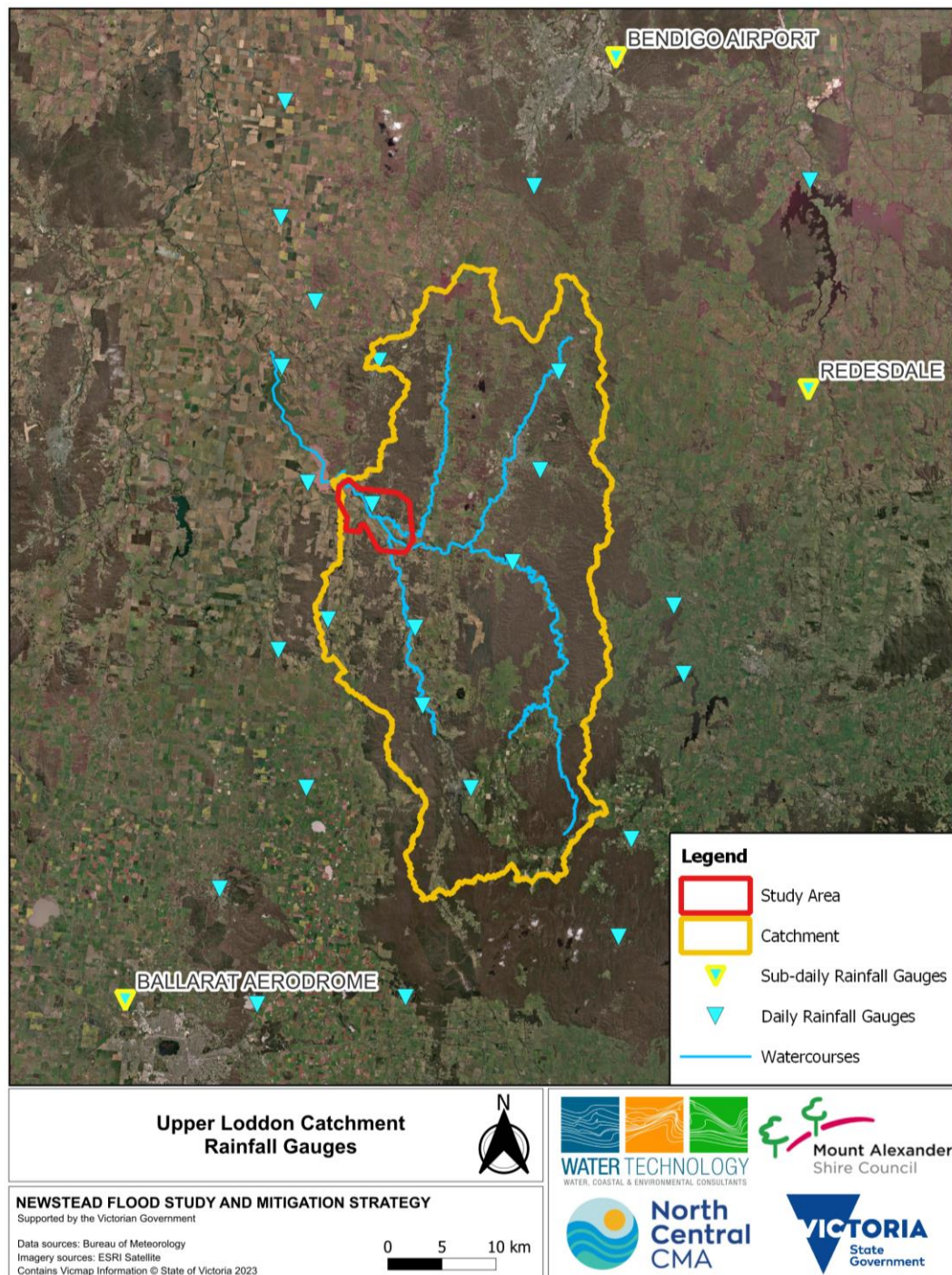


Figure 5-1 Upper Loddon River Rainfall Gauges



Table 5-1 Daily rainfall stations

Station Name	Dist. From Newstead	Station No.	Start	End
Newstead	0.6 km NE	088048	1897	Current
Joyce Creek	6.1 km NW	088032	1907	
Eberys	10.7 km SW	088021	1913	
Yandoit	11.6 km SE	088066	1901	2014
Maldon (Stump Rd)	13.6 N	088161	2005	Current
Vaughan	14.0 km SE	088108	1958	
Campbelltown	15.1 km SW	088011	1889	2011
Cairn Curran Reservoir	15.4 km NW	088009	1949	Current
Castlemaine Prison	16.1 km E	088110	1966	
Shepards Flat	18.6 km S	088054	1928	2023
Baringhup (Blue Hills)	19.4 km NW	088132	1972	2013
Harcourt	21.0 km NE	088188	1968	2016
Smeaton (Blampied (Bardia))	26.1 km SW	088113	1968	Current
Daylesford	27.2 km SE	088020	1867	
Eastville (Bonnie Banks)	28.0 km N	081092	1969	2016
Trentham (Post Office)	28.8 km SE	088059	1878	2017
Malmsbury Reservoir	29.3 km SE	088042	1872	Current
Sandhurst Reservoir	32.9 km NE	081121	1986	2012
Lauriston Reservoir	34.3 km NE	088037	1948	2017
Creswick	37.6 km SW	088019	1949	Current
Woodstock-On-Loddon	38.3 km N	081100	1970	
Redesdale	40.3 km NE	088051	1903	2017
Moorabool Reservoir	45.0 km S	087045	1912	2017
Blackwood	46.2 km SE	087017	1878	2015
Glen Park (White Swan Reservoir)	46.9 km S	089048	1953	Current
Eppalock Reservoir	50.9 km NE	081083	1965	

Table 5-2 Sub-daily Rainfall Stations

Site	Name	Start Date	End Date
81123	Bendigo Airport	Nov 1991	Current
89002	Ballarat Aerodrome	Jan 1960	Current
88051	Redesdale	Jan 1903	Current



Daily rainfall totals were summed over the duration of the events and a spatial distribution of total rainfall created by interpolating the rainfall totals with an inverse distance weighted distribution. The average rainfall over each subarea of the RORB model was then applied to that subarea.

Temporal distributions were derived from sub-daily records for the events and each subarea in the model was modelled with the temporal distribution of the closest sub-daily station.

5.2 Streamflow

There are a number of streamflow gauges within the catchment that have been used in calibration and validation of the hydrologic model. Streamflow gauges selected for use in the modelling are shown in Figure 5-2. While the project scope was to define flows at Newstead only, it was decided to include the additional gauges as part of the calibration process and aim to achieve a representative fit across the catchment more broadly where possible.

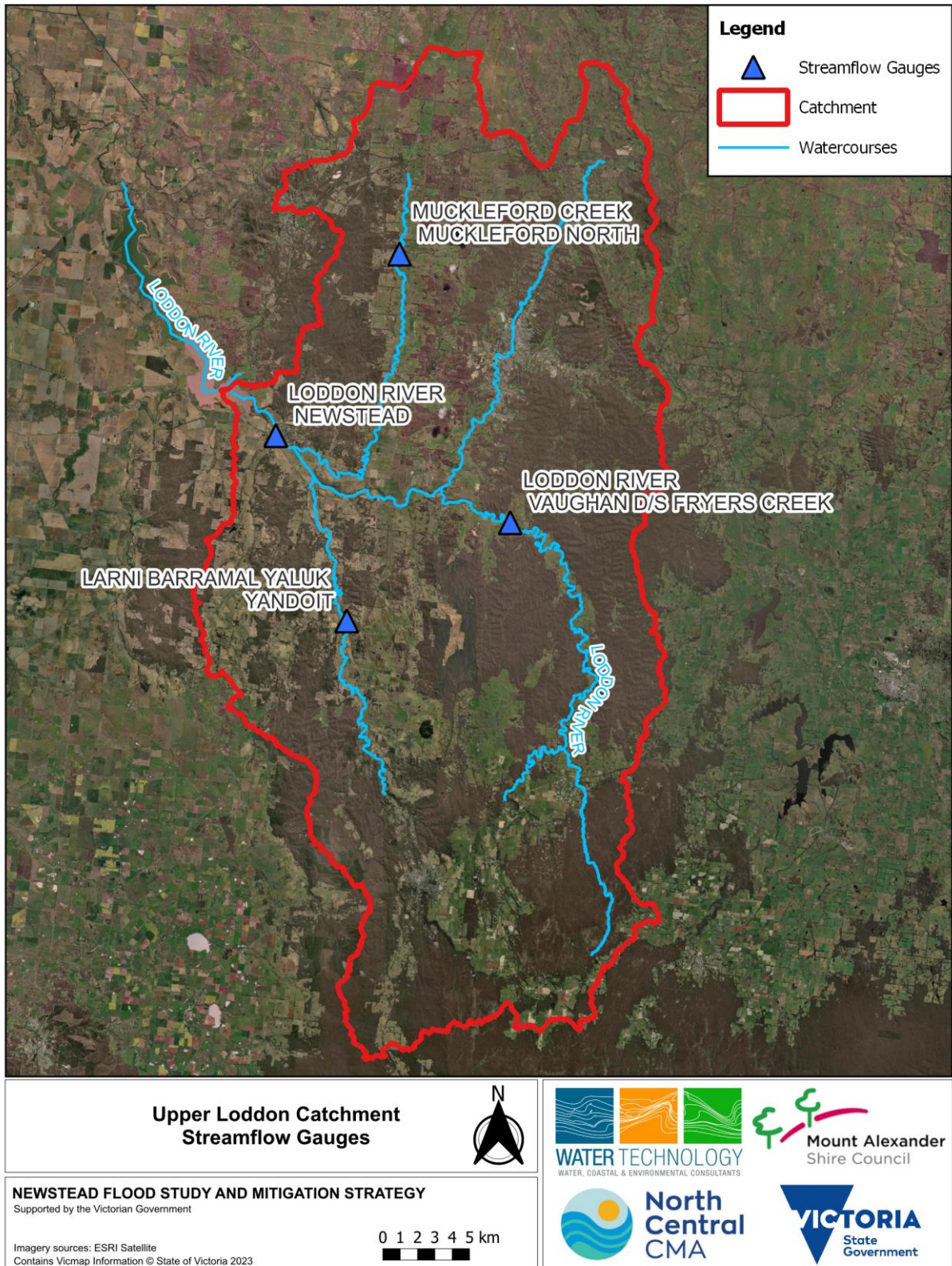


Figure 5-2 Utilised streamflow gauges



5.3 October 2022 calibration

Over a period of three days from 7am on the 12th of October until 9am on the 15th of October, significant rainfall occurred over the Loddon River catchment causing flooding along the Loddon River and its tributaries. The rainfall on extremely saturated catchments resulted in significant impacts in Newstead, along with widespread flooding across much of Victoria. The October 2022 event is the largest flood height recorded at the Loddon River at Newstead gauge. Resident recollections state that the Newstead levee was close to overtopping, which was prevented only by adding sandbags to several low points in the levee.

5.3.1 Rainfall

Rainfall totals recorded between 9am on the 11th of October until 9am on the 16th of October at rainfall stations near and within the Loddon River catchment are shown in Table 5-3 with the rainfall distribution and isopleths are shown in Figure 5-3.

Table 5-3 October 2022 rainfall totals (arrows represent accumulated rainfall)

Station	Station Name	Rainfall to 9am 12 th October (mm)	Rainfall to 9am 13 th October (mm)	Rainfall to 9am 14 th October (mm)	Rainfall to 9am 15 th October (mm)	Rainfall to 9am 16 th October (mm)	Total Rainfall (mm)
87017	Blackwood	0.4	41.4	43.8	5.5	1.2	92.3
88009	Cairn Curran Reservoir	0	22	39.6	0.8	0	62.4
88110	Castlemaine Prison	9.6	42	48	2.8	0	102.4
88020	Daylesford	0	85.8	29	0	0	114.8
88021	Eberys	0	40	34.6	2.4	0	77
88032	Joyces Creek	0	29.8	33	0.8	0	63.6
88037	Lauriston Reservoir	1	49.6	50.6	7.6	0.2	109
88161	Maldon Stump St	0.2	52.6	44.4	0.8	0	98
88042	Malmsbury Reservoir	0.2	46.4	55.6	2	0.2	104.4
88048	Newstead	0	30.8	34.8	3.2	0	68.8
88051	Redesdale	8.8	52.4	51.4	0	0	112.6
88054	Shepherds Flat	0	0	33	52	0	85
88113	Smeaton (Blampied (Bardia))	0	38	37.2	1.8	0	77
88108	Vaughan	→	41.2	41.6	5.4	0	88.2

