



Summary Report

Newstead Flood Study and Mitigation Strategy (M1751-2023)

Mount Alexander Shire Council

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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 and that the Guildford model only covers 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 – Final version published 20 August 2024

R02 – Hydrology Report – Final version published 31 October 2024

R03 - Draft Hydraulic Modelling Report – Final version published 13 December 2024

R04 – Final Hydraulic Modelling Report – Final version published 3 April 2025

R05 - Design Modelling and Mapping Outputs – Final version published 3 April 2025

R06 – Municipal Flood Emergency Plan (MFEP) Documentation – Draft published 8 May 2025

R07 – Flood Damage and Structural Mitigation Options – Draft published 28 October 2025

R05 – Final Summary Report – This report

1.2 Objectives and outputs

The Newstead Flood Study and Mitigation Strategy 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 (PMF).
- 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 parts of the township located on the western side of the Loddon River. Flooding in Newstead has historically caused levee breaches which were mitigated by sandbagging during the flood event. Flooding of the Loddon River also leads to the town being isolated when major traffic routes are 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.

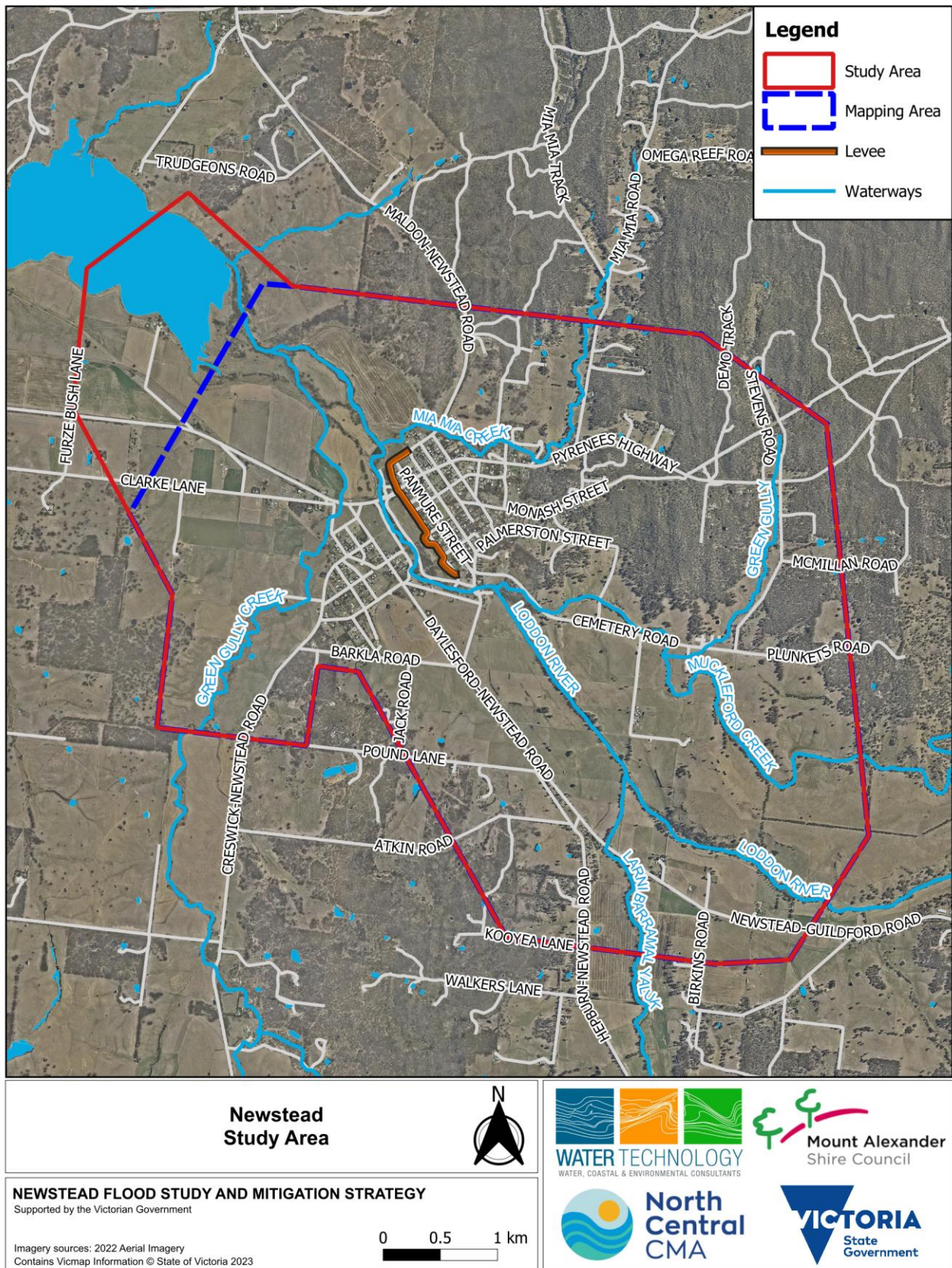


Figure 1-1 Newstead study area



1.4 Flood behaviour

The Loddon River originates in the Great Dividing Range within the Hepburn and Mount Alexander shires, flowing north until Vaughan where it turns in a westerly direction towards the township of Newstead. Upstream of Newstead, the Loddon River is joined by several tributaries including Campbells Creek, Larni Barramal Yaluk, Muckleford Creek, Green Gully, Green Gully Creek and Mia Mia Creek. Flooding in Newstead is primarily caused by the Loddon River, but localised flood events can cause flooding along any of the tributaries. The eastern portion of the Newstead township is located behind a levee bank.

When the Loddon River floods, widespread breakouts from the river channel and tributaries are observed in the 20% AEP event inundating farmland upstream and downstream of the township and the Pyrenees Highway is overtopped by Green Gully Creek. The flood behaviour is similar in the 10% AEP event.

The Newstead levee is overtopped in the 5% AEP event, with flood levels up to 0.5 m observed inside the levee. For the 2% AEP event, the flooding behind the levee causes flooding above floor at 80 properties and large areas of Newstead become isolated/inaccessible.

Note that all intelligence data presented in this report has been produced based on the near-term climate change considerations for the year 2030 (based on the Shared Social Pathway SSP5 scenario).



2 DATA REVIEW AND VALIDATION

The first stage of the project included the collation and review of available data relevant to flooding in Newstead. This included the following:

- Previous flood studies and reports

There was no flood study of Newstead nor any previous hydrologic model covering the upper reaches of the Loddon River have been undertaken before this study. During the data collation and review process the following studies were identified as relevant:

- Newstead Erosion Control – Loddon River Investigation and Design
- Newstead Levee Investigation Report
- Risk Assessment – Newstead Levee
- Newstead Levee Alignment – Modelling Assessment
- Mia Mia Creek Flood Impact Assessment
- North Central CMA Erosion Assessment and Works Prioritisation Project
- Historical flood events and accompanying anecdotal evidence
 - The Newstead Local Flood Guide (developed by the SES) lists records of historic flood levels and impacts for the 1890, 1909, October 1934, October 2000, January 2011, October 2016 and October 2022 flood events
 - Evidence was gathered for the 1870, 1916, 1934, 2010, 2011 and 2022 flood events. The hydraulic model calibration focused on the October 2022 event, the largest flood on record at Newstead.
 - Surveyed water levels from the events in 2000, 2010 and 2022, a total of 63 flood marks were provided by the NCCMA.
 - Anecdotal evidence was obtained during the community consultation session conducted in June 2024.
- Recorded streamflow

Following four (4) active streamflow gauges within the study area have data available with water level and streamflow data available to the present date.

- Loddon River @ Newstead (407215)
- Larni Barramal Yaluk @ Yandoit (407221)
- Loddon River @ Vaughan D/S Fryers Creek (407217)
- Muckleford Creek @ Muckleford North (407300)
- Recorded rainfall
 - Daily and sub-daily rainfall data provided by the Bureau of Meteorology were used in this study.
 - A total of 23 daily rain gauges have been in use, with records covering various periods since 1867. Of these, 5 gauges remain operational. The Newstead gauge, which is the nearest active gauge within the township, has a long-standing record from 1897 to the present day.
 - Bendigo Airport, Redesdale, and Ballarat Aerodrome gauges capture sub-daily rainfall measurements.
- Storages

There are several storages within the study area, including:



- Cairn Curran Reservoir, located downstream of the Newstead Township, and
- Several water storage dams in open space (e.g., Newstead Racecourse).
- **Levees**
 - The Newstead levee located on the east side of the Loddon River stretching from the southern end of Layard Street to the northern end of Panmure Street, with a length of about 1.5 km.
 - Additional levees have been identified through the latest LiDAR along the Loddon River and Larni Barramal Yaluk, located in the upper portions of the study area.
- **Road and drainage infrastructure**
 - The road and related infrastructure have been identified using aerial imagery, topographic data, Department of Transport (DoT) records, and council asset information. Further detail for these structures has been gathered through topographic surveys and site inspections.
- **Topographic data**
 - The 2022 Department of Transport Digital Twin Project LiDAR was the only available high-resolution dataset covering the entire study area.
 - The dataset was verified against survey data provided by Price Merrett for the current project, as described in R01 – Data Review and Validation Report. Based on the verification, the LiDAR dataset showed a high degree of accuracy and was considered suitable for use in the hydraulic model.
 - The LiDAR captured a water level in the Loddon River, and hence was not accurately representing the river bathymetry below the water level. Surveyed cross-sections for the Loddon River from 2012 were provided by ALS, covering a small area upstream and downstream the Loddon River at Newstead gauge. The data was used to enhance bathymetry of the Loddon River in this area.
 - Survey data for the Newstead Levee was included in the model in favour of the LiDAR to accurately represent the levee crest. The LiDAR was further supplemented with breaklines to represent minor levees and some roads acting as hydraulic controls, ensuring flow could not overtop these structures until it reached the crest level (as determined by sampling the 1m LiDAR DEM).



3 MODEL DEVELOPMENT AND CALIBRATION MODELLING

3.1 Overview

The Hydrology Report (R02) describes in detail the hydrologic (RORB) model build and parameter selection adopted for the study. The report also details the calibration and validation modelling of the historic events (November 2010, January 2011, September 2016 and October 2022).

The Hydraulic Modelling Report (R03) describes the hydraulic (TUFLOW) model built, and calibration and validation process in detail. Model performance and alignment with the anecdotal evidence was utilised to determine the hydraulic roughness. Other parameters were selected based on consideration of adopted values from nearby flood studies and regional approximations in the absence of local calibration data.

3.2 General Methodology

The hydrologic assessment of the Newstead flood study followed the following steps:

- Development of a catchment wide RORB rainfall runoff model.
- Calibration of the RORB model to the historic events (November 2010, January 2011, September 2016 and October 2022).
- Completion of a flood frequency analysis (FFA) for the Loddon River at Newstead (407215).
- Adopting routing parameters based on calibration for design event modelling.
- Design event modelling and reconciliation of design event peak flows at the Loddon River at Newstead Gauge with expected quantiles as informed by the FFA.

3.3 Rating Curve Review

At the beginning of the project a detailed review of the Loddon River at Newstead streamflow Gauge rating table was required due flows over 20,500 ML/day are extrapolated. Given that all the significant events at Newstead are larger than this, it was crucial to understand the accuracy of the rating curve for high flows.

A thorough investigation into the gauge was conducted, with the following steps undertaken:

1. A TUFLOW hydraulic model of the gauge site was developed to create a modelled rating curve for a range of steady state flows.
2. The rating table of the Loddon River at Newstead gauge was compared to results of hydraulic modelling of the gauge site to achieve a close match for high flows above gaugings (within the extrapolated region of the rating table). The rating curve review is detailed in the Data Review and Validation Report R01.
3. Several calibration events including the October 2022 flood event, were modelled and showed a suitable agreement with observed gauging. 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).

3.4 Flood Frequency Analysis

A flood frequency analysis (FFA) was completed for the Loddon River at Newstead (407215). The analysis considered all available complete calendar years of data, from 1976 to 2023. The analysis was completed in the software package FLIKE, as recommended by ARR2019. The annual series used data as published by DEECA on Victoria's Water Measurement Information System (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.



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

The adopted FFA quantiles are shown in Table 3-1.

Table 3-1 Adopted FFA quantiles for Loddon River at Newstead (407215)

AEP	Peak Design Flow (ML/day)		
	Log Pearson III	LP III 5% Limit	LP III 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

A graph of Log Pearson III distribution and the observed values is shown in Figure 3-1.