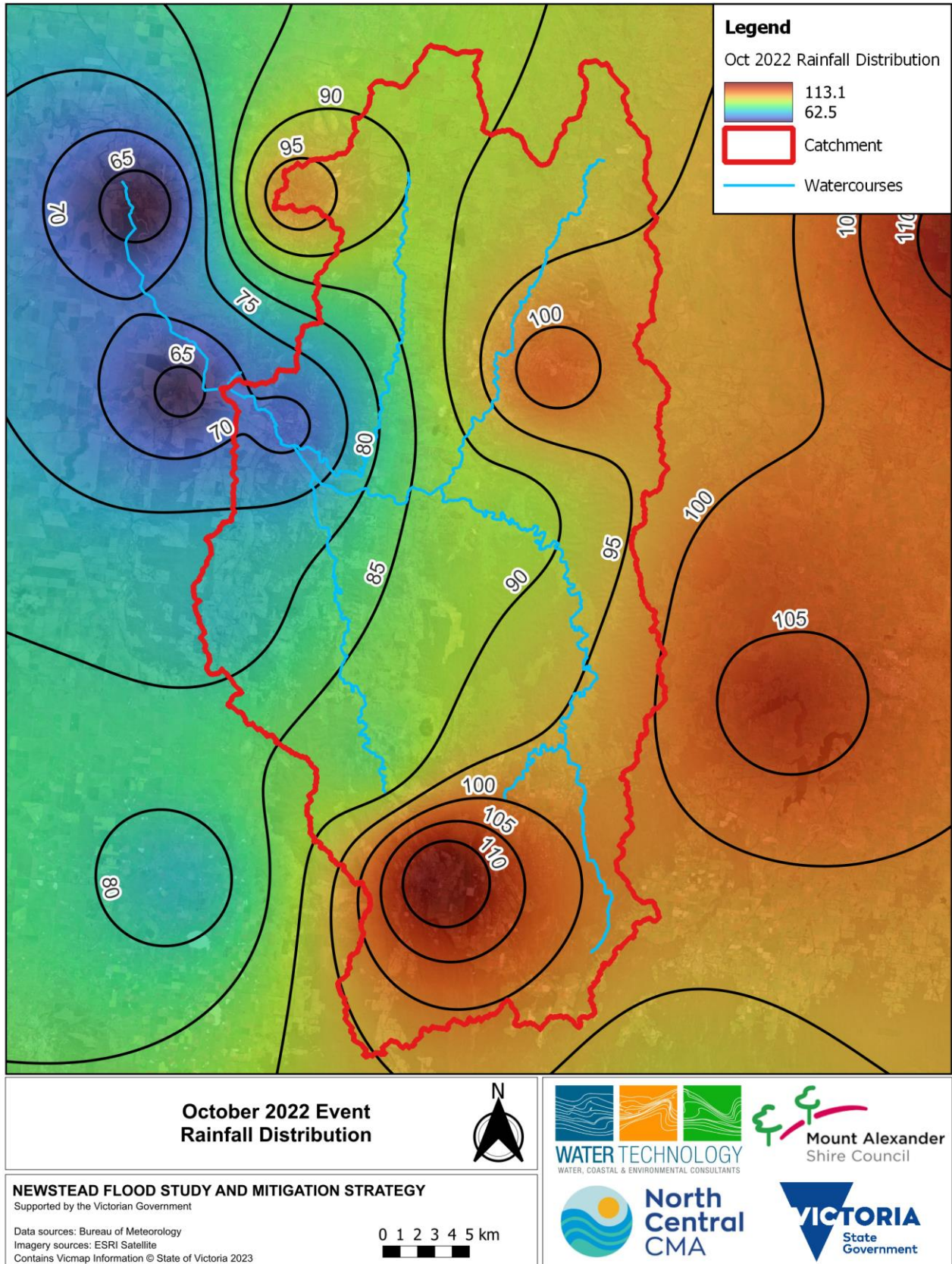


Figure 5-3 Rainfall distribution and isopleths for October 2022 event

For the temporal distribution of rainfall, sub-daily rainfall data from each of the sub-daily stations shown in Figure 5-1 were extracted in half hour increments. The rainfall pluviographs are provided in Figure 5-4.

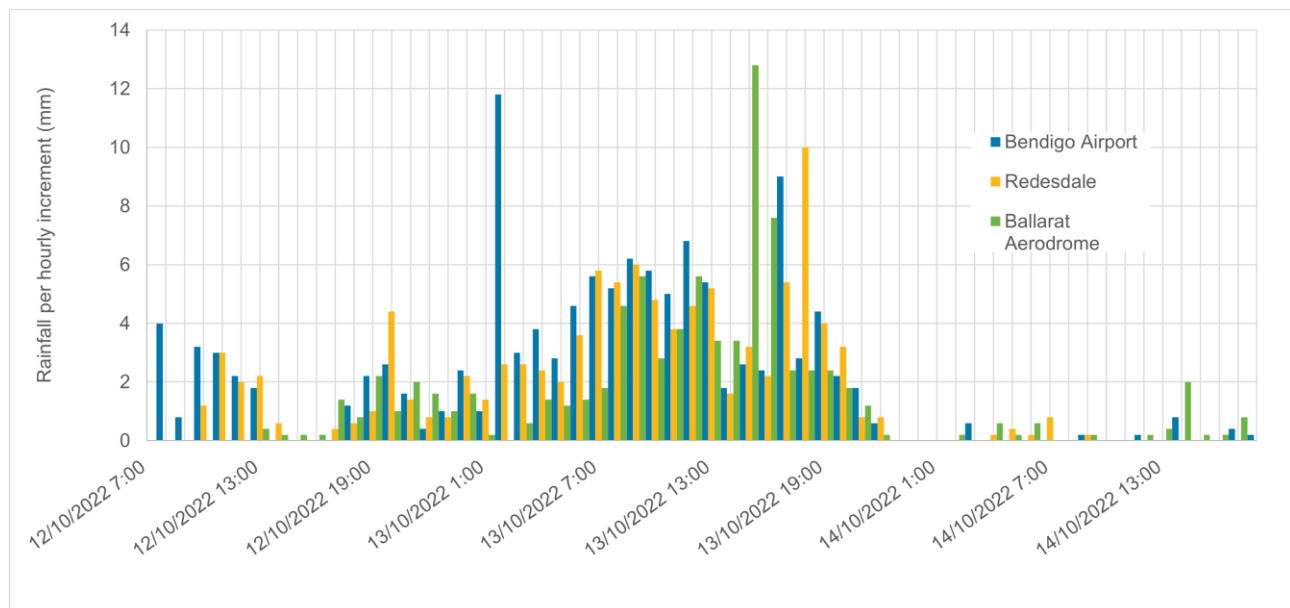


Figure 5-4 Hourly rainfall increments for the sub-daily rainfall stations from 7am 12 October 2022 to 6pm 14 October 2022

5.3.2 Streamflow

The RORB model was calibrated using an initial loss/continuing loss method. The m routing parameter adopted the recommended value of 0.8 in line with the RORB manual. The model adopted a single m across the full catchment but varied the value of k_c at each interstation area, with loss parameters adjusted to reach a level of agreement with the recorded peak flows at the streamflow gauges. K_c values were adjusted to match the shape and timing of the hydrograph at Newstead as closely as possible.

The K_c/D_{av} regional relationship suggested by Pearse et al⁸ was initially adopted as a starting point given the empirical derivation of this relationship from Victorian data. The value was then adjusted during calibration to better match recorded data. This varied K_c by interstation area based on differing average routing distance D_{av} . The model had interstation areas upstream of each gauge to enable a comparison between recorded and modelled flows. Interstations were also added downstream of smaller catchment areas where finer catchment delineation was required. Effort was made to maintain consistency of loss parameters where possible while still reaching an agreement between the modelled and recorded flows.

Streamflow from the October 2022 event is characterised by a single flood peak at each of the four gauging stations within the catchment. Aside from some minor timing delays for the smaller tributaries, the magnitude, shape and timing of the modelled hydrographs are generally acceptable (Figure 5-5).

K_c values derived from Pearse et al⁸ were retained for the Muckleford Creek and Green Gully interstation areas, as well as the catchment upstream of the model outlet. However, decreased values were required for the Loddon River, Larni Barramal Yaluk and Mia Mia Creek interstation areas to provide a closer fit to the recorded flows. Losses were kept almost uniform across the catchment, with initial loss values typical for this

⁸ Pearse, M., P. Jordan and Y. Collins (2002). A simple method for estimating RORB model parameters for ungauged rural catchments. Water Challenge: Balancing the Risks: Hydrology and Water Resources Symposium 2002., Institution of Engineers, Australia: Barton, A.C.T.: 128-134.



part of Victoria while the continuing loss values were relatively small likely due to the antecedent conditions where the catchment was considered to be saturated. The calibration result is deemed to be acceptable given the strong agreement between the modelled and calculated hydrographs, particularly at the Newstead gauge for which this event shows the strongest calibration. A good calibration at this gauge is key in the current study.

The adopted calibration parameters are shown in Table 5-4.

Table 5-4 October 2022 RORB calibration parameters

Interstation Area/Gauge	K _c	m	IL (mm)	CL (mm/hr)
407217 Loddon River at Vaughan (d/s Fryers Creek)	18	0.8	18	0.75
407221 Larni Barramal Yaluk at Yandoit	21.98		18	0.75
407300 Muckleford Creek at Muckleford North	12.46		18	0.75
Green Gully interstation	3.12		18	0.75
407215 Loddon River at Newstead	19.51		20	0.5
Mia Mia Creek interstation	4.32		18	0.75
Catchment outlet	17.47		18	0.75

Calibration result statistics for the October 2022 flood event are summarised in Table 5-5 below. The modelled and recorded streamflow for the event are shown in Figure 5-5 for each streamflow gauge.

Table 5-5 October 2022 calibration statistics

Interstation Area/Gauge	Peak Discharge Absolute Error (m ³ /s)	Peak Discharge % Error	Time to Peak Absolute Error (hrs)	Volume % Error
407217 Loddon River at Vaughan (d/s Fryers Creek)	6.5	2.3	3.0	-0.4
407300 Muckleford Creek at Muckleford North	6.97	7.7	-4.0	3.3
407221 Larni Barramal Yaluk at Yandoit	20.6	13.4	5.0	-10.5
407215 Loddon River at Newstead	15.6	1.8	1.0	-4.1

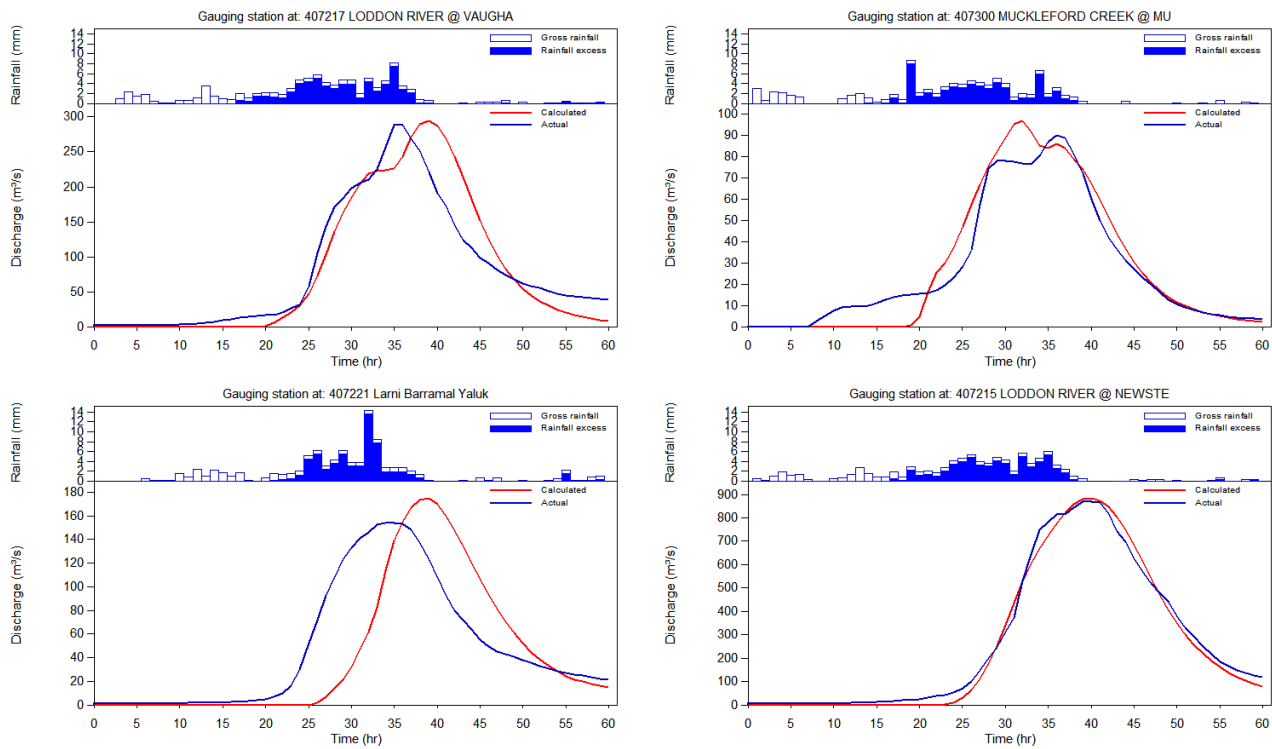


Figure 5-5 Modelled and recorded stream gauges, October 2022 event



5.4 September 2016 calibration

Widespread heavy rainfall across Victoria and Southeastern Australia during September continued a sequence of wet months which began in May as the 2015–16 El Niño event broke down. It was the second-wettest September on record for Australia (as a whole) at the time. The heavy September rainfalls, combined with catchments which were considered saturated as a result of above-average winter rainfall, resulted in substantial flooding in many regions. Rainfall which resulted in flooding at Newstead continued for almost 10 days, from midnight between 8th and 9th of September until midday 18th of September. The entirety of the event has been considered as part of the hydrology assessment.