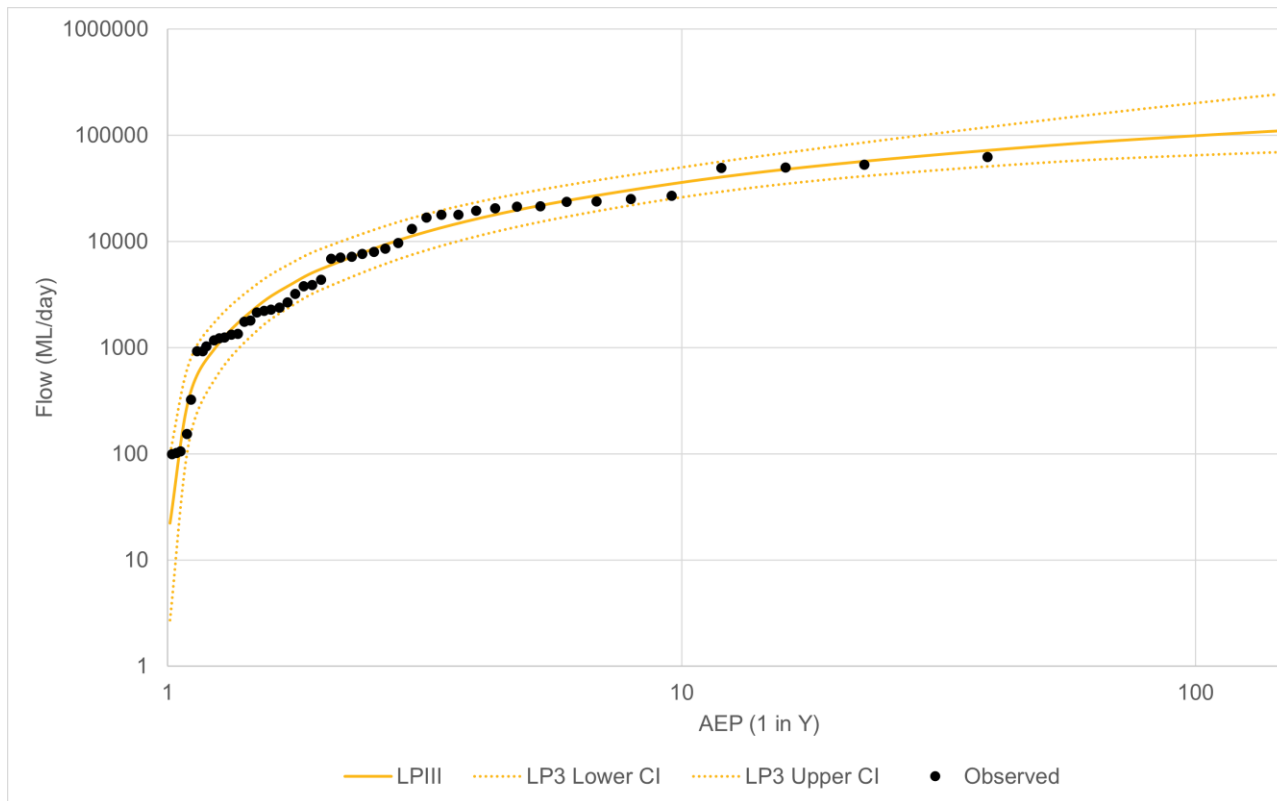


Figure 3-1 FFA: Log Pearson III Distribution

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 3-2 below.

Table 3-2 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%



3.5 RORB summary

3.5.1 Model build

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.

The final RORB model included 201 sub-catchments encompassing a total catchment area of approximately 1103 km², with the hydraulic study area located in the western end of the catchment, see Figure 3-2. The reaches were all defined as Type 1 'natural' and impervious fractions ranged from 0.05 to 0.7. Interstation areas were placed at the gauge locations throughout the catchment. By using interstation areas, it was possible to apply varying K_c values to each catchment individually during the model's calibration phase.

3.5.2 Model parameters

The hydrologic (RORB) model was calibrated using several streamflow gauges, including the Loddon River at Newstead gauge (407215). Where possible, additional gauges were incorporated during calibration to ensure a representative fit across the wider catchment.

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 calibration was completed for 2010, 2011, 2016 and 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 3-3 shows a summary of the RORB parameters adopted for the calibration events.

Table 3-3 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
Mia Mia Creek interstation	4.32		18 - 45	0.75 – 3.00
Catchment outlet	17.47		18 - 45	0.75 – 3.00

The calibration process is detailed in the Hydrology Report R02.



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 3-4 below.

Table 3-4 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			

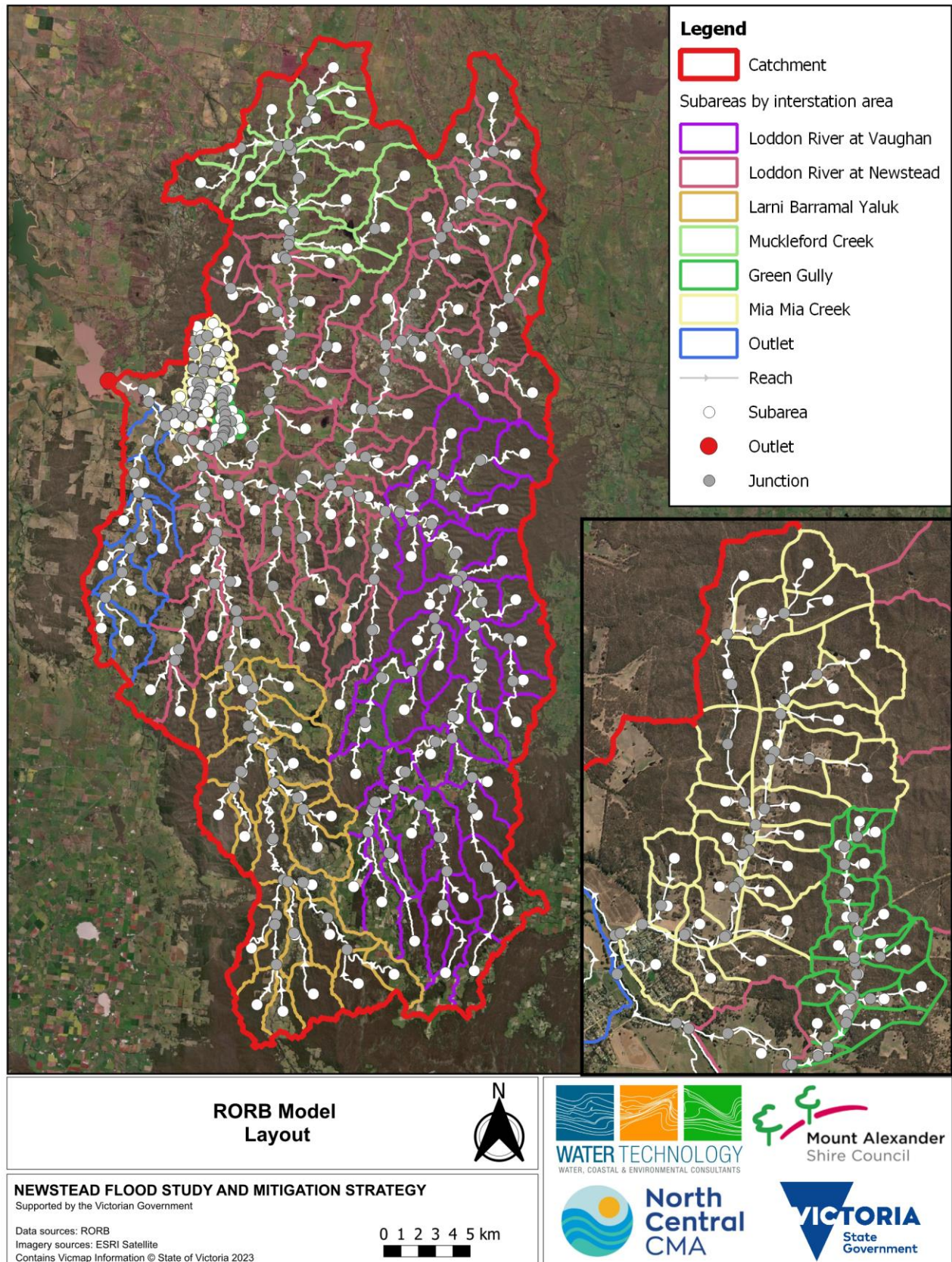


Figure 3-2 RORB model layout



3.5.3 Rainfall

3.5.3.1 Historic events

The RORB model was run for the 2010, 2011, 2016 and 2022 flood events. 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.

3.5.3.2 Design Rainfall

Design rainfall depths were obtained from the Bureau of Meteorology Design Rainfall Data System³. Initially, the baseline 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 baseline 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 Datahub⁴.

- *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.
- *Spatial Variation* was applied in RORB using an Intensity-Frequency-Duration (IFD) data file. GIS tools were used to assign a point rainfall (taken as the average of rainfall grid cells that intersect a subarea) to each subarea. The weighted average rainfall for the catchment and the percentage of the weighted average to be applied to each subarea 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.
- *Median Pre-bursts* rainfall depth was subtracted from the storm Initial Loss to obtain the burst Initial Losses applicable for this study. The burst initial losses were then applied to the design burst rainfall depths. 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.
- *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.

³ <http://www.bom.gov.au/water/designRainfalls/revised-ifu/>

⁴ <https://data.arr-software.org/>



3.6 TUFLOW summary

3.6.1 Model parameters and design

A hydraulic model of Newstead was built using the TUFLOW modelling package. The TUFLOW model design and parameter selection is described in detail in R03 – Draft Hydraulic Modelling Report . A short summary of the modelling logic and selected parameters is provided below however readers wishing to know more about the model build should refer to the full report.

The key TUFLOW model parameters, along with the design approach for key components of the model, are shown in Table 3-5. The TUFLOW model extent and boundary areas are shown in Figure 3-3.

Table 3-5 Key TUFLOW model parameters

Parameter	Value
Model Build	2023-03-AE-iSP-w64
Model Precision	Single Precision
Grid Cell Size	3 metres
Model Orientation	Along Loddon River orientation at Newstead
Sub Grid Sampling	Sample frequency 5, sample distance 0.75 metre
Solution Scheme	HPC
Inflows	RORB hydrographs at 6 inflow locations
Outflow	Height-Flow boundary with a slope of 0.1%
Hydraulic Roughness	Manning's 'n', varies with land use
1-Dimensional elements	Culverts and pipes linked to 2-D domain (note bridges modelled as 2-D bridge flow constrictions)

Table 3-6 Hydraulic roughness

Land use / Topographic description	Roughness coefficient (Manning's n)
Open space, minimal vegetation	0.0375
Open space, moderate vegetation	0.080
Open space, heavy vegetation	0.120
Built-up and residential areas – high density (buildings modelled separately)	0.100
Built-up and residential areas – low density (buildings modelled separately)	0.050
Building footprints	0.400
Industrial, commercial or large buildings	0.300
Waterbodies	0.020
Waterways	0.030
Roads	0.020

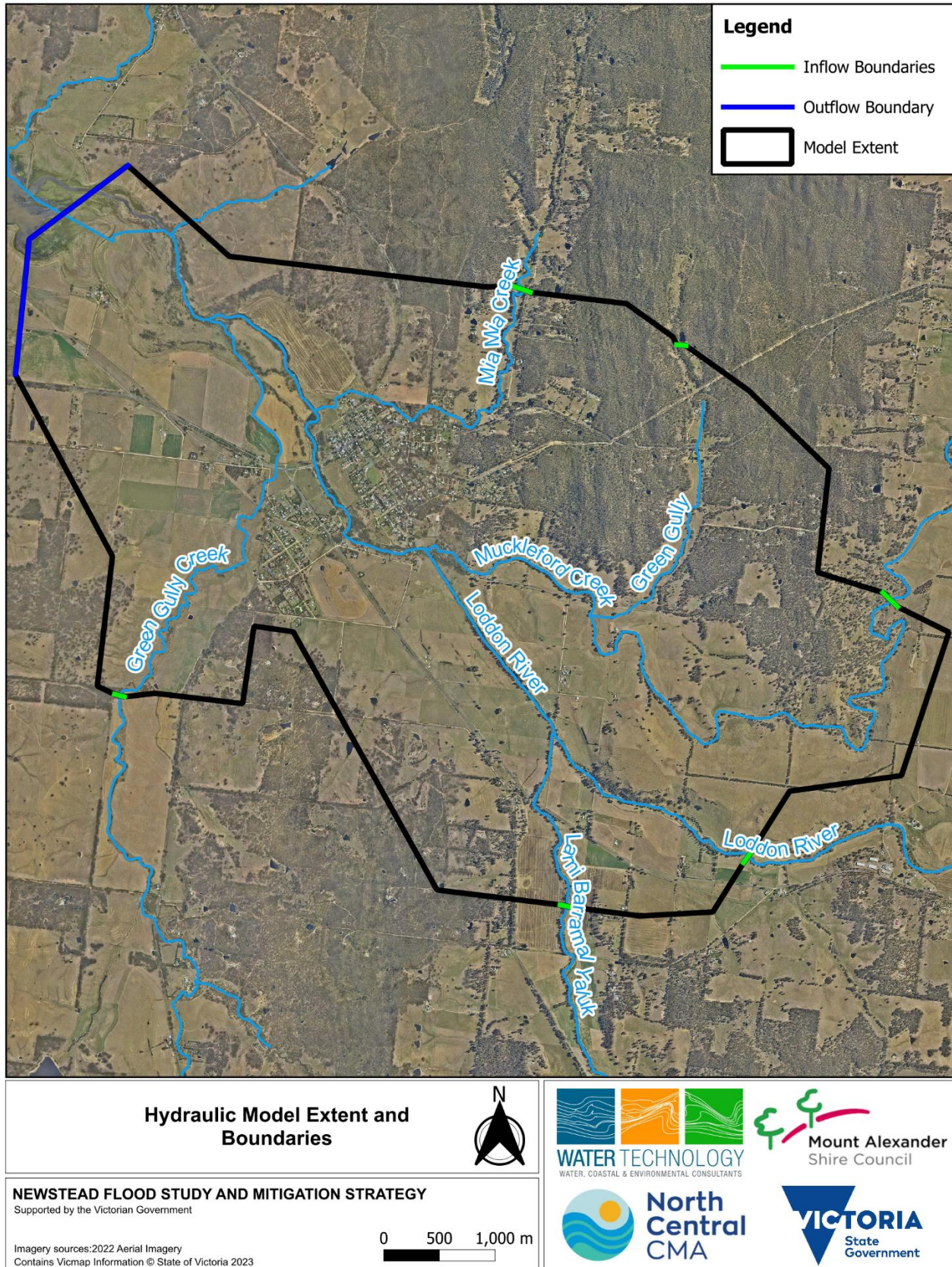


Figure 3-3 Hydraulic model extent and boundaries



3.7 Calibration modelling results

The results of the calibration modelling were used to ensure the models were performing as expected, reproducing depths and extent from the flooding experienced in large flood events.

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.

The hydraulic model calibration focused on the October 2022 event, the largest flood on record at Newstead. The September 2016 event was also modelled as a validation event as it represents a longer duration storm event. The modelled calibration results were compared to anecdotal evidence obtained during the community consultation session conducted in June 2024.

The following calibration data sources were available.

- The Newstead Local Flood Guide (developed by the SES) listing records of historic flood levels and impacts for the 1890, 1909, October 1934, October 2000, January 2011, October 2016 and October 2022 flood events
- Photo evidence gathered for the 1870, 1916, 1934, 2010, 2011 and 2022 flood events.
- Surveyed water levels from the events in 2000, 2010 and 2022, a total of 63 flood marks were provided by the NCCMA.
- Anecdotal evidence obtained during the community consultation session conducted in June 2024.

More detail around the calibration data is presented in the Model Calibration Reports (R02 and R03). Figure 3-4 and Figure 3-5 show the modelled flood depth for the October 2022 and September 2016 events, respectively.

Modelling of the two calibration/validation events has shown an acceptable match to the available calibration data sources, including stream gauge data, flood marks, anecdotal records and photos, indicating the hydraulic model is suitable for design modelling of riverine inundation in Newstead.

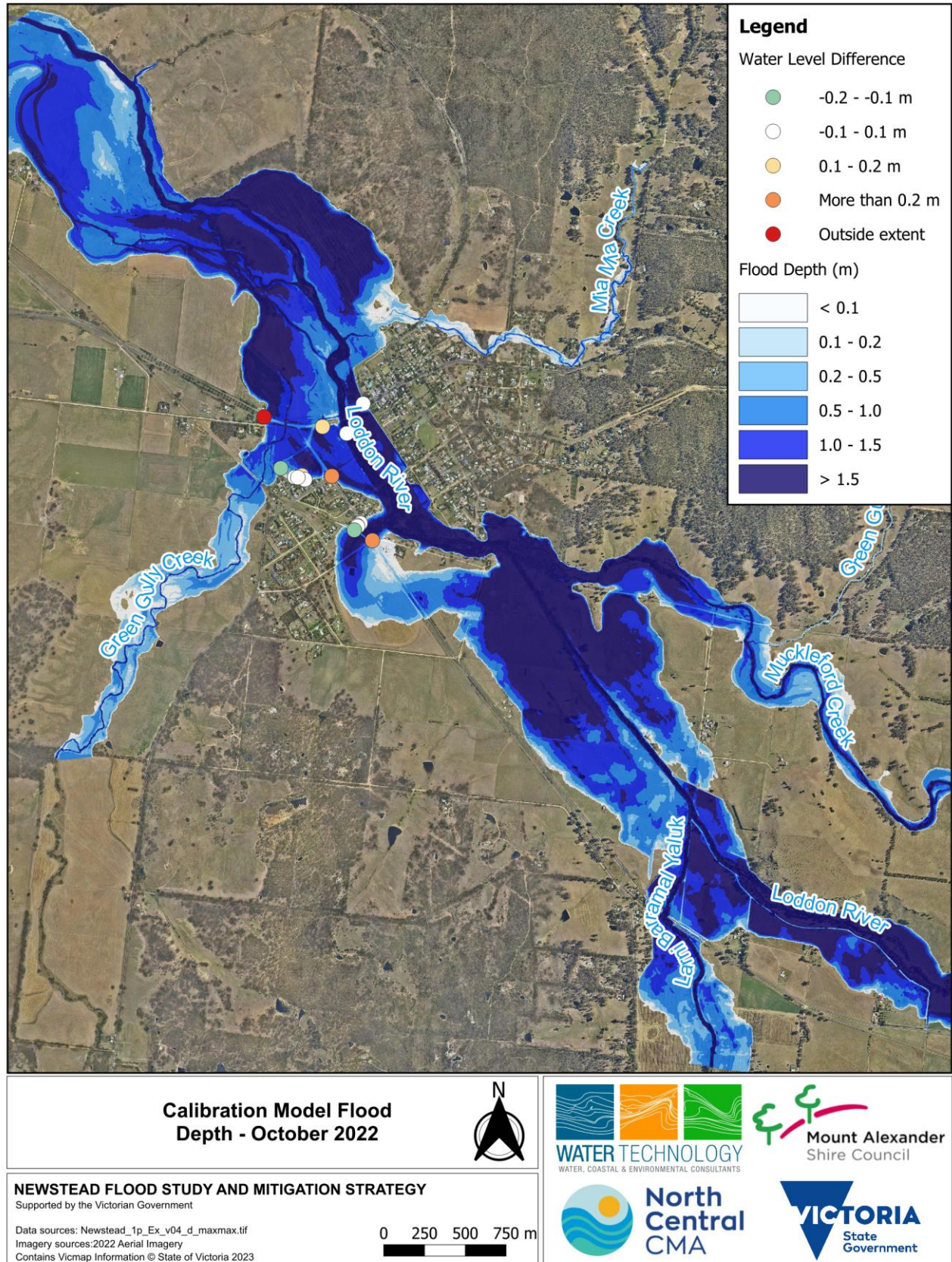


Figure 3-4 Calibration model flood depth – October 2022

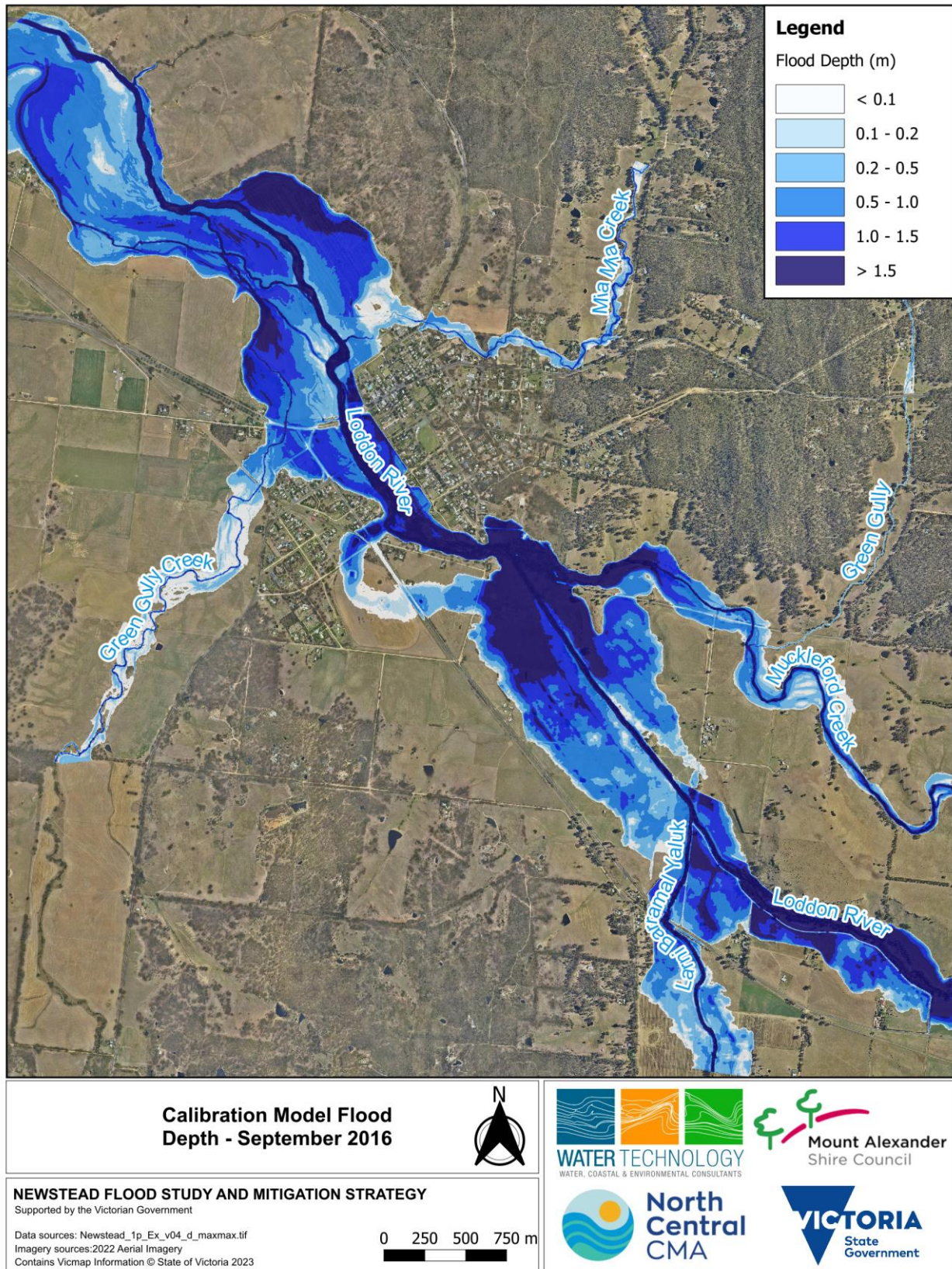


Figure 3-5 Calibration model flood depth – September 2016



4 DESIGN MODELLING

4.1 Hydrology

The RORB hydrologic model was run for a range of design flow events. The design flows at the Newstead gauge, along with the FFA results and confidence limits, are shown in Table 4-1.

Table 4-1 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

4.1.1 Climate Change

The impact of increased rainfall intensity associated with climate change was investigated, with current day scenario design modelling based on the near-term climate change considerations for 2030 (SSP5 – 8.5).

- The model was run for a range of design flow events and the resultant flows at the Newstead Gauge for the near-term climate change scenario is shown in

Table 4-2.