5.4.1 Rainfall

Rainfall totals recorded between 9am on the 8th of September until 9am on the 19th of September at stations near and within the Loddon River catchment are shown in Table 5-6 with the rainfall distribution and isopleths are shown in Figure 5-6.



Table 5-6 September 2016 rainfall totals (arrows represent accumulated rainfall)

Station	Station Name	Rainfall to 9 am (mm)											Total Rainfall (mm)
		9 th Sep	10 th Sep	11 th Sep	12 th Sep	13 th Sep	14 th Sep	15 th Sep	16 th Sep	17 th Sep	18 th Sep	19 th Sep	
88009	Cairn Curran Reservoir	22.8	6.4	0	0.4	22.4	57.2	11	0.4	0.2	0.8	0	121.6
88110	Castlemaine Prison	33	12	0.5	0.4	17	53	14.6	0.8	0	1.6	0	132.9
88020	Daylesford	37.6	→	27.2	→	13.2	65.6	20.4	2.2	0	0	0	166.2
88021	Eberys	31.4	7.8	0.4	0	17.4	53.6	10.8	0	0	0	0	121.4
88118	Harcourt	27.8	10	0	2	20.8	62.8	21.6	0	0	2.4	0.6	148
88032	Joyces Creek	25.6	4.6	0	0	25	51.2	14	0	0	0.6	0	121
88037	Lauriston Reservoir	17.8	21.2	0.2	0.8	13.4	55.2	23.6	0.2	0.4	0.4	0	133.2
88161	Maldon Stump St	27.4	7.2	0	0.8	23.6	49.2	9.2	1.8	0	0	0	119.2
88042	Malmsbury Reservoir	17.4	21.8	0.4	0.4	11.2	53.8	21.2	0.2	1	0.6	0.6	128.6
88048	Newstead	27.4	5	0.8	0.2	21.6	55.6	12.4	0.4	0	0.8	0	124.2
88054	Shepherds Flat	→	55	0	0	23.2	51	14.8	0	0	0	0	144
88113	Smeaton (Blampied (Bardia))	25	11.8	0	1.6	16.6	64	8.4	0.8	0	0	1.4	129.6
88059	Trentham Post Office	31	11.9	0	2.2	19.8	60.8	18.6	0.6	0.4	0	0.8	146.1
88108	Vaughan	30	14.8	0	0	14	54.8	18.4	0.8	0.4	0	0.8	134
87045	Moorabool Reservoir	34	16.2	0.4	3	18.6	49.6	12.2	2	0.4	2.8	1.6	140.8
89048	Glen Park (White Swan Reservoir)	37	20.4	0.6	6.2	20.8	51.2	14.4	2.4	0.4	3.4	1.2	158
88019	Creswick	38	23	1	2	→	69	1.5	1	0	3	0	138.5
81100	Woodstock-On-Loddon (Alexandra Park)	23	7	0	0	24	66	10.2	0	0	2	0	132.2
81092	Eastville (Bonnie Banks)	24.4	4.2	0	0	33.6	52.6	12.2	0	0	1.2	0	128.2
81083	Eppalock Reservoir	14.6	8.6	0	0	16.4	34	11.4	0.2	0	2	4.4	91.6
81123	Bendigo Airport	22.6	5	0	0	20	43.8	12.8	0	0	3.2	1.6	109

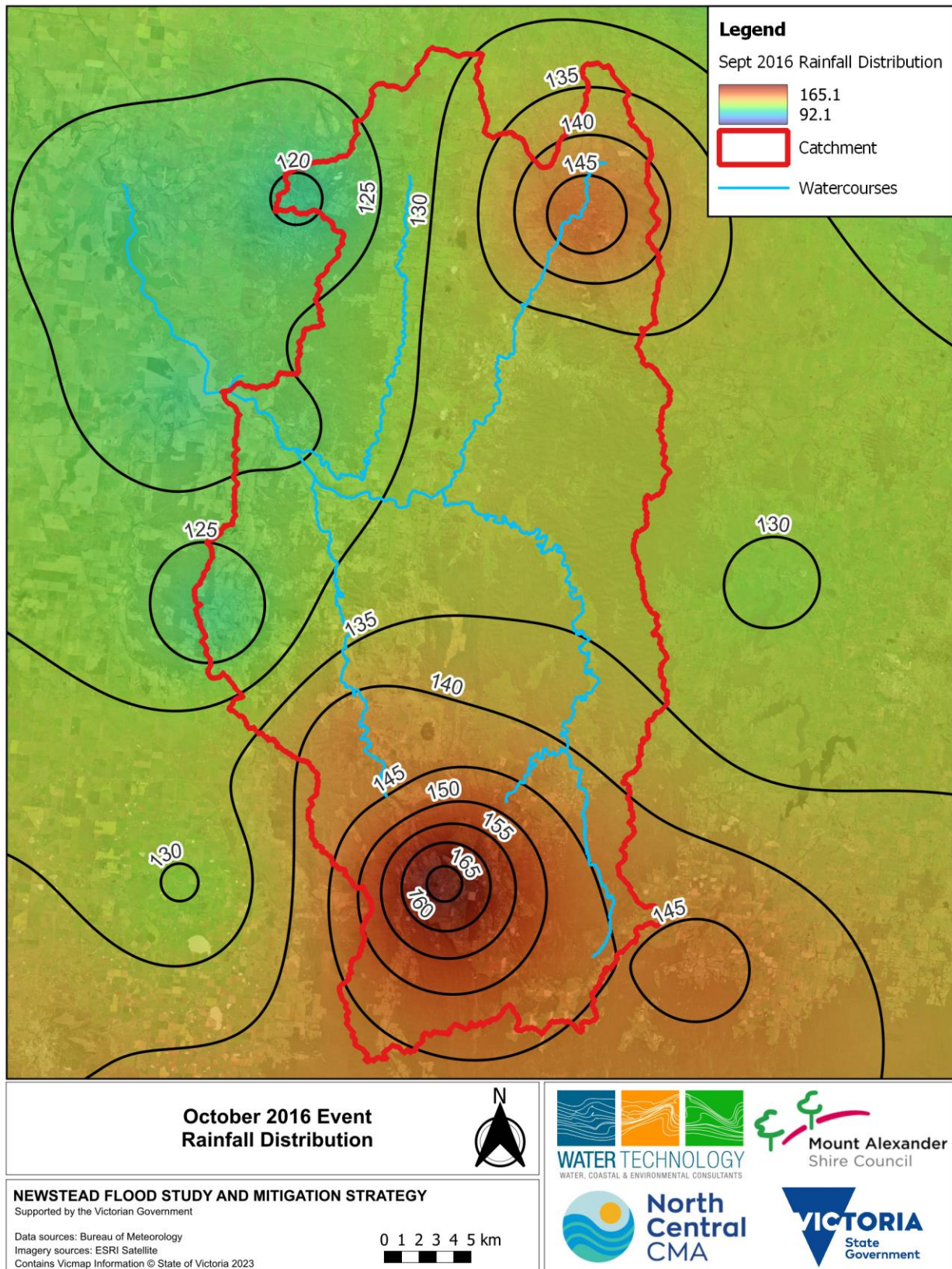


Figure 5-6 Rainfall distribution and isopleths for September 2016 event



For the temporal distribution of rainfall, sub-daily rainfall data from each of the sub-daily stations shown in Figure 5-1 were extracted in half hour increments. Note that there was no sub-daily rainfall record from the Redesdale station. The rainfall pluviographs are provided in Figure 5-7.

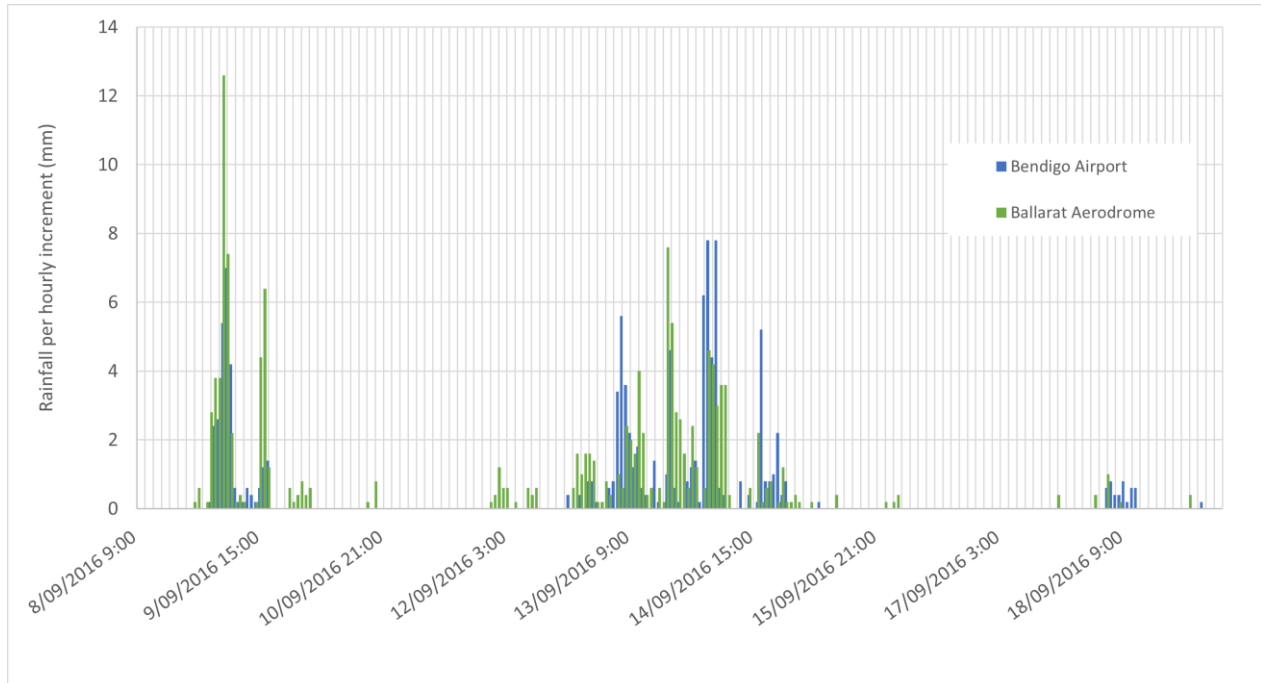


Figure 5-7 Hourly rainfall increments for the sub-daily rainfall stations from 9am 8 September 2016 to 9am 19 September 2016

5.4.2 Streamflow

The RORB model was calibrated using an initial loss/continuing loss with a similar approach as adopted for the October 2022 event, using a single rainfall burst. Streamflow for the September 2016 event is characterised by an initial, smaller peak around midnight between the 9th and 10th of September followed by a sharper and taller second peak around the 14th September with the peak at Newstead occurring at 1400 hours on the 14th September. Hydrograph timing and peak values were well represented by the model at all gauging stations. The total discharge volumes were underestimated at three out of four gauging stations. This is likely a result of the long duration of the event, causing minor fluctuations in the hydrograph not captured by the model.

K_c values determined for the October 2022 calibration were retained, and losses were kept almost uniform across the catchment. Larger initial and continuing loss values were required compared to the October 2022 event to get a suitable fit. The higher losses are expected due to the extremely saturated nature of the catchment in October 2022, while it is noted that the September 2016 event did occur on a relatively wet catchment.

The calibration result is deemed to be acceptable given the strong agreement between the modelled and calculated hydrograph peak values and timing, particularly at the Newstead gauge.

The adopted calibration parameters are shown Table 5-7.



Table 5-7 September 2016 RORB calibration parameters

Interstation Area/Gauge	K _c	m	IL (mm)	CL (mm/hr)
407217 Loddon River at Vaughan (d/s Fryers Creek)	18	0.8	30	1.75
407221 Larni Barramal Yaluk at Yandoit	21.98		30	0.25
407300 Muckleford Creek at Muckleford North	12.46		30	2.75
Green Gully interstation	3.12		30	1.75
407215 Loddon River at Newstead	19.51		30	1.75
Mia Mia Creek interstation	4.32		30	1.75
Catchment outlet	17.47		30	1.75

Calibration result statistics for the September 2016 flood event are summarised in Table 5-8 below. The modelled and recorded streamflow for the event are shown in Figure 5-8 for each gauge modelled.