Several additional scenarios have modelled for the 1% AEP event to assess the potential impacts:

The following two scenarios were also considered.

- Projected flows to 2100 under SSP5 – 8.5
- Projected flows to 2100 under SSP3 – 7.0 (1% AEP and 10% AEP only)

The results of the Long-term modelling for the two SSP scenarios are provided in Table 4-3 and Table 4-4.

Table 4-2 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



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

The resultant flows at the Newstead Gauge for the long-term climate change scenario is shown in .

Table 4-3.

Table 4-3 Design flows, critical durations and representative temporal patterns for long-term (2100) climate change scenario (SSP5 – 8.5).

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%

Table 4-4 Design flows, critical durations and representative temporal patterns for long-term (2100) climate change scenario (SSP3– 7.0).

AEP	Loddon River at Newstead Peak Flow (m³/s)	% Increase compared to 2030 SSP5	Critical Duration	Representative Temporal Pattern	Approximate near-term (2030) AEP
10%	821.6	29	18 hour	TP09	Just smaller than 5%
1%	1804.9	35	18 hour	TP09	Between 0.5% and 0.2%,



4.2 Hydraulics

Design flows in the waterways entering the hydraulic model were determined using a hydrology model (RORB) as described in the Hydrology Report (R02).

The flood extents for the full range of modelled AEP events for each catchment area are shown in Figure 4-1, and the 1% AEP maximum depth results are shown in Figure 4-2.

Flood depth maps for the full range of AEPs and the PMF event are provided in Appendix A of the Final Hydraulic Modelling Report (R04). Flood depths for the 2100 1% AEP under SSP5-8.5 is shown in Figure 4-3.

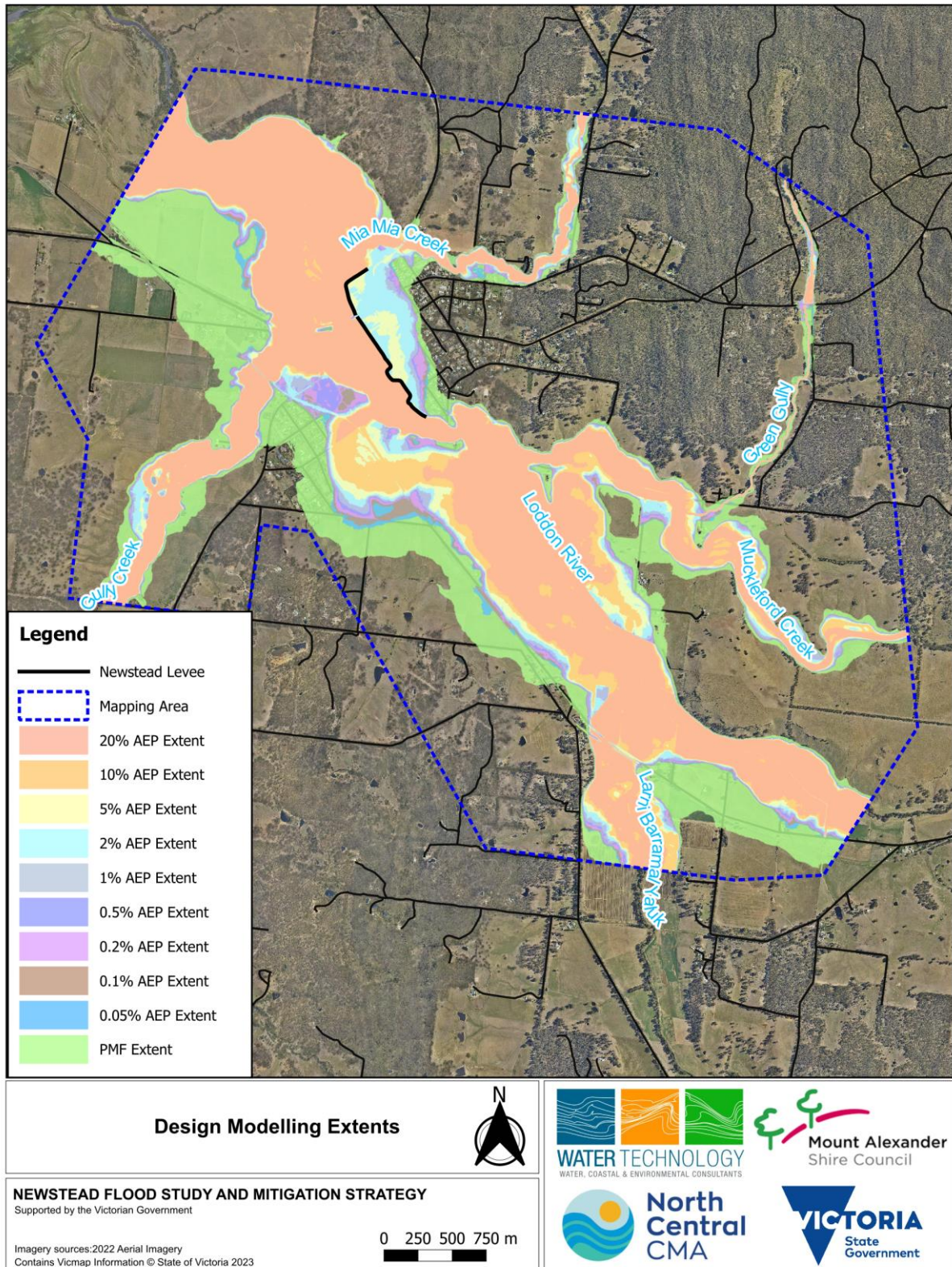


Figure 4-1 Design modelling flood extents

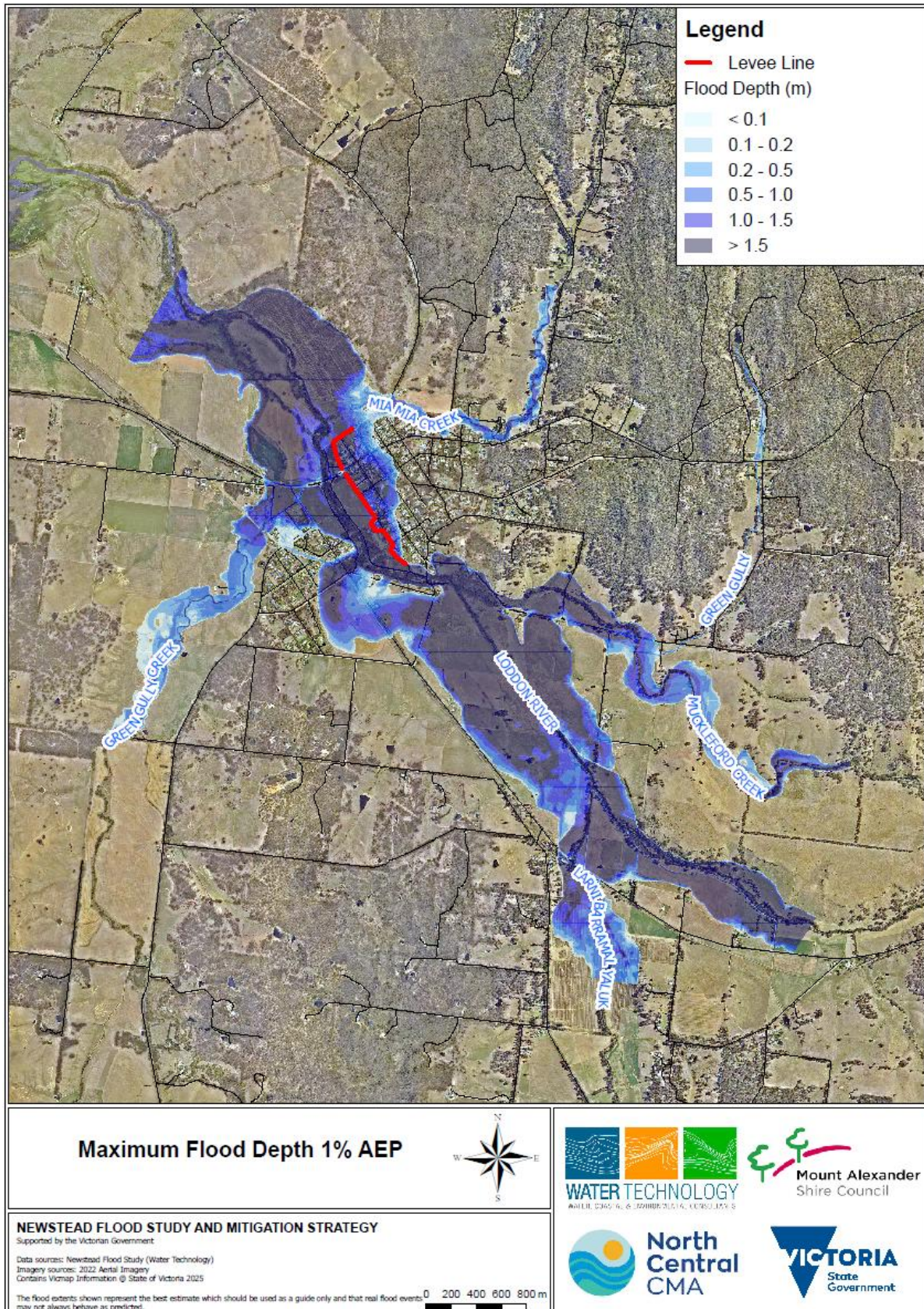


Figure 4-2 1% AEP flood depth

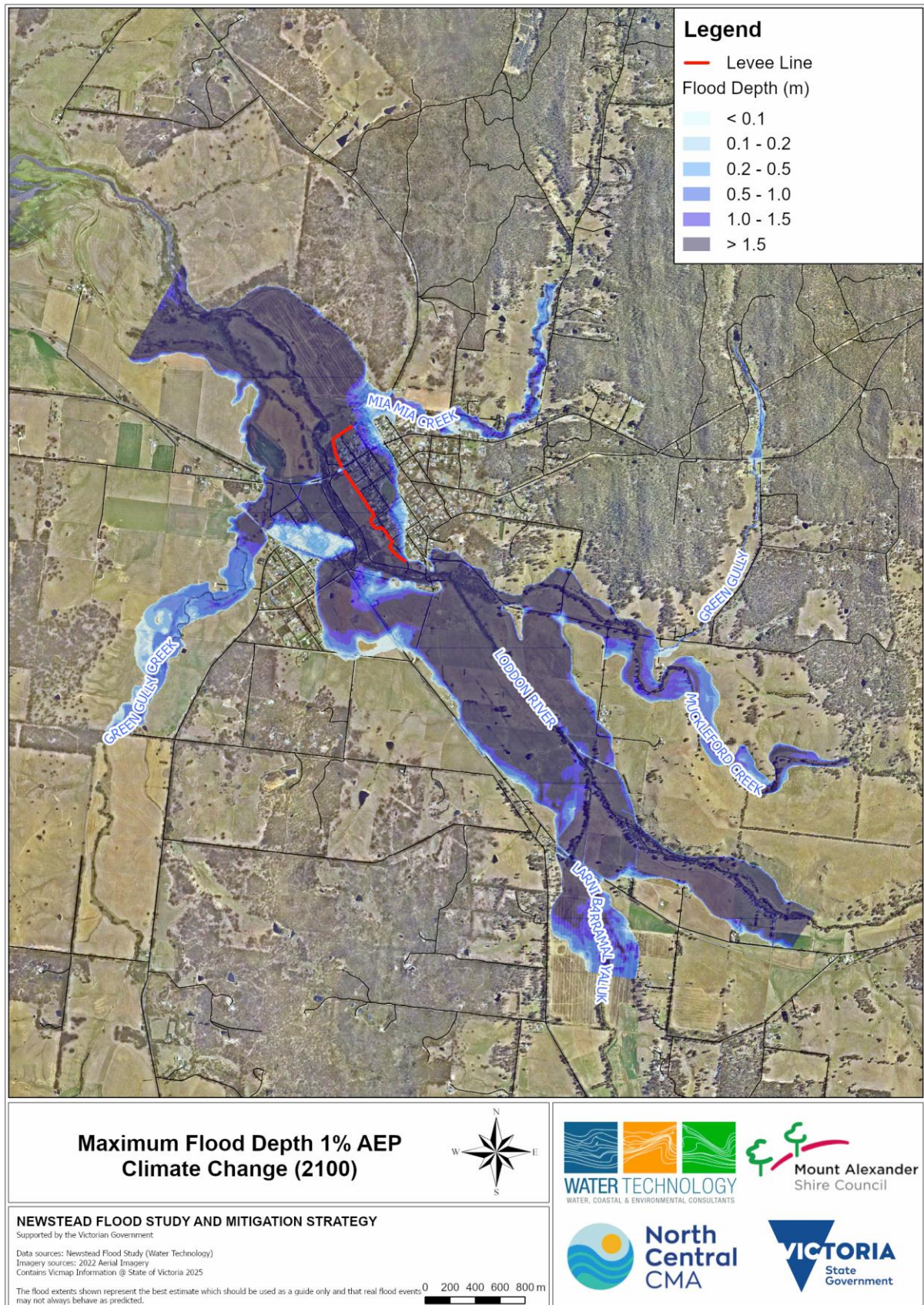


Figure 4-3 1% AEP SSP 5 – 8.5 2100 depth



4.3 Sensitivity testing

Sensitivity testing of the model was undertaken for hydraulic roughness coefficients, blockage of the hydraulic structures and the downstream boundary condition. Sensitivity testing was completed for the 1% AEP event 12-hour duration only, since this is the critical duration at Newstead.