Table 5-8 September 2016 calibration statistics

Interstation Area/Gauge	Peak Discharge Absolute Error (m ³ /s)	Peak Discharge % Error	Time to Peak Absolute Error (hrs)	Volume % Error
407217 Loddon River at Vaughan (d/s Fryers Creek)	19.6	10.1	-1.0	-40.6
407300 Muckleford Creek at Muckleford North	3.2	4.7	-8	-5.3
407221 Larni Barramal Yaluk at Yandoit	-9.9	-8.3	2.0	0.4
407215 Loddon River at Newstead	-19.7	-3.2	0.0	-17.0

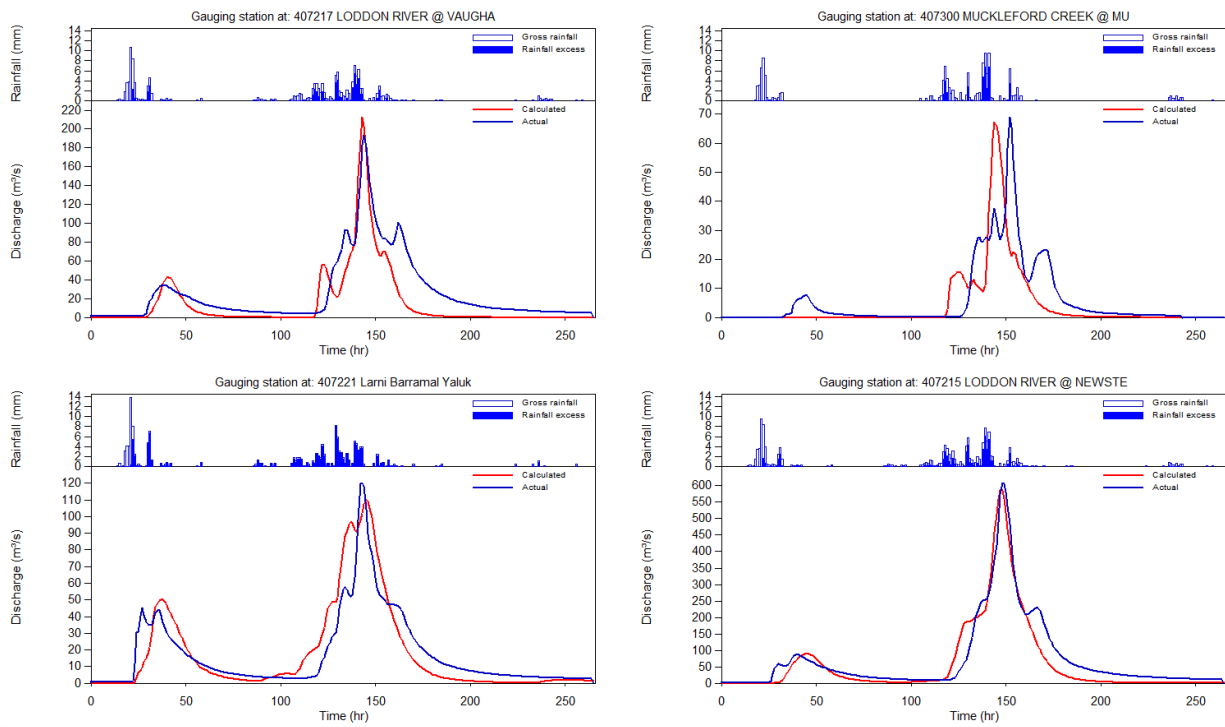


Figure 5-8 Modelled and recorded stream gauges, September 2016 event



5.5 January 2011 calibration

Following a wet spring in late 2010 (which included flooding in September and November), Victoria experienced the wettest January on record thus far. A broad slow-moving trough centred over western Victoria and a ridge of high pressure to the south of Tasmania were the main drivers for the rainfall which commenced on Sunday the 9th of January. Heavy rainfall and flash flooding persisted between the 9th and 15th of January, resulting in rainfall totals of 100 – 300 mm across two-thirds of the state and consequently major and moderate flooding spanning north, west and central Victoria. This led to the second largest flood event on record at Newstead. As in 2022, the southern section of the levee started to overtop during this flood event, but was sandbagged to prevent overtopping in these areas.

5.5.1 Rainfall

Rainfall totals recorded between 9am on the 9th of January until 9am on the 15th of January at stations near and within the Loddon River catchment are shown in Table 5-9 with the rainfall distribution and isopleths are shown in Figure 5-9.

Table 5-9 January 2011 rainfall totals (arrows represent accumulated rainfall)

Station	Station Name	Rainfall to 9am 10 th Jan (mm)	Rainfall to 9am 11 th Jan (mm)	Rainfall to 9am 12 th Jan (mm)	Rainfall to 9am 13 th Jan (mm)	Rainfall to 9am 14 th Jan (mm)	Rainfall to 9am 15 th Jan (mm)	Total Rainfall (mm)
88132	Baringhup (Blue Hills)	20	19.6	43	39.6	62	2.2	186.4
87017	Blackwood	→	31.6	48	15.2	→	102.6	197.4
88009	Cairn Curran Reservoir	8	38	23.8	14.6	97.8	12	194.2
88011	Campbelltown	6.4	36.4	40.8	22	86.2	0.6	192.4
88110	Castlemaine Prison	10.4	26.6	47	35.8	64.8	7	191.6
88020	Daylesford	0.8	40	43.4	38.6	82.1	0	204.9
88021	Eberys	17.4	10.8	52.6	14.6	73	11	179.4
88118	Harcourt	12.2	18.6	53.8	26.2	73	5.4	189.2
88032	Joyces Creek	12	19.2	38	21	70	3.2	163.4
88037	Lauriston Reservoir	3	27	28.6	59	→	124.4	242
88161	Maldon Stump St	28.2	6.6	42	33.6	84.6	2	197
88042	Malmsbury Reservoir	0.6	22.8	28	80.4	73.4	22.6	227.8
88048	Newstead	9.2	16	52.6	22.4	74.6	5.2	180
88051	Redesdale	17.8	10.8	32.6	21.8	78.6	8.4	170
88054	Shepherds Flat	20	26.3	→	→	→	152.5	198.8
88113	Smeaton (Blampied (Bardia))	0	39.4	48	23.2	91	4.2	205.8
88059	Trentham (Post Office)	2	29.6	50.8	26.4	110.8	7.2	226.8



Station	Station Name	Rainfall to 9am 10 th Jan (mm)	Rainfall to 9am 11 th Jan (mm)	Rainfall to 9am 12 th Jan (mm)	Rainfall to 9am 13 th Jan (mm)	Rainfall to 9am 14 th Jan (mm)	Rainfall to 9am 15 th Jan (mm)	Total Rainfall (mm)
88108	Vaughan	9.8	28.4	48	37.6	52	6	181.8
88066	Yandoit	5.6	22.2	62.6	21	67.4	5	183.8
81123	Bendigo Airport	20.6	8	40.8	25.2	64.2	5	163.8

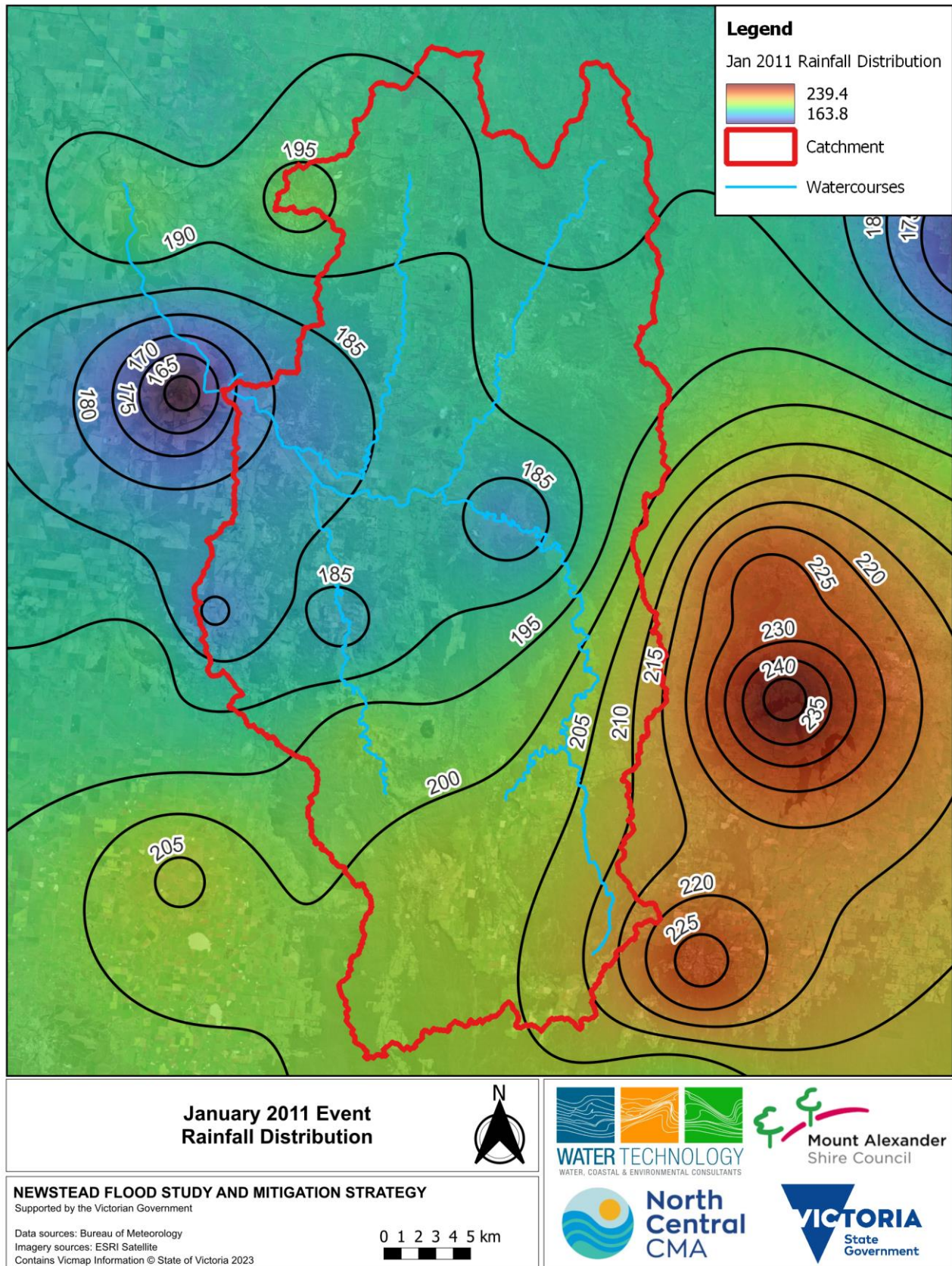


Figure 5-9 Rainfall distribution and isopleths for January 2011 event

For the temporal distribution of rainfall, sub-daily rainfall data from each of the sub-daily stations shown in Figure 5-1 were extracted in half hour increments. The pluviographs are provided in Figure 5-10. The storm event can be separated into three separate bursts, occurring in the first 62 hours, between 62 hours and 83 hours and in the last 37 hours respectively.

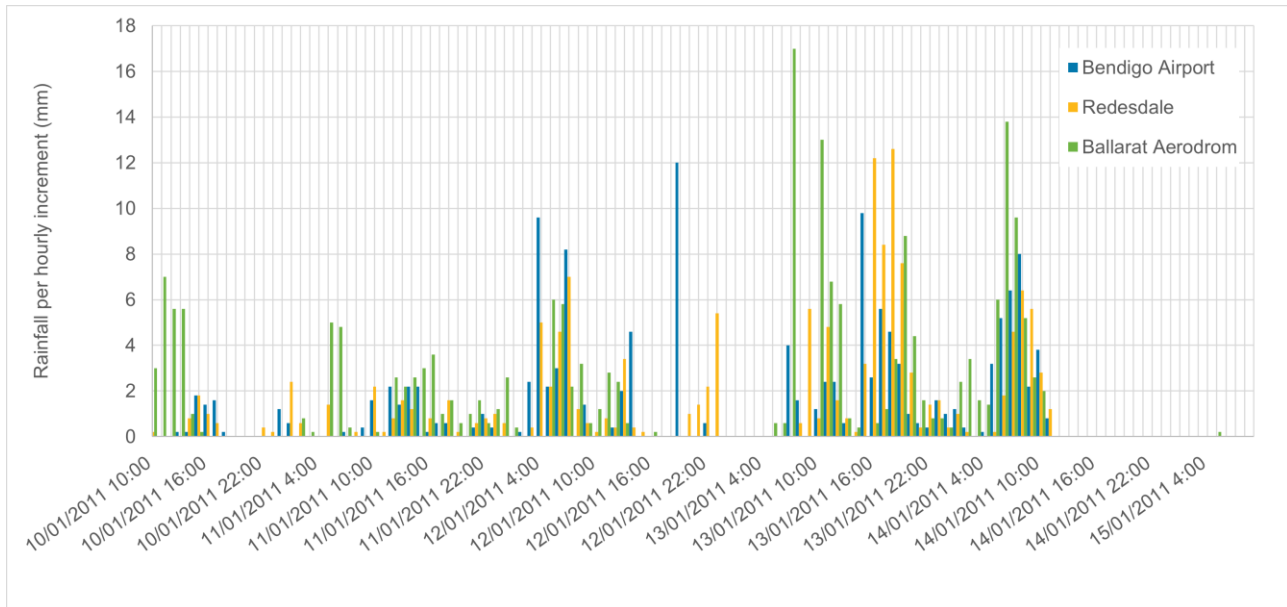


Figure 5-10 Hourly rainfall increments for the sub-daily rainfall stations from 10am 10 January 2011 to 9am 15 January 2011

5.5.2 Streamflow

The model was calibrated using an initial loss/continuing loss with a similar approach as adopted for the 2022 and 2016 events. A multiple burst approach was used based on the three separate rainfall bursts which results in three separate peaks in the recorded hydrographs. This allows for a separate IL/CL pair to be applied to each burst.

Hydrograph timing and peak values were well represented for all three peaks at each of the gauging stations. The total discharge volumes were also well predicted by the model, aside from a 20% deviation at the Muckleford Creek gauge. K_c values determined for the 2022 and 2016 model calibrations were retained, with a slight reduction for the Muckleford Creek interstation. Losses varied between interstation areas and each storm burst. Losses decreased during the event, as expected when the catchment gets wetter as the storm even progresses. The Larni Barramal Yaluk and Muckleford Creek catchments required generally lower losses while the upper Loddon River catchment (upstream of Vaughan) required higher losses throughout the event. The calibration result is considered the strongest across the catchment as a whole out of the modelled events.