The sensitivity analysis shows that the hydraulic model is somewhat sensitive to hydraulic roughness parameters adopted. For the 1% AEP event, structure blockage and boundary conditions were not shown to have a significant impact on results in the township aside from localised increases upstream of blocked culverts and the model boundary. The details of the sensitivity testings are described in the Hydraulic Modelling Report (R04).



5 FLOOD DAMAGES AND MITIGATION

5.1 Overview

Detail associated with the flood damage and mitigation potential in Newstead is documented in the Flood Damages and Structural Mitigation Options Report (R07).

Flooding in Newstead is primarily caused by the Loddon River, but localised flood events can cause flooding along any of the tributaries. The eastern portion of the Newstead township is located behind a levee bank. When the Loddon River floods, widespread breakouts from the river channel and tributaries are observed in the 20% AEP event inundating farmland upstream and downstream of the township and the Pyrenees Highway is overtopped by Green Gully Creek. The flood behaviour is similar in the 10% AEP event.

The Newstead levee is overtopped in the 5% AEP event, with flood levels up to 0.5 m observed inside the levee. For the 2% AEP event, the flooding behind the levee causes flooding above floor at 80 properties and large areas of Newstead become isolated/inaccessible.

To classify the impact of flooding and risk to the Newstead community, hydraulic flood model results were used to determine the properties and assets likely to be inundated during a range of design events.

5.2 Road inundation

During major flood events the road network is most commonly inundated. There is risk associated with travelling through floodwaters of any depth. Flood water can often unknowingly exceed safe vehicle fording depths and velocities. This presents a risk to community who may become isolated and seek to evacuate and to operational staff and emergency services.

Flood mapping shows several roads within the mapped area can become impacted by flood water during relatively frequent flood events (i.e. 20% AEP). The extent of road inundation for all modelled events is shown in Figure 5-1 and Figure 5-2. Consideration should be given to this information in planning for suitable evacuation routes.

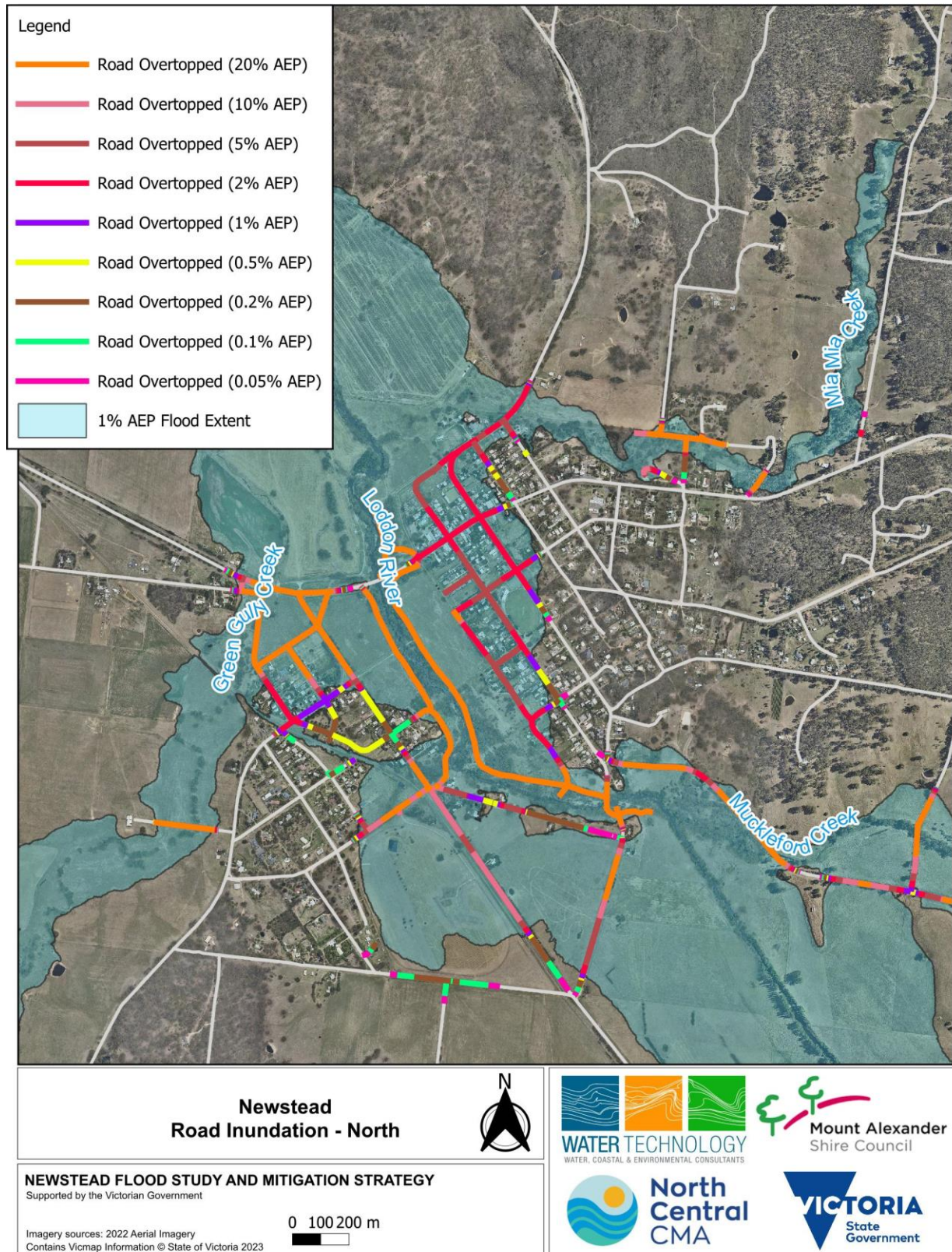


Figure 5-1 Road Inundation - North

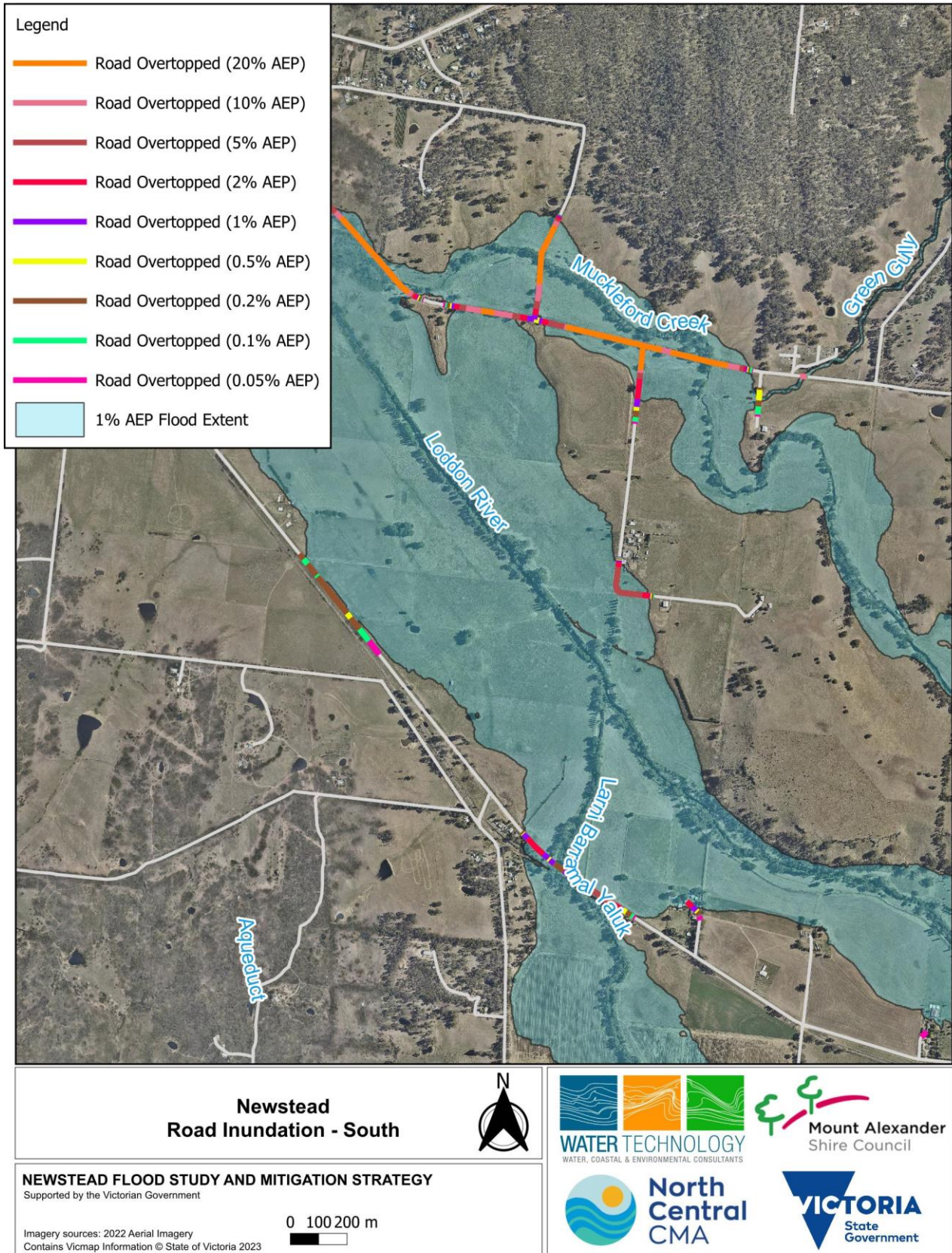


Figure 5-2 Road Inundation - South



5.3 Property inundation

Floor level survey of 148 buildings was captured within the study area, including 24 commercial and 124 residential buildings. These buildings were selected for floor level survey based on the preliminary flood modelling undertaken during this study. It should be noted that there were minor limitations within the floor level survey data captured, in that only the main residential dwelling or commercial building was captured for each property, outbuildings were not surveyed. The number of properties flooded below floor indicates a property with a residential dwelling or commercial building on it. This does not include parcels of land which are flooded but do not have an associated building i.e. vacant lots, farm paddocks etc.

To classify the flood risk at a property scale, two categories were used, these were:

- Property flooded below floor.
 - This indicates the property is within the flood extent, however the flood level is below the surveyed floor level.
- Property flooded above floor.
 - This indicates the property is within the flood extent and the flood level is above the surveyed floor level.

The 1% AEP flood extent and the properties flooded above floor during the range of modelled design events are shown in Figure 5-3. Figure 5-4 outlines the properties which are shown to be flooded above and below floor. The values in those tables were obtained using the difference between flood level and surveyed floor level for each modelled event. Noting that a positive value (shown in red) indicates the property is flooded above floor, while a negative value refers to property flooded below floor.

The existing conditions 1% AEP flood extent and the properties flooded above floor during the range of modelled design events are shown in Figure 5-3 and Figure 5-4. A summary can be found in Table 5-1.