The adopted calibration parameters are shown in Table 5-10.



Table 5-10 January 2011 RORB calibration parameters

Interstation Area/Gauge	Kc	m	IL – Burst 1 (mm)	CL – Burst 1 (mm/hr)	IL – Burst 2 (mm)	CL – Burst 2 (mm/hr)	IL – Burst 3 (mm)	CL – Burst 3 (mm/hr)
407217 Loddon River at Vaughan (d/s Fryers Creek)	18	0.8	55	3	35	2.5	25	1.5
407221 Larni Barramal Yaluk at Yandoit	21.98		45	1.5	25	1	25	1
407300 Muckleford Creek at Muckleford North	10		35	0.5	20	1	15	1
Green Gully interstation	3.12		45	3	25	2	25	1
407215 Loddon River at Newstead	19.51		45	3	25	2	25	1
Mia Mia Creek interstation	4.32		45	3	25	2	25	1
Catchment outlet	17.47		45	3	25	2	25	1

Calibration result statistics for the January 2011 flood event are summarised in Table 5-11 below. The modelled and recorded streamflow for the event are shown in Figure 5-11 for each gauge.

Table 5-11 January 2011 calibration statistics

Interstation Area/Gauge	Peak Discharge Absolute Error (m³/s)	Peak Discharge % Error	Time to Peak Absolute Error (hrs)	Volume % Error
407217 Loddon River at Vaughan (d/s Fryers Creek)	2.5	1.1	4.0	-5.2
407300 Muckleford Creek at Muckleford North	7.7	5.1	0.0	-20.2
407221 Larni Barramal Yaluk at Yandoit	-0.5	-0.4	2.0	3.0
407215 Loddon River at Newstead	32	4.5	2.0	0.8

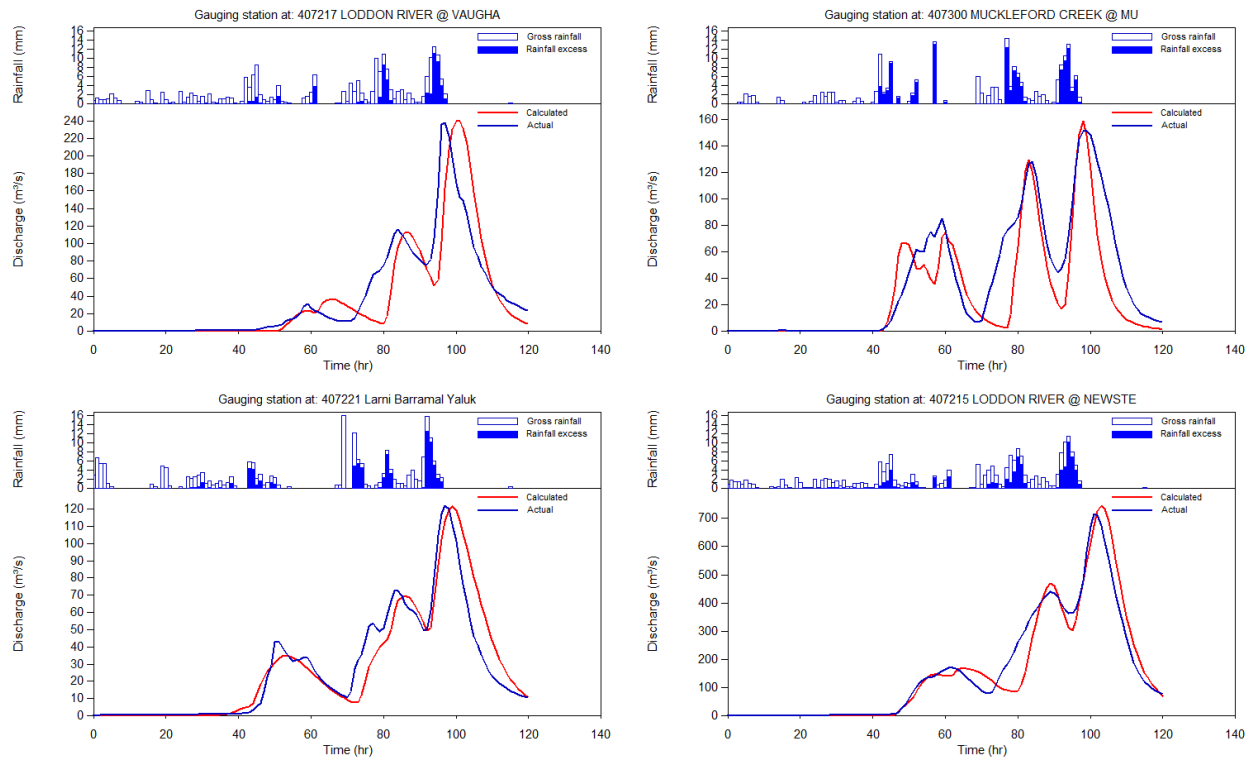


Figure 5-11 Modelled and recorded stream gauges, January 2011 event



5.6 November 2010 calibration

Victoria experienced several large rainfall events during 2010, the largest one at Newstead occurred in late November caused by a trough and low moving across the state. The trough lingered over the state in the following days and widespread rainfall was recorded on the 26th and 27th of November. Rainfall became heavier on the 28th and began clearing to the east on the 29th.

5.6.1 Rainfall

Rainfall totals recorded between 9am on the 24th of November until 9am on the 29th of November at stations near and within the Loddon River catchment are shown in Table 5-12 with the rainfall distribution and isopleths are shown in Figure 5-12.

Table 5-12 November 2010 rainfall totals (arrows represent accumulated rainfall)

Station	Station Name	Rainfall to 9am 25 th Nov (mm)	Rainfall to 9am 26 th Nov (mm)	Rainfall to 9am 27 th Nov (mm)	Rainfall to 9am 28 th Nov (mm)	Rainfall to 9am 29 th Nov (mm)	Total Rainfall (mm)
88132	Baringhup (Blue Hills)	31	0.2	51.4	43.6	0	126.2
87017	Blackwood	31	→	→	88.2	2.8	122.8
88009	Cairn Curran Reservoir	28	1.4	42.8	45.2	0	117.4
88011	Campbelltown	28.8	2.2	26	37.8	0.2	95
88110	Castlemaine Prison	26	14.8	50.6	50.6	0	142
88020	Daylesford	34.8	6	→	→	74	114.8
88021	Eberys	36.4	1.8	23.2	33.6	0	95
88118	Harcourt	22.2	2.8	68.6	51.4	0	145
88032	Joyces Creek	30.2	1.8	32	59.8	0	123.8
88037	Lauriston Reservoir	29	3.4	24.2	64.6	0	121.2
88161	Maldon Stump St	31.6	10.4	42.4	54.6	0	139
88042	Malmsbury Reservoir	26.2	13.2	27.6	59	0.2	126.2
88048	Newstead	34.2	2.2	37.8	49.4	0	123.6
88051	Redesdale	21.2	7	51.8	44.8	0	124.8
81121	Sandhurst Reservoir	→	38.6	→	→	98.8	137.4
88054	Shepherds Flat	30.5	11	→	68	0	109.5
88113	Smeaton (Blampied (Bardia))	32	12	34	38	0	116
88059	Trentham (Post Office)	25.4	13.6	28	58.8	1.8	127.6
88108	Vaughan	26.4	10.8	54	73.4	0	164.6
88066	Yandoit	35	3.2	24.4	53.8	0	116.6

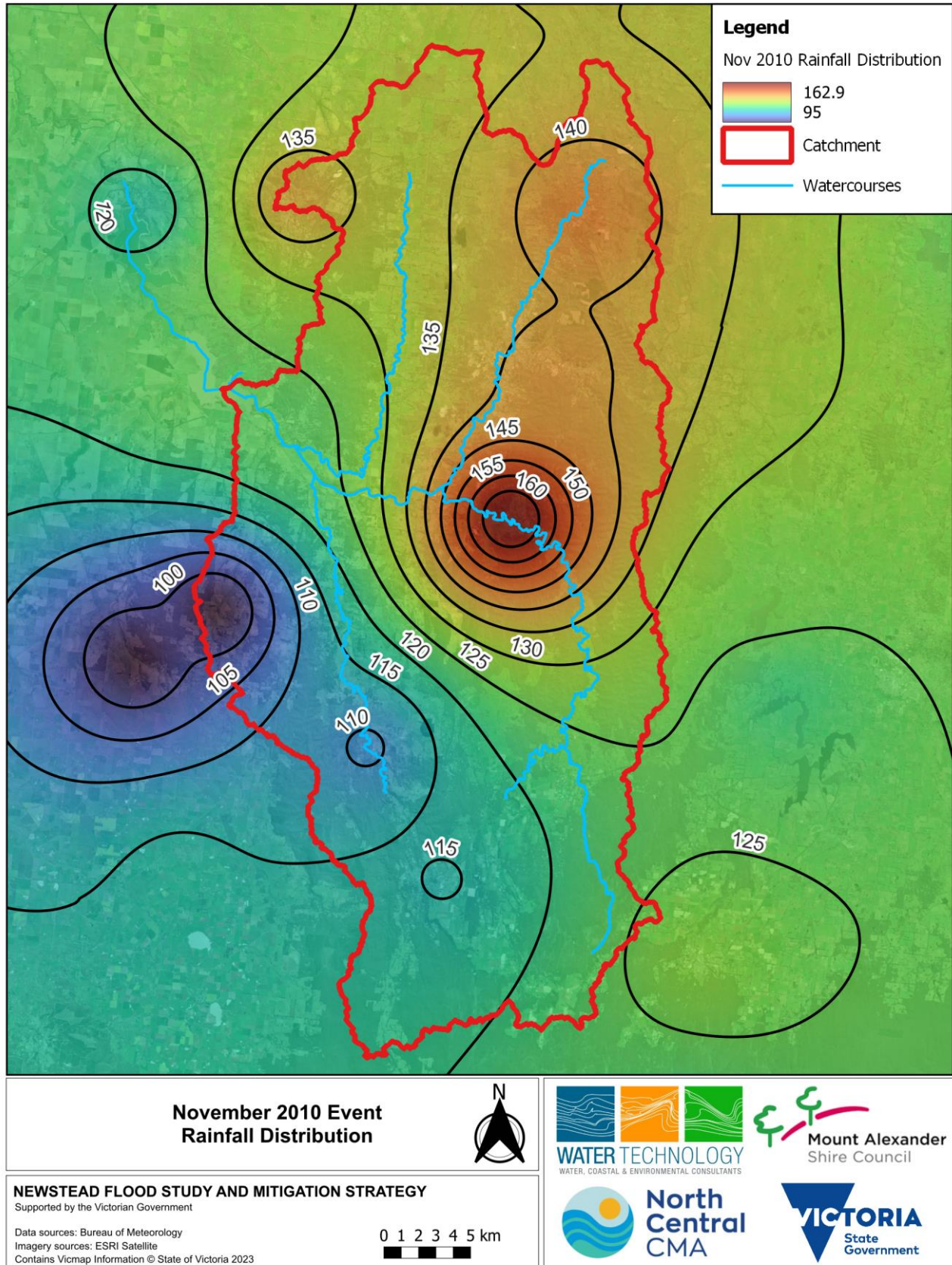


Figure 5-12 Rainfall distribution and isopleths for November 2010 event

For the temporal distribution of rainfall, sub-daily rainfall data from each of the sub-daily stations shown in Figure 5-1 were extracted in half hour increments. The pluviographs are provided in Figure 5-13. The storm event can be separated into two separate bursts, occurring in the first 32 hours and in the last 113 hours respectively.

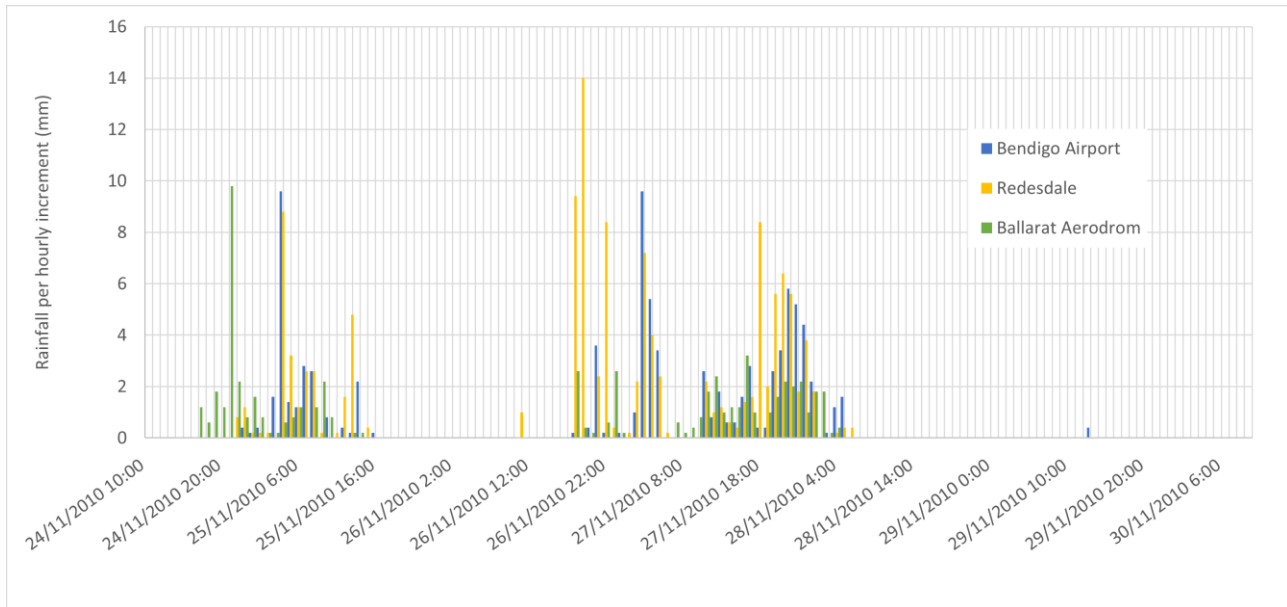


Figure 5-13 Hourly rainfall increments for the sub-daily rainfall stations from 10am 24 November 2010 to 10am 30 November 2010

5.6.2 Streamflow

The model was calibrated using an initial loss/continuing loss with a similar approach as adopted for the 2022, 2016 and 2011 events. A multiple burst approach was used based on the two separate rainfall bursts. This allows for a separate IL/CL pair to be applied to each burst.