Table 5-1 Summary of property inundation

Design flood event AEP	No. of properties flooded below floor - <u>residential</u>	No. of properties flooded above floor - <u>residential</u>	No. of properties flooded below floor - <u>commercial</u>	No. of properties flooded above floor - <u>commercial</u>
20%	2	0	0	0
10%	6	0	0	0
5%	32	2	1	0
2%	24	67	1	17
1%	21	81	3	18
0.5%	27	86	3	18
0.2%	24	98	5	19
0.1%	20	103	5	19
0.05%	18	106	4	20
PMF	0	124	0	24

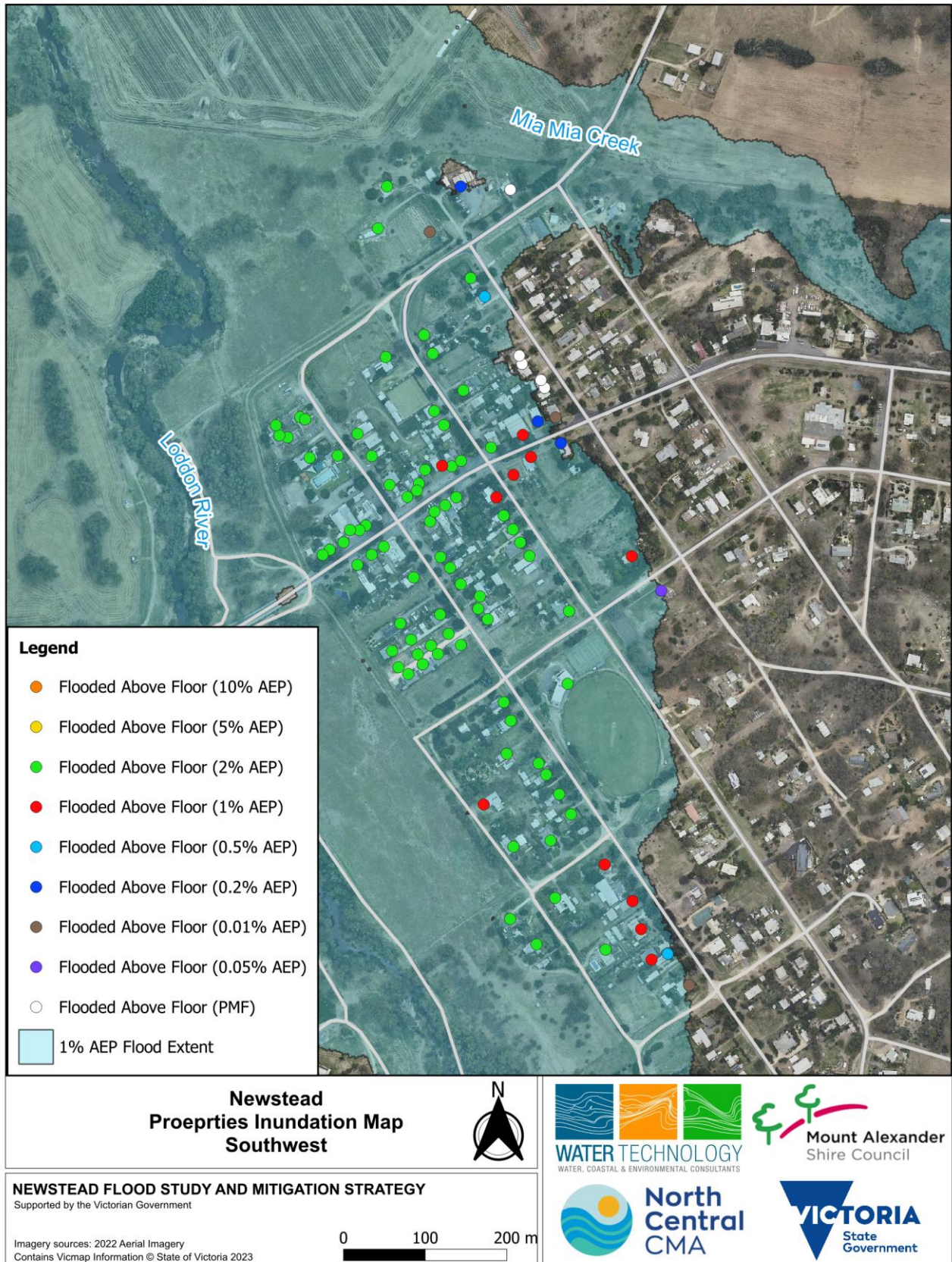


Figure 5-3 Properties flooded above floor – Northeast Newstead

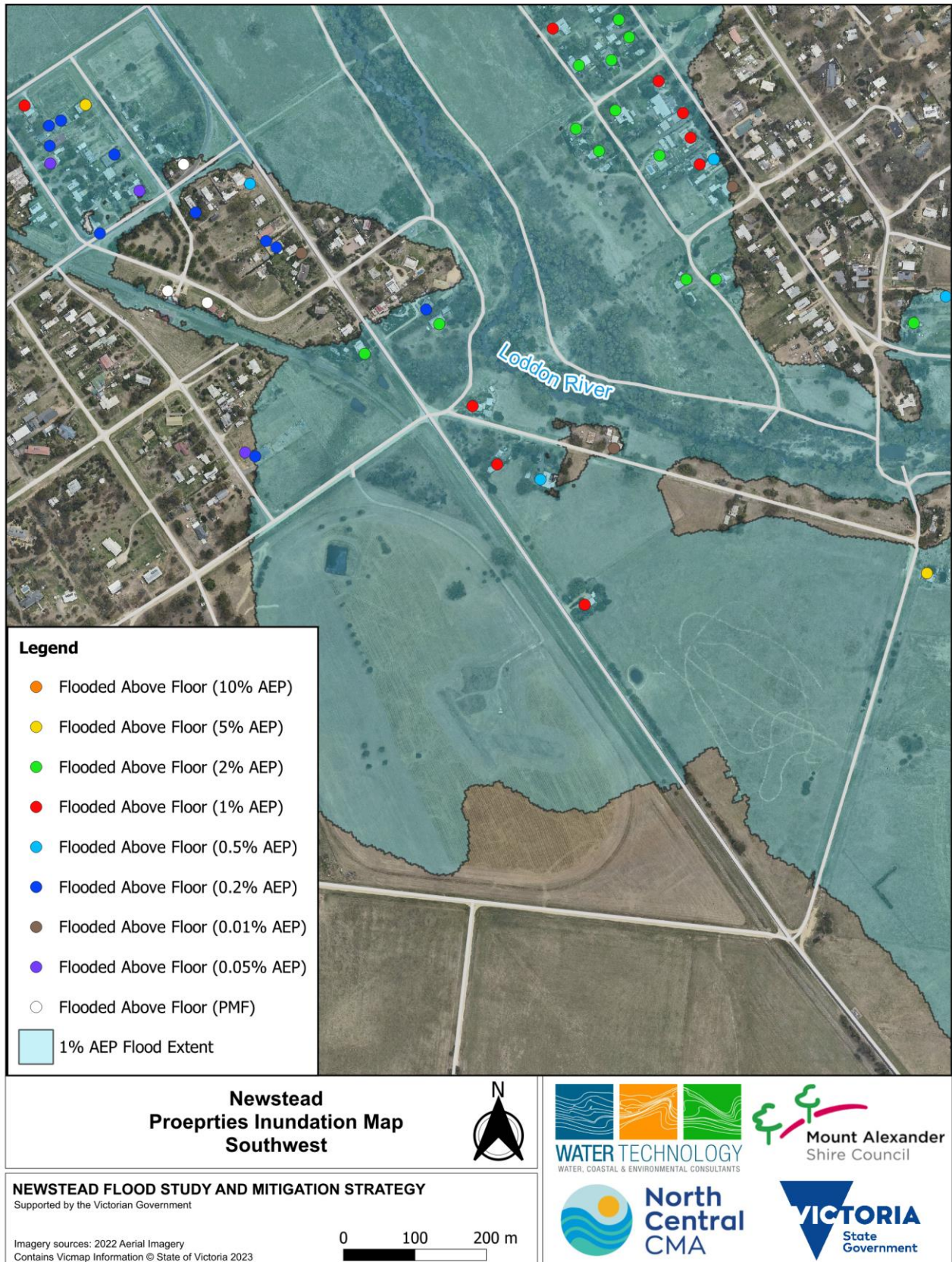


Figure 5-4 Properties flooded above floor – Southwest Newstead



5.4 Damage assessment

Floor level survey was available for 124 residential and 24 commercial buildings. Flood model results for the range of existing conditions events were processed to calculate the Average Annual Damages (AAD) for Newstead, which totals \$951,241. The damages figure considers flooding of roads, properties and buildings. The damages assessment table is shown in Figure 5-5.



	AEP									
	PMF	0.05%	0.10%	0.20%	0.50%	1%	2%	5%	10%	20%
Residential Buildings Flooded Above Floor	124	106	103	98	86	81	67	2	0	0
Commercial Buildings Flooded Above Floor	24	20	19	19	18	18	17	0	0	0
Properties Flooded Below Floor	689	517	511	503	493	475	461	430	357	340
Total Properties Flooded	837	643	633	620	597	574	545	432	357	340
Direct Potential External Damage Cost	\$9,929,312	\$6,389,510	\$6,225,264	\$6,060,100	\$5,803,102	\$5,638,070	\$5,308,640	\$4,314,070	\$3,803,182	\$3,305,974
Direct Potential Residential Damage Cost	\$17,118,766	\$11,965,081	\$11,362,391	\$10,490,362	\$9,087,556	\$8,298,899	\$6,051,423	\$151,691	\$0	\$0
Direct Potential Commercial Damage Cost	\$2,600,015	\$1,686,619	\$1,630,404	\$1,567,636	\$1,435,526	\$1,317,542	\$874,880	\$0	\$0	\$0
Total Direct Potential Damage Cost	\$29,648,093	\$20,041,210	\$19,218,059	\$18,118,098	\$16,326,184	\$15,254,511	\$12,234,943	\$4,465,761	\$3,803,182	\$3,305,974
Total Actual Damage Cost (0.8*Potential)	\$23,718,474	\$16,032,968	\$15,374,447	\$14,494,478	\$13,060,947	\$12,203,609	\$9,787,954	\$3,572,609	\$3,042,546	\$2,644,779
Infrastructure Damage Cost	\$1,174,464	\$692,519	\$662,133	\$611,301	\$541,752	\$513,084	\$469,729	\$293,092	\$220,982	\$161,052
Rural Cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total Cost	\$24,892,938	\$16,725,487	\$16,036,581	\$15,105,779	\$13,602,699	\$12,716,693	\$10,257,683	\$3,865,700	\$3,263,528	\$2,805,831
Average Annual Damage (AAD)	\$951,241									

Figure 5-5 Existing conditions Average Annual Damage (AAD)



5.5 Structural Mitigation Options

5.5.1 Overview

Several structural mitigation options were assessed during this study, focusing on the areas of Newstead impacted by inundation in the 1% AEP flood event. The mitigation options were hydraulically assessed using the 1% AEP design flood event.

The mitigation options assessed in this study are summarised as follows:

- Mitigation Option 1 - Vegetation clearance by reducing the land use roughness in an area covering the riverbed and banks in the vicinity of the Pyrenees Highway bridge.
- Mitigation Option 2 – Raising of the existing levee above the 1% AEP flood level.
- Mitigation Option 3 – Extending the raised levee from option 2 at the northern and southern ends to tie into the existing topography and create a flood barrier for eastern Newstead.
- Mitigation Option 4 – Removal of the Pyrenees Highway bridge and flattening the topography of the bridge abutments to the surrounding ground level.
- Mitigation Option 5 - Combination of vegetation removal option (Mitigation Option 1 above) and raising and extension of existing levee (Mitigation Option 3 above).

The above five options were presented at the community consultation session. Mitigation Option 5 was the preferred option from the community receiving 10 of 13 votes. Feedback from community members regarding the alignment was taken on board as well as a desire to understand the change in impacts on the western side of town as a result of the proposed options. As a result, an additional two options were investigated, and further floor level survey (24 properties) was undertaken.

- Mitigation Option 6 - Raising, extension and realignment of existing levee at two locations to keep the levee on public land and to include properties on the northern end of Wyndham Street within the levee.
- Mitigation Option 7 - Green Gully Creek culvert assessment (A desktop assessment only).

The options were investigated separately and are discussed below. *Not all mitigation options were modelled for all durations. Specifically mitigation options 1, 4 and 5 were only modelled for the 12-hour duration event which is the critical duration along the Loddon River at Newstead but not the critical duration for the smaller tributaries.*

5.5.2 Mitigation Option 1: Vegetation Clearance

This option was represented in the model as a wholesale change in the land use (removal of all vegetation) to identify the maximum reduction in flood levels achievable. Vegetation clearance was modelled by reducing the land use roughness in an area covering the riverbed and banks in the vicinity of the Pyrenees Highway bridge. A flood level difference map for the 1% AEP event is presented in Figure 5-6, comparing the mitigation option to the existing conditions.