Hydrograph peak values and total discharge volumes were well represented at each of the gauging stations. However, all modelled hydrographs display a delay of approximately 10 hours. A range of storm configurations were trialled, varying the number of burst and total event duration. The displayed results showed the best agreement with gauged hydrographs. Kc values determined for the 2022 and 2016 model calibrations were retained. Losses varied between interstation areas and each storm burst. Losses decreased during the event, as expected when the catchment gets wetter as the storm even progresses. The calibration result is considered acceptable given the good representation of peak flows and total volumes, despite the timing delay.

The adopted calibration parameters are shown Table 5-13.



Table 5-13 November 2010 RORB calibration parameters

Interstation Area/Gauge	K _c	m	IL – Burst 1 (mm)	CL – Burst 1 (mm/hr)	IL – Burst 2 (mm)	CL – Burst 2 (mm/hr)
407217 Loddon River at Vaughan (d/s Fryers Creek)	18	0.8	45	1	30	0.25
407221 Larni Barramal Yaluk at Yandoit	21.98		40	0.5	10	2.25
407300 Muckleford Creek at Muckleford North	12.46		40	1	20	1
Green Gully interstation	3.12		40	2	30	1
407215 Loddon River at Newstead	19.51		40	2	30	1
Mia Mia Creek interstation	4.32		40	2	30	1
Catchment outlet	17.47		40	2	30	1

Calibration result statistics for the November 2010 flood event are summarised in Table 5-14 below. The modelled and recorded streamflow for the event are shown in Figure 5-14 for each gauge modelled.

Table 5-14 November 2010 calibration statistics

Interstation Area/Gauge	Peak Discharge Absolute Error (m ³ /s)	Peak Discharge % Error	Time to Peak Absolute Error (hrs)	Volume % Error
407217 Loddon River at Vaughan (d/s Fryers Creek)	-21.1	-7.8	10	5.8
407300 Muckleford Creek at Muckleford North	-1.1	-0.9	9.0	-14.1
407221 Larni Barramal Yaluk at Yandoit	2.04	3.3	11.0	-5.3
407215 Loddon River at Newstead	78.9	13.8	10.0	0.8

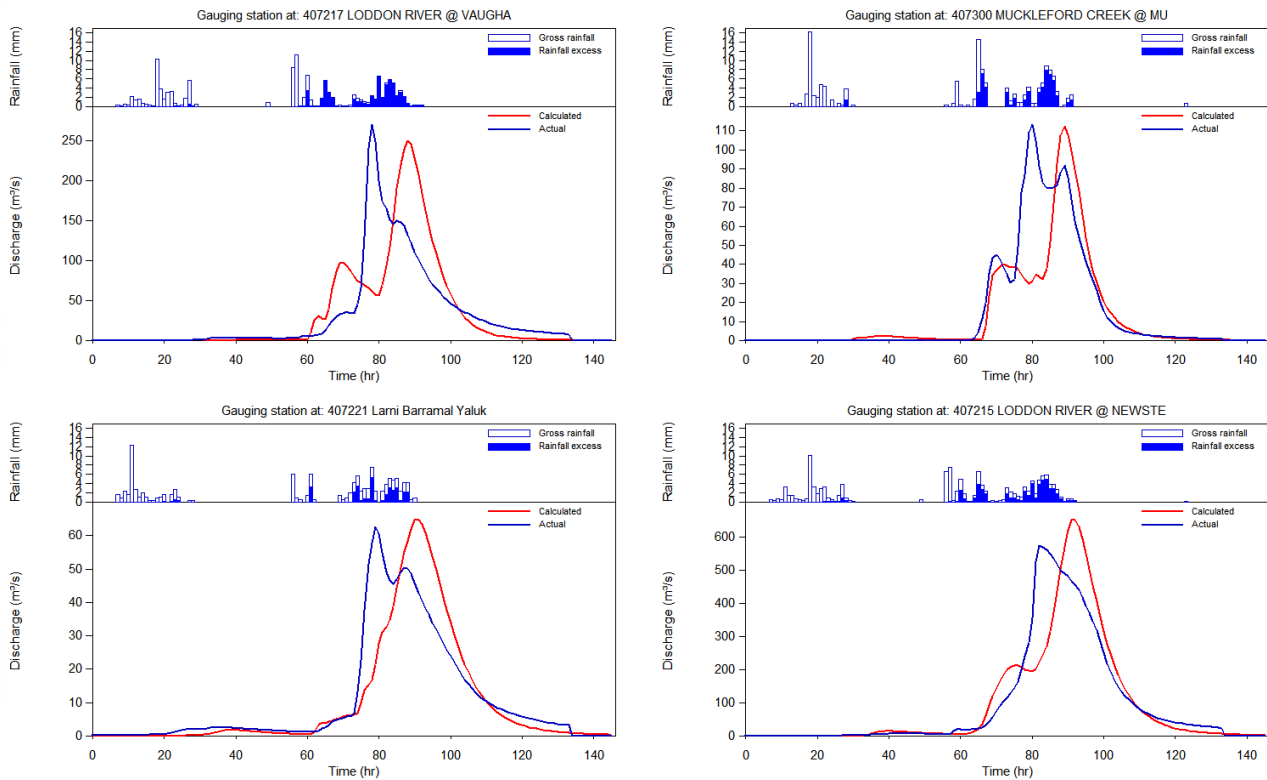


Figure 5-14 Modelled and recorded stream gauges, November 2010 event

5.7 Calibration/Validation discussion

The hydrology calibration shows that the RORB model developed for the study is suitable to replicate a range of flood events including large floods such as the January 2011 and October 2022 events. The modelling agrees with recorded flows at a number of streamflow gauges throughout the catchment and shows close match to peak flow, peak timing and volume error. Table 5-15 shows a summary of the RORB parameters adopted for the calibration events.

Table 5-15 Summary of values for calibration events

Interstation Area/Gauge	K_c	m	IL (all bursts) mm	CL (all bursts) mm/hr
407217 Loddon River at Vaughan (d/s Fryers Ck)	18.00	0.8	18 - 55	0.25 – 3.00
407221 Larni Barramal Yaluk at Yandoit	21.98		18 - 45	0.25 – 2.25
407300 Muckleford Creek at Muckleford North	10.00 - 12.46		15 - 40	0.75 – 3.00
Green Gully interstation	3.12		18 - 45	0.75 – 3.00
407215 Loddon River at Newstead	19.51		20 - 45	0.50 – 3.00



Interstation Area/Gauge	K _c	m	IL (all bursts) mm	CL (all bursts) mm/hr
Mia Mia Creek interstation	4.32		18 - 45	0.75 – 3.00
Catchment outlet	17.47		18 - 45	0.75 – 3.00



6 DESIGN HYDROLOGY

6.1 Overview

The adopted methodology described below is based on current guidelines described in the 2019 revision of Australian Rainfall and Runoff (ARR2019). An ensemble approach was used in this assessment to determine the design flow inputs. The ensemble approach modelled 10 available temporal patterns for each storm duration. The temporal pattern which determined the median peak flow for each duration was then adopted as the design flow after reconciliation with the FFA via appropriate model parameter selection.

6.2 Design rainfall

Design rainfall depths were obtained from the Bureau of Meteorology Design Rainfall Data System⁹. Initially, the raw IFD data was utilised in order to enable reconciliation with FFA. Climate change factors were then adopted by scaling the design rainfall to provide consideration of the near-term (2030) and long-term (2100) changes to IFDs from when they were developed (2016).

Rainfall depths were obtained in ascii grid format to enable spatial variation of rainfall to be considered in line with the recommendations of ARR2019 for catchments exceeding 20km². Areal reduction factor (ARF) parameters and temporal patterns were obtained from the ARR Datahub¹⁰.

Temporal patterns for the catchment were adopted from the Murray Basin region. Due to the size of the catchment, areal temporal patterns are recommended for use by ARR2019. Areal temporal patterns are available for storms 12 hours in duration and longer. Given the critical duration was shown to be longer than 12 hours, point temporal patterns were not considered for design rainfall distribution.

To account for the varying catchment size of the different tributaries to be mapped, three different ARFs were adopted, see Table 6-1. To reduce the total number of model simulations, the tributaries were grouped based on similar catchment size and the ARFs were based on the average catchment area within the group. The ARF was calculated based on the full catchment area upstream of the Loddon River outfall for each of the tributaries, and upstream of the study mapping area for the Loddon River, based on the method specified in Book 2, Chapter 4 of ARR2019. Note that a single ARF based on the entire catchment area was adopted for the modelling adopting the 2016 IFD rainfall described in Section 6.5.

Table 6-1 Catchment groups for ARF

Catchment or group	Average area (km ²)
Loddon River	582
Muckleford Creek and Larni Barramal Yaluk	216
Mia Mia Creek, Green Gully Creek and Green Gully	21.8

6.2.1 Spatial variation of design rainfall

Due to the size of the catchment, spatial variation of design rainfall was applied in RORB. A point rainfall (taken as the average of rainfall grid cells that intersect a subarea) was applied to each subarea. The weighted average rainfall for the catchment and the percentage of the weighted average to be applied to each subarea

⁹ <http://www.bom.gov.au/water/designRainfalls/revised-ifd/>

¹⁰ <https://data.arr-software.org/>



was then calculated in a spreadsheet for each duration and magnitude of event as per the methodology described in Book 2, Chapter 6 of ARR2019.

A custom Intensity-Frequency-Duration (IFD) file was prepared for the catchment to use in RORB, assigning the weighted average rainfall to each duration and magnitude. The weighted average rainfalls (before application of ARF) for the entire catchment across a range of events is shown in Table 6-2.

Table 6-2 Upper Loddon River catchment IFD (weighted average) rainfall totals

Duration	Annual Exceedance Probability (AEP)								
	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	0.05%
1 hour	22.9	28.4	34.3	42.8	49.9	55.1	62.4	68.2	74.1
1.5 hour	25.9	32.0	38.5	48.0	55.9	61.7	70.0	76.5	83.1
2 hour	28.3	34.8	41.8	51.9	60.4	66.7	75.6	82.6	89.8
3 hour	32.2	39.5	47.1	58.1	67.4	74.3	84.3	92.1	100.1
4.5 hour	37.1	45.0	53.4	65.4	75.4	83.1	94.2	102.9	111.9
6 hour	41.1	49.7	58.7	71.4	81.9	90.2	102.2	111.7	121.4
9 hour	47.8	57.4	67.4	81.2	92.5	101.7	115.3	125.9	136.8
12 hour	53.3	63.8	74.6	89.3	101.1	111.2	126.1	137.7	149.6
18 hour	61.8	73.8	86.0	102.3	115.1	126.7	143.7	156.8	170.4
24 hour	68.3	81.5	95.0	112.4	126.2	139.1	157.8	172.3	187.3
30 hour	73.4	87.7	102.2	120.8	135.4	147.8	166.6	180.9	195.6
36 hour	77.6	92.7	108.1	127.9	143.2	156.2	175.7	190.7	205.9
48 hour	84.0	100.6	117.5	139.1	155.9	171.1	193.1	210.2	227.6
72 hour	92.2	110.6	129.5	154.2	173.5	193.8	221.6	243.6	266.5
96 hour	97.4	116.8	136.7	163.6	185.0	208.9	241.4	267.7	295.4
120 hour	101.1	120.9	141.2	169.8	192.8	218.7	254.6	283.8	315.1

An example of spatially varied rainfall depths applied to each subarea is shown in Figure 6-1 below for the 1% AEP, 18-hour event. Design rainfall depths range from 102 mm in the central western parts of the catchment up to 140 mm in the southeast of the catchment for this specific event.

Due to the spatial variance of IFD data supplied by the BoM, the design spatial pattern differs for every event magnitude and duration. To simplify and expediate reconciliation of design flows produced by the model with those expected from the FFA at the Loddon River at Newstead gauge, initial reconciliation runs adopted the 1% AEP spatial pattern only. Once flows were reconciled and design losses assigned, ensembles of the ten temporal patterns were run for each AEP individually. This allowed the spatial variation to be defined at each AEP, accounting for variance across the durations. Final design flows were determined in this way and losses further adjusted to reconcile with the FFA results.

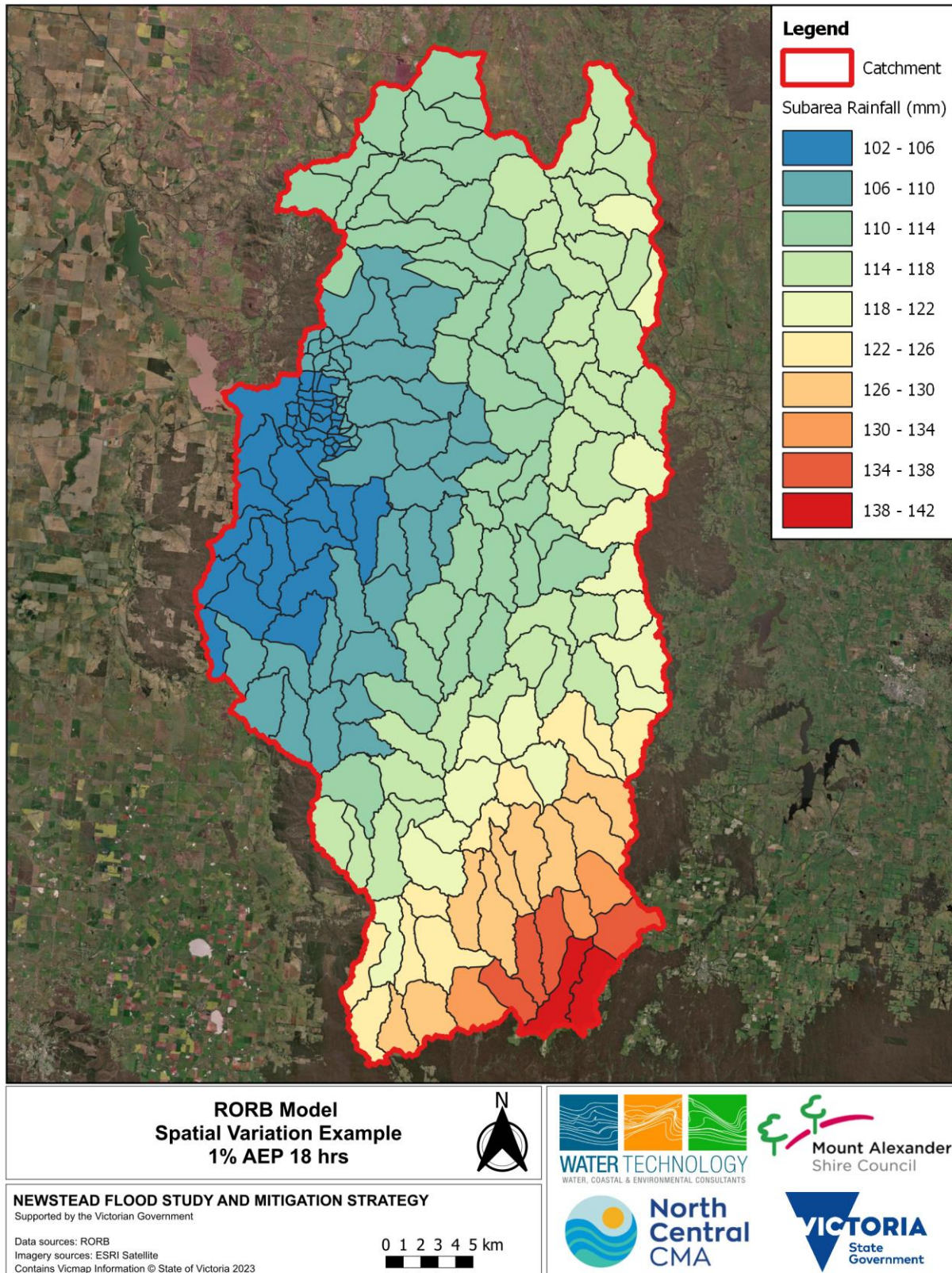


Figure 6-1 Example of Spatially Varied Rainfall, 1% AEP 24 Hour Event

6.2.2 Pre-burst

Losses derived from the ARR datahub are intended to be applied to a whole storm event, while design rainfall depths obtained from the Bureau of Meteorology represent storm bursts. The application of pre-burst rainfall is intended to represent a complete storm by appending the pre-burst to the start of the burst rainfall. This can be achieved by modelling the complete storm and applying the storm Initial Loss, or lowering the Initial Loss to represent a burst Initial Loss according to the following equation:

$$IL_b = IL_s - \text{pre-burst depth}$$

For this study, burst Initial Losses were applied by subtracting the median pre-burst depth from the storm Initial Loss and applying the resultant burst Initial Loss to the design burst rainfall.

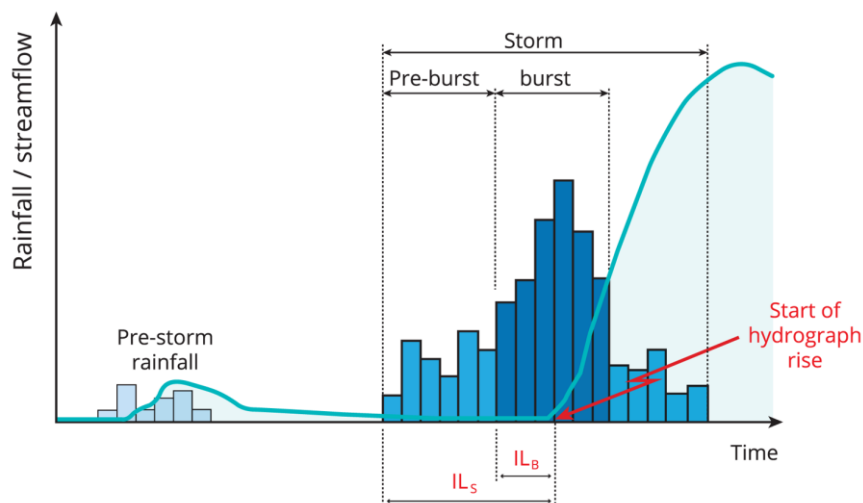


Figure 6-2 Conceptualisation of storm vs burst rainfall and its interaction with Initial Loss¹¹

Consideration was given to the Victorian Specific Information of the ARR datahub, which recommends the use of 75th percentile pre-burst depths when applying datahub values for other hydrologic inputs¹². The median pre-burst depth was selected because the losses were reconciled with FFA results, thus the aim of producing unbiased flows has been achieved.

The ARR datahub provides pre-burst depths for storms between 1 hour and 72 hours only, and for AEPs up to the 1% event only. All long duration storms had no associated pre-burst and it was assumed that this would carry forward to storms longer than 72 hours. For events rarer than the 1% AEP, the pre-burst depths from the 1% AEP were applied.

6.2.3 Embedded bursts

Embedded bursts are bursts within a design temporal pattern which, when multiplied by the design rainfall depth, create a shorter duration storm of lower frequency (i.e. higher magnitude) than the intended design burst. RORB has a built-in feature to filter embedded bursts which spreads troublesome timestep peaks across other time increments, thus removing the embedded burst but maintaining the general temporal pattern as supplied. Temporal pattern filtering was used in the design modelling.

¹¹ Sourced from ARR2019, Book 5 Chapter 3

¹² https://data.arr-software.org/vic_specific



6.3 Design losses

Design losses were determined by reconciliation of the modelled peak flows at the Loddon River at Newstead gauge with the results of the Flood Frequency Analysis described in Section 3. Regional losses were sourced from the ARR datahub as a starting point and the model ran iteratively with adjustments made. A summary of the adopted design losses compared with ARR Datahub losses, the range of losses from the calibration events and adopted RORB parameters of several studies in the catchment and nearby is shown in Table 6-3. Design modelling adopted an initial loss of 21 mm and a continuing loss of 1.75 mm/hr as shown in Table 6-5 below. The resultant peak flows and FFA results are shown in Figure 6-3 and Table 6-5.

Table 6-3 Design Loss Summary

Study	K_c	D_{av}	K_c/D_{av}	Initial Loss (mm)	Continuing Loss (mm/hr)
	N/A			26	4.4
Cairn Curran Dam Hydrology (2012)	35	38.7	0.9	35	2
Creswick Flood Mitigation and Urban Drainage Plan (2012)	29.2	22.44	1.3	25	4.5
	10.5	44.69	0.235	35	1.5
	4.79	20.48	0.234	35	1.5
Study (2012)	29.2	22.44	1.3	20	2.5
Loddon River at Newstead	19.51	24.91	0.78	20-45	0.5-3
				21	1.75

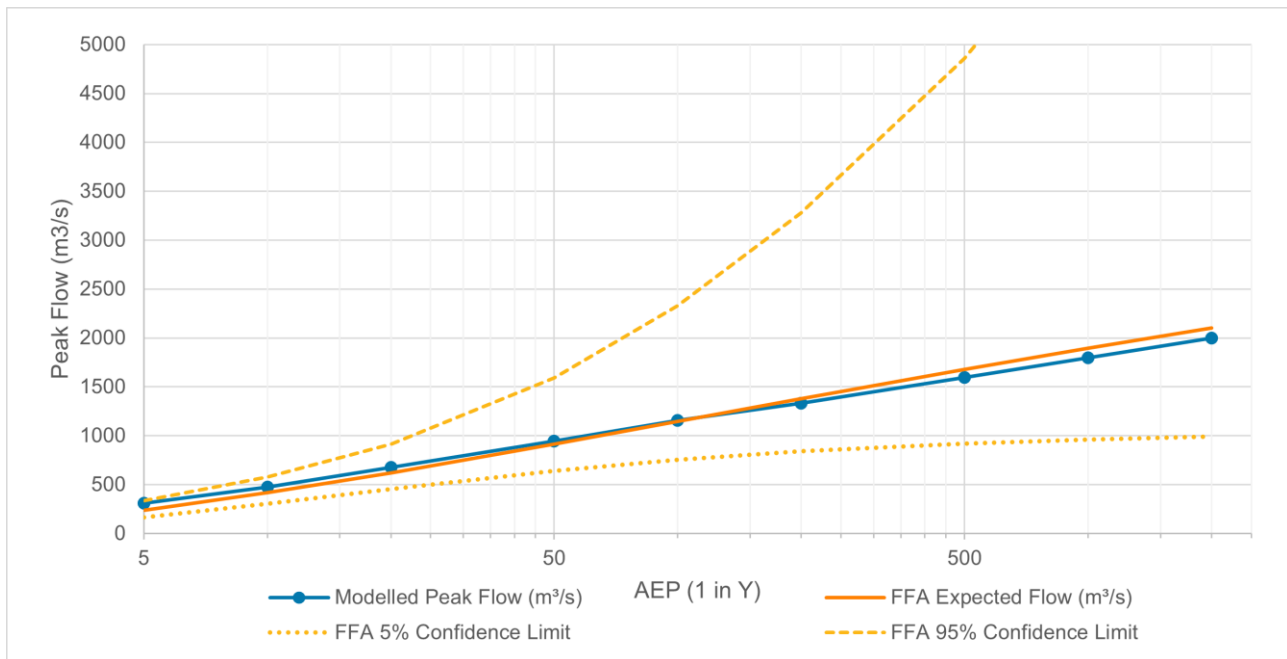


Figure 6-3 Modelled flows and FFA flows at Newstead

6.4 Design RORB routing parameters

Given the satisfactory performance of the RORB model at the Newstead gauge in the calibration events, the calibration routing parameters were adopted for design. While the calibration events adopted varying losses across the catchment/interstation areas, design modelling adopted a single IL and CL for the whole model based on the reconciliation of modelled flows with FFA. The adopted design parameters are shown in Table 6-4 below.

Table 6-4 Design RORB kc values by interstation area

Interstation Area/Gauge	K _c	D _{av} (km)	K _c /D _{av}	m	Initial Loss (mm)	Continuing Loss (mm/hr)
407217 Loddon River at Vaughan (d/s Fryers Creek)	18	27.99	0.64	0.8	21	1.75
407221 Larni Barramal Yaluk at Yandoit	21.98	22.9	0.96			
407300 Muckleford Creek at Muckleford North	12.46	9.97	1.25			
Green Gully interstation	3.12	2.5	1.25			
407215 Loddon River at Newstead	19.51	24.91	0.78			
Mia Mia Creek interstation	4.32	4.98	0.87			
Catchment outlet	17.47	13.98	1.25			



6.5 Design flows

The design flows at the Newstead gauge, along with the FFA results and confidence limits, are shown in Table 6-5 below. Overall, the RORB design flows match the FFA flows well, with a good fit (within 10%) between the 5% AEP and 0.1% AEP events. At the lower end of the AEP's the RORB model flow is higher than the FFA value.