This option showed a reduction in flood depth inside the levee of 150mm in the 12-hour event, however no significant reduction in extent. Reductions in flood depth along the western side of town are in the order ~150mm. When comparing the properties flooded above floor, there is a reduction of 5 properties.

This option is not likely to be supported by the CMA due to waterway health impacts. A targeted vegetation removal along the waterway would result in a far smaller impact (reduction in flood levels).

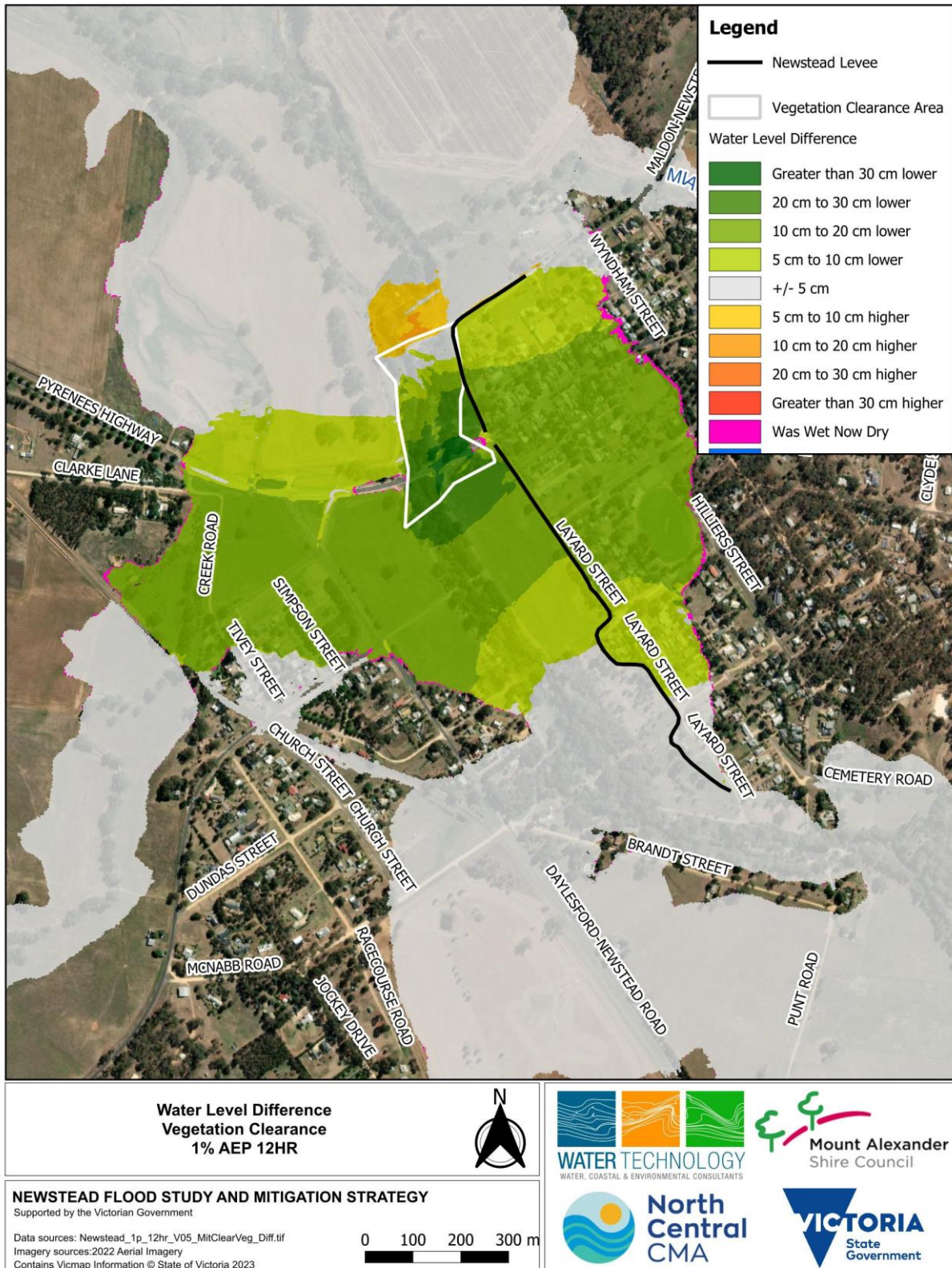


Figure 5-6 1% AEP flood level difference – Vegetation clearance



5.5.3 Mitigation Option 2: Raised Levee

This option assessed raising of the current levee to above the 1% AEP flood level. A flood level difference map for the 1% AEP event is presented in Figure 5-7, comparing the mitigation option to the existing conditions.

The 1% AEP flood shows a reduction in above floor flooding of 33 properties and upto 300mm reduction in depth inside the levee, however flooding still occurs inside the levee above floor level as the levee is outflanked and flooding from the Loddon River and Mia Mia Creek. Increases in flood levels on the western side of town of around 150mm are shown across properties in Simpson Street, Creek Road and Tivey Street. There is minimal increase in flood extent.

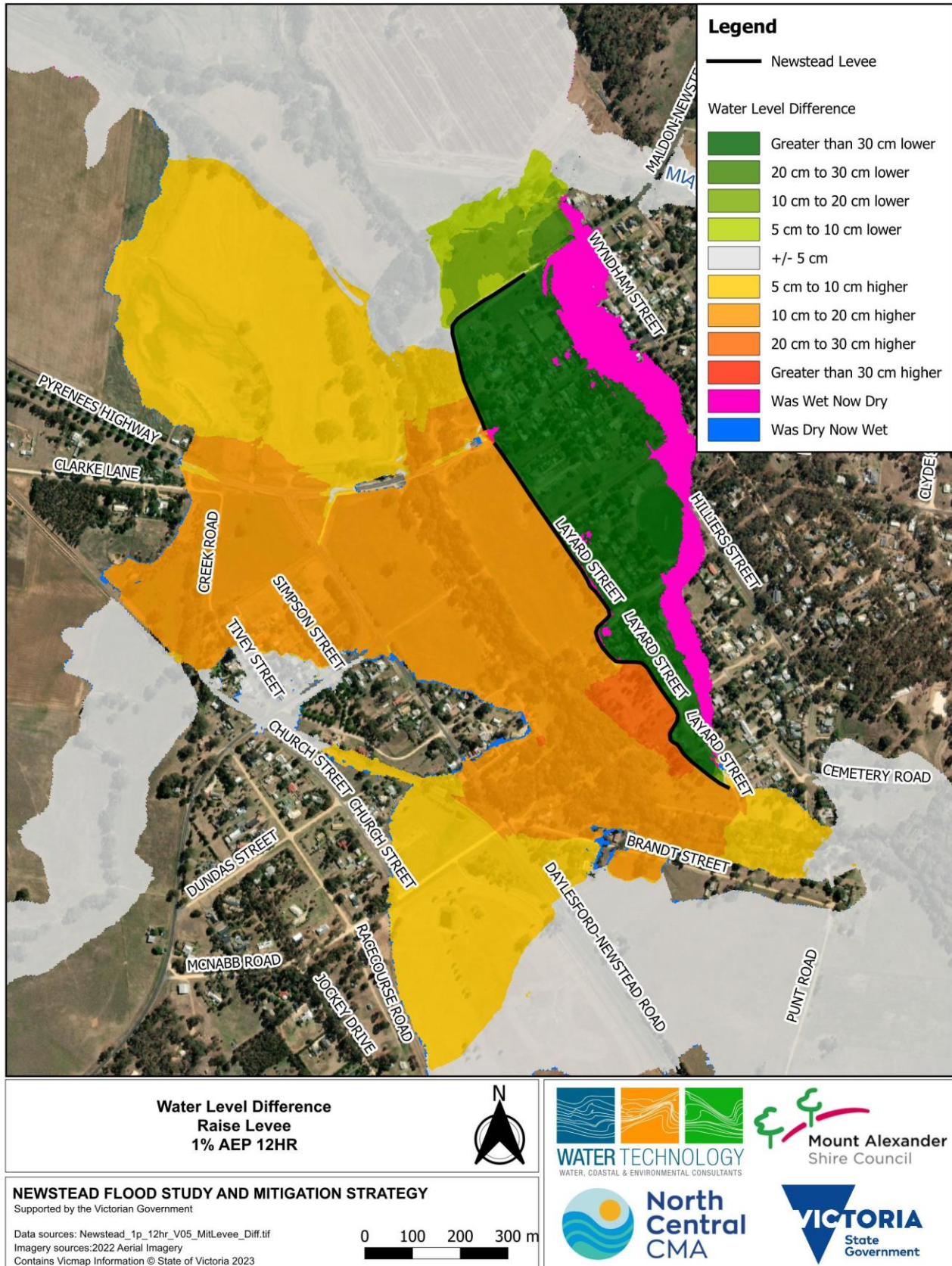


Figure 5-7 1% AEP flood level difference – Raised levee



5.5.4 Mitigation Option 3: Raised and Extended Levee

The raised levee from option 2 was extended at the northern and southern ends to tie into the existing topography and create a flood barrier for eastern Newstead. A flood level difference map for the 1% AEP event is presented in Figure 5-8, comparing the mitigation option to the existing conditions.

The extension of the levee to stop the outflanking from the Loddon River shows a larger reduction in extent compared to Mitigation Option 2. There are reductions in depth upto 300mm depths inside the levee, however above floor flooding still occurs inside the levee as a result of overtopping from Mia Mia Creek. This option shows a reduction in above floor flooding of 67 properties in the 1% AEP event. Increases in flood levels on the western side of town of around 150mm are shown across properties in Simpson Street, Creek Road and Tivey Street as well as an increase in flood extent.

In the 1% AEP flood event, 19 dwellings have an increase in flood level, however there are no properties which show a change from below floor to above floor inundation in this event.

In the 2% AEP flood event, 17 dwellings have an increase in flood level, however there are no properties which show a change from below floor to above floor inundation in this event.

In the 5% AEP flood event, one dwelling changes from below to above floor flooding, however the change in flood level is less than 15mm.