Table 6-5 Design flows, critical durations and representative temporal patterns

AEP	Loddon River at Newstead Peak Flow (m³/s)	Critical Duration	Representative Temporal Pattern	FFA 5% Confidence Limit (m³/s)	FFA Expected Quantile (m³/s)	FFA 95% Confidence Limit (m³/s)
20%	307.4	18 hour	TP09	167.3	238.9	336.8
10%	477.4	18 hour	TP09	303.1	417.0	577.8
5%	677.2	18 hour	TP09	453.5	621.6	915.7
2%	945.1	18 hour	TP09	639.8	916.4	1,588.1
1%	1,156.8	18 hour	TP09	753.4	1,147.7	2,329.5
0.5%	1,331.3	18 hour	TP09	841.2	1,379.5	3,280.2
0.2%	1,594.2	18 hour	TP09	920.8	1,679.1	4,859.1
0.1%	1,794.4	18 hour	TP09	962.3	1,896.5	6,399.2
0.05%	2,000.9	18 hour	TP09	993.3	2,103.5	8,304.8

6.6 Near-term climate change considerations for 2030 (SSP5 – 8.5)

Following the reconciliation of modelled flows with FFA at Newstead, the most recent ARR climate change recommendations were adopted to obtain near-term (2030) rainfall intensities in line with the Book 1 Chapter 6 update to ARR2019⁴. The chapter provides guidance as to how the impacts associated with current and future rises in global temperatures influence extreme rainfall and how they should be considered in design flood estimation. For this study, it was assumed that the baseline period of the FFA aligns with the baseline period of the 2016 BoM IFDs, i.e. 1961-1990. The middle year of the FFA record is 1998 (based off period of record from 1973-2023) but by including the information about flows from 1942 onwards the known data overlaps with the baseline period, thus this assumption is reasonable.

The IFDs and reconciled losses were scaled to 2030 for the near-term risk assessment under the SSP5-8.5 scenario in accordance with the equations supplied in the ARR chapter. The spatially weighted custom Intensity-Frequency-Duration (IFD) data file presented in Table 6-2 was scaled to account for rainfall increases associated with climate change. Table 6-6 shows the increase in rainfall intensity per duration and shows the updated rainfall depths. Design losses were also scaled as per Table 6-7, increasing the initial loss from 21 to 21.71 and the continuing loss from 1.75 to 1.88. The updated 2030 near-term climate change design flows at the Newstead gauge are shown in Table 6-9 below.

Table 6-6 Near-term climate change rainfall intensity increase per storm duration

	<= 1 hr	1.5 Hours	2 Hours	3 Hours	4.5 Hours	6 Hours	9 Hours	12 Hours	18 Hours	>=24 Hours
2030 (near-term)	20 %	18%	17%	16%	14%	13%	12%	12%	11%	10%



Table 6-7 Near-term climate change rainfall loss increase

	IL increase	CL increase
2030 (near-term)	4%	9%

Table 6-8 Upper Loddon River catchment IFD (weighted average) rainfall totals with near-term climate change considerations for the year 2030

Duration	Annual Exceedance Probability (AEP)								
	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	0.05%
1 hour	27.4	34.1	41.1	51.4	59.9	66.1	74.9	81.8	89.0
1.5 hour	30.5	37.8	45.4	56.6	66.0	72.8	82.6	90.2	98.1
2 hour	33.1	40.8	48.9	60.7	70.7	78.0	88.5	96.7	105.1
3 hour	37.4	45.8	54.6	67.5	78.1	86.2	97.8	106.9	116.2
4.5 hour	42.2	51.3	60.9	74.6	85.9	94.7	107.4	117.3	127.6
6 hour	46.5	56.2	66.3	80.7	92.5	101.9	115.5	126.2	137.2
9 hour	53.6	64.3	75.5	91.0	103.5	113.9	129.2	141.0	153.3
12 hour	59.7	71.4	83.5	100.0	113.3	124.6	141.2	154.2	167.5
18 hour	68.6	81.9	95.5	113.5	127.7	140.6	159.5	174.1	189.1
24 hour	75.1	89.6	104.4	123.7	138.8	153.0	173.6	189.6	206.1
30 hour	80.8	96.4	112.4	132.9	148.9	162.6	183.2	199.0	215.1
36 hour	85.4	102.0	118.9	140.7	157.5	171.8	193.2	209.8	226.4
48 hour	92.4	110.6	129.2	153.0	171.5	188.2	212.4	231.2	250.3
72 hour	101.5	121.7	142.5	169.6	190.9	213.1	243.7	268.0	293.1
96 hour	107.1	128.4	150.4	180.0	203.5	229.8	265.6	294.5	325.0
120 hour	111.2	133.0	155.3	186.8	212.1	240.6	280.0	312.2	346.6

Table 6-9 Design flows, critical durations and representative temporal patterns for near-term (2030) climate change scenario

AEP	Loddon River at Newstead Peak Flow (m³/s)	Critical Duration	Representative Temporal Pattern
20%	399.9	18 hour	TP09
10%	606.5	18 hour	TP09
5%	842.6	18 hour	TP09
2%	1155.7	18 hour	TP09
1%	1403.8	18 hour	TP09
0.5%	1618.3	18 hour	TP09
0.2%	1929.6	18 hour	TP09
0.1%	2163.6	18 hour	TP09



AEP	Loddon River at Newstead Peak Flow (m³/s)	Critical Duration	Representative Temporal Pattern
0.05%	2405.1	18 hour	TP09

Table 6-10 shows the near-term climate change design flow at each hydraulic model inflow location critical duration, as well as the critical duration and the temporal pattern generating the median peak flow. The Mia Mia Creek, Green Gully Creek and Green Gully catchments are smaller than 75 km², indicating that point temporal patterns are more representative. Design modelling was undertaken using areal and point temporal patterns as well as varying ARF as described in Section 6.1 to produce accurate flows from each catchment. Table 6-10 shows that the critical duration varies between the catchments, and that the critical duration is generally shorter for the smaller catchments. There is also variation in the temporal pattern generating the median peak flow at each inflow location. However, upon closer inspection of each temporal pattern peak flow, the difference in peak flow between temporal patterns is negligible. This information will be used to limit the number of critical durations and temporal patterns used in the design hydraulic modelling.

Table 6-10 Design flows, critical durations and representative temporal patterns for near-term (2030) climate change scenario at hydraulic model inflow locations

AEP	Loddon River Inlet (m³/s)	Larni Barramal Yaluk Inlet (m³/s)	Muckleford Creek Inlet (m³/s)	Green Gully Creek Inlet (m³/s)*	Mia Mia Creek Inlet (m³/s)*	Green Gully Inlet (m³/s)*
20%	260.4	77.9	81.2	25.9	16.5	2.4
	18 hrs TP09	18 hrs TP09	18 hrs TP09	12 hrs TP10	12 hrs TP10	3 hrs TP06
10%	390.7	119	123.9	35	22.4	3.6
	18 hrs TP09	18 hrs TP09	18 hrs TP09	9 hrs TP03	9 hrs TP8	3 hrs TP05
5%	533.2	162.2	174.3	48.8	30.6	5.2
	18 hrs TP09	18 hrs TP03	18 hrs TP09	9 hrs TP09	3 hrs TP04	3 hrs TP02
2%	721.2	226.8	238.8	67.7	47.3	8.0
	18 hrs TP09	18 hrs TP03	12 hrs TP03	9 hrs TP06	3 hrs TP01	3 hrs TP08
1%	882.8	278.6	299.6	84.3	59.7	10.1
	12 hrs TP09	18 hrs TP03	12 hrs TP09	9 hrs TP06	3 hrs TP08	3 hrs TP09
0.5%	1013.1	332	337.8	97.8	66.2	11.1
	12 hrs TP09	18 hrs TP03	12 hrs TP01	9 hrs TP06	3 hrs TP08	3 hrs TP09
0.2%	1205.8	403.8	400.6	118.1	76.3	12.9
	12 hrs TP09	18 hrs TP03	12 hrs TP05	6 hrs TP07	3 hrs TP08	1.5 hrs TP02
0.1%	1353	460.5	449.5	134	83.9	14.5
	12 hrs TP09	18 hrs TP03	12 hrs TP01	6 hrs TP02	3 hrs TP08	1.5 hrs TP02
0.05%	1503.4	520.6	496.7	150.8	91.5	16.2
	12 hrs TP09	18 hrs TP09	12 hrs TP01	6 hrs TP07	3 hrs TP08	1.5 hrs TP02

* Peak flows for Mia Mia Creek, Green Gully Creek and Green Gully were achieved using point temporal patterns



6.7 Long-term climate change consideration for 2100 (SSP5 – 8.5)

Similarly to what was done for the near-term climate change, the IFDs and reconciled losses were scaled to 2100 for the long term climate change assessment under the SSP5-8.5 scenario in accordance with the equations supplied in ARR Book 1 Chapter 6⁴. The spatially weighted custom Intensity-Frequency-Duration (IFD) data file presented in Table 6-2 was scaled to account for rainfall increases associated with climate change, see . Design losses were also scaled, increasing the initial loss from 21 to 24.15 and the continuing loss from 1.75 to 2.33. The updated 2100 design flows at the Newstead gauge are presented in Table 6-14 below, showing a 40 to 50% increase to the design event flows in the Loddon River.

Table 6-11 Long-term climate change rainfall intensity increase per storm duration

	<=1 hr	1.5 Hours	2 Hours	3 Hours	4.5 Hours	6 Hours	9 Hours	12 Hours	18 Hours	>=24 Hours
2100 (long-term)	86%	77%	71%	64%	58%	54%	50%	47%	43%	41%

Table 6-12 Long-term climate change rainfall loss increase

	IL increase	CL increase
2100 (long-term)	15%	33%

Table 6-13 Upper Loddon River catchment IFD (weighted average) rainfall totals with long-term climate change considerations for the year 2100

Duration	Annual Exceedance Probability (AEP)								
	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	0.05%
1 hour	42.5	52.9	63.8	79.6	92.8	102.4	116.2	126.9	137.9
1.5 hour	45.8	56.6	68.1	84.9	98.9	109.2	123.9	135.3	147.1
2 hour	48.3	59.6	71.5	88.8	103.3	114.0	129.3	141.3	153.6
3 hour	52.9	64.7	77.2	95.4	110.5	121.9	138.3	151.1	164.2
4.5 hour	58.6	71.2	84.4	103.4	119.1	131.2	148.8	162.6	176.8
6 hour	63.3	76.6	90.4	110.0	126.1	138.8	157.4	172.0	187.0
9 hour	71.7	86.2	101.1	121.9	138.7	152.6	173.0	188.9	205.3
12 hour	78.3	93.7	109.7	131.3	148.6	163.5	185.4	202.4	219.9
18 hour	88.4	105.5	123.0	146.2	164.6	181.2	205.4	224.2	243.7
24 hour	96.3	114.9	133.9	158.5	177.9	196.2	222.5	243.0	264.1
30 hour	103.6	123.6	144.1	170.4	190.9	208.4	234.8	255.1	275.7
36 hour	109.4	130.7	152.5	180.4	201.9	220.2	247.7	268.9	290.3
48 hour	118.5	141.8	165.6	196.1	219.8	241.2	272.3	296.4	320.9
72 hour	130.1	156.0	182.6	217.4	244.7	273.2	312.4	343.5	375.7
96 hour	137.3	164.6	192.8	230.7	260.8	294.6	340.4	377.4	416.6
120 hour	142.6	170.5	199.1	239.4	271.8	308.4	358.9	400.2	444.3



Table 6-14 Design flows, critical durations and representative temporal patterns for 2100 climate change scenario

AEP	Loddon River at Newstead Peak Flow (m³/s)	% Increase compared to 2030	Critical Duration	Representative Temporal Pattern	Approximate near-term (2030) AEP
20%	621.5	55	18 hour	TP09	Just larger than 10%
10%	918.2	51	18 hour	TP09	Between 5% and 2%, closer to 5%
5%	1219.8	45	18 hour	TP09	Just larger than 2%
2%	1631.2	41	12 hour	TP09	Just larger than 0.5%
1%	1985.8	41	12 hour	TP09	Between 0.2% and 0.1%, closer to 0.2%
0.5%	2272.3	40	12 hour	TP09	Between 0.1% and 0.05%
0.2%	2685.9	39	12 hour	TP09	Larger than 0.05%
0.1%	3013.9	39	12 hour	TP09	Larger than 0.05%
0.05%	3346.8	39	12 hour	TP09	Larger than 0.05%



7 SUMMARY AND NEXT STEPS

The hydrology calibration and design validation process has shown the RORB model developed for the study is suitable to replicate a range of flood events including large floods such as the January 2011 and October 2022 events. The calibration process has relied on the use of multiple streamflow gauges throughout the catchment with a key emphasis on the Loddon River at Newstead gauge. Modelling results show a suitable fit to the recorded flows at each of the gauge locations for the four events modelled.

The RORB parameters adopted (namely initial loss, continuing loss and k_c) sit within expected ranges based on regional parameters from ARR2019 and RORB regional approximation equations as well as within the range of values adopted for the calibration of four flood events.

Consideration of the climate change to assess both the near-term (2030) and long-term (2100) scenarios have been assessed as part of the design hydrology process.

The results of the event based calibration and design validation to FFA identify the parameters adopted in both the RORB model are suitable for adoption in design flood modelling for Newstead.

Following approval of the hydrology approach, hydraulic modelling will be used to simulate two of the calibration events within a TUFLOW model to be built. This will be calibrated against the Loddon River at Newstead gauge as well as surveyed flood levels throughout the town.

Calibration and draft 1% AEP modelling results can then be presented at a project steering committee meeting before the second round of community consultation. The steering committee meeting and subsequent consultation will focus on the results of the calibration and draft design modelling.

Melbourne

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800

Sydney

Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150
Telephone (02) 9354 0300

Brisbane

Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide

1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000

Perth

Level 1, 21 Adelaide Street
Fremantle WA 6160
Telephone (08) 6555 0105

New Zealand

7/3 Empire Street
Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta

First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Geelong

51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800

Wimmera

597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast

Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227
Telephone (07) 5676 7602

watertech.com.au