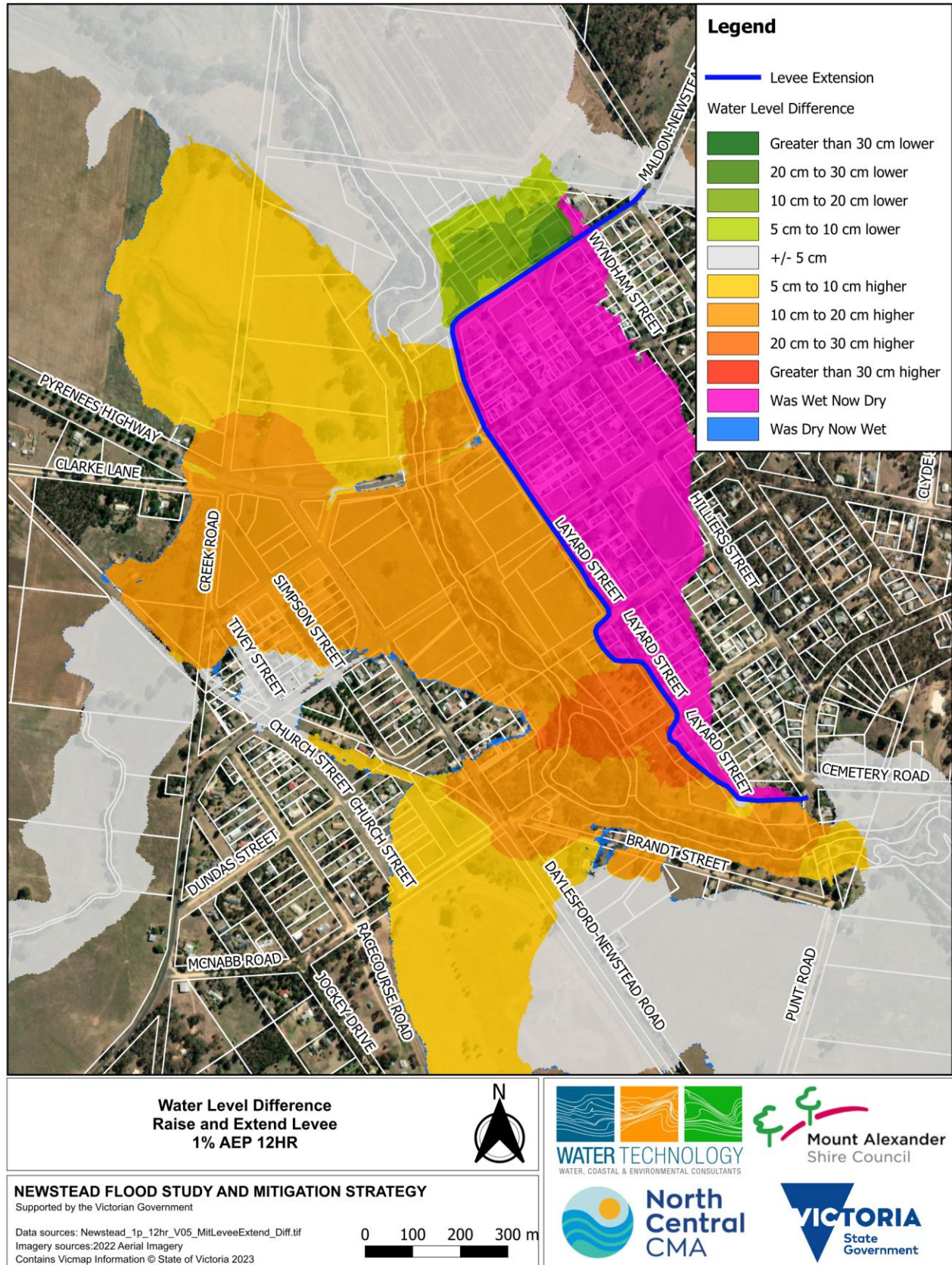


Figure 5-8 1% AEP flood level difference – Raised and extended levee



5.5.5 Mitigation Option 4: Bridge Removed (Pyrenees Highway Bridge)

Removal of the Pyrenees Highway bridge was modelled by removing the bridge structure and flattening the topography of the bridge abutments to the surrounding ground level. A flood level difference map for the 1% AEP event is presented in Figure 5-9, comparing the mitigation option to the existing conditions.

Removing the Pyrenees highway bridge and abutments reduces the flood level by up to 150 mm inside the levee and up to 300 mm outside the levee including through the western side of town, however does not significantly reduce the 1% AEP flood extent. The reduction in flood level results in 5 less properties flooded above floor (in a 1% AEP event) compared to existing conditions. The impacts are similar to those observed for the vegetation clearance option (Mitigation Option 1). There is a minor increase immediately downstream of the bridge. While this shows that the bridge does have some impacts on upstream flood levels, it has no impacts on the flood extent and removing the bridge would provide limited benefits in terms of property inundation.

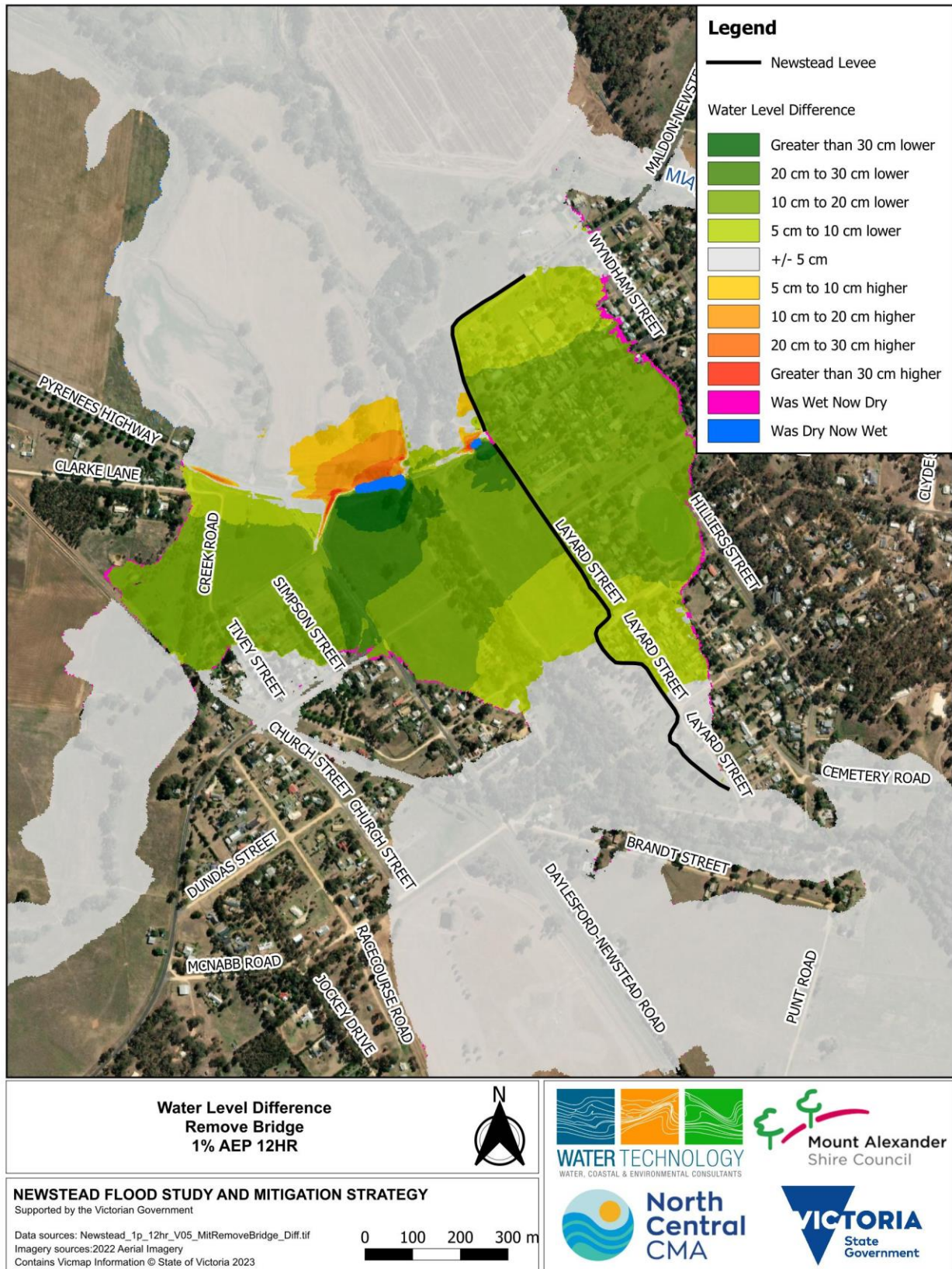


Figure 5-9 1% AEP flood level difference – Bridge removed



5.5.6 Mitigation Option 5: Raised and Extended Levee + Vegetation Clearance

Mitigation options 1 and 3 were combined to assess if vegetation removal can counter for some of the impacts created by raising the levee. A flood level difference map for the 1% AEP event is presented in Figure 5-10, comparing the mitigation option to the existing conditions.

Combining options 1 and 3 reduces the flood extent inside the levee, while flood levels outside the levee are still increased (up to 250 mm) but to smaller magnitude than Option 3. There are 67 less properties flooded above floor compared to existing conditions, with no additional properties flooded above floor outside of the levee. The impacts of flood extent and property inundation are similar to those observed for option 3. The area of increased flood levels outside the levee (through the western side of town) is significantly reduced. There are still similar to Option 3 (upto 150mm) around Brandt Street.

This option which involves extensive removal of vegetation to achieve the reduction in flood levels is not likely to be supported by the CMA due to waterway health impacts. A targeted vegetation removal along the waterway would result in a far smaller impact (reduction in flood levels) outside of the levee.

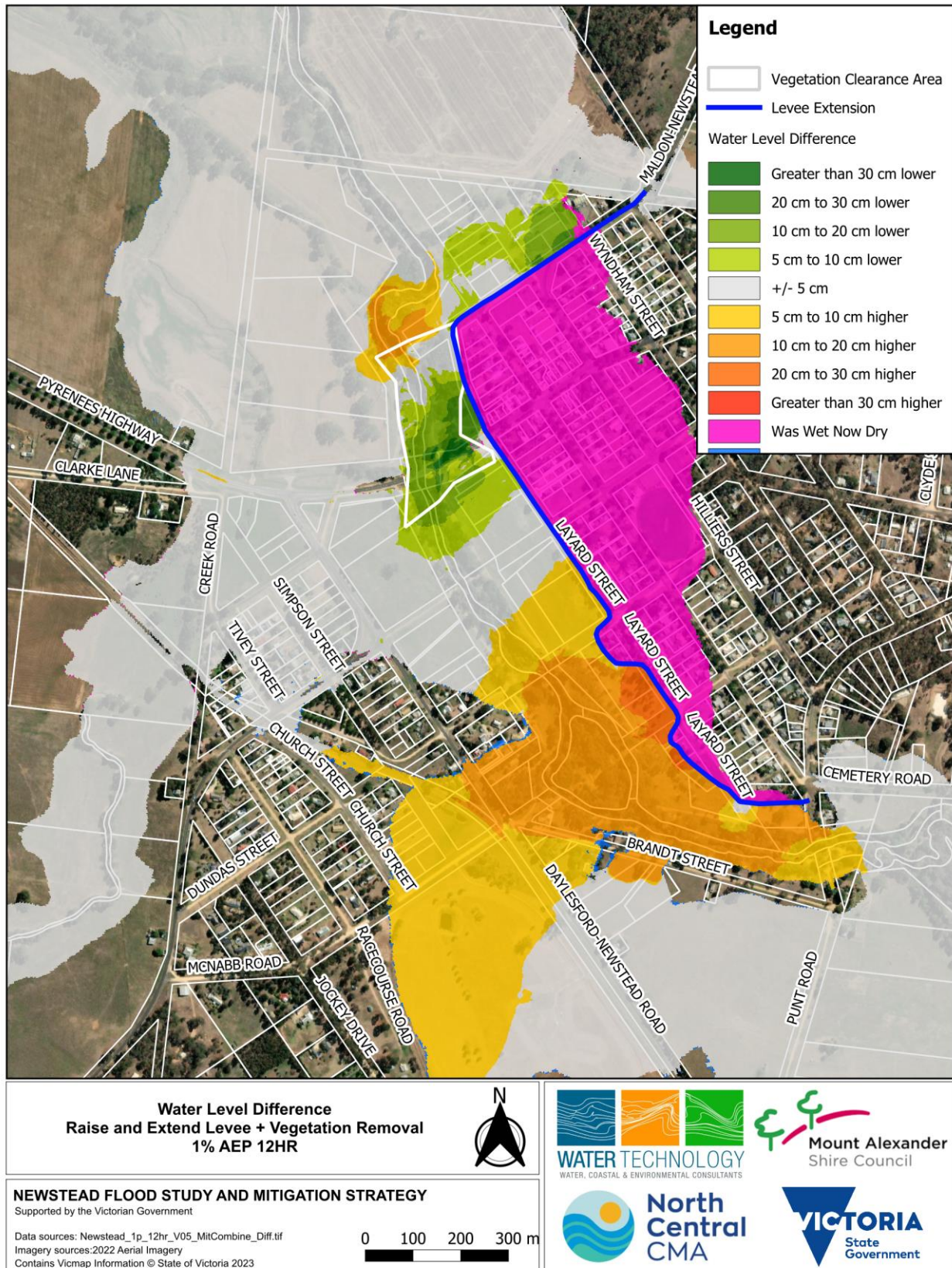


Figure 5-10 1% AEP flood level difference – Raised and extended levee with vegetation clearance





5.5.8 Community Consultation

The above five options were presented at the community consultation session. Mitigation Option 5 was the preferred option from the community receiving 10 of 13 votes. Feedback from community members regarding the alignment was taken on board as well as a desire to understand the change in impacts on the western side of town as a result of the proposed options. As a result, an additional two options were investigated, and further floor level survey (24 properties) was undertaken.

5.5.9 Mitigation Option 6: Raised, Extended and Realigned Levee

The raised and extended levee from Mitigation Option 3 was realigned at two locations to keep the levee on public land and to include properties on the northern end of Wyndham Street within the levee.

- The revised alignment at the northern end of the levee runs closer to Mia Mia Creek rather than the existing alignment which followed the Maldon-Newstead Road. This alignment provides flood protection for an additional five dwellings in the area.
- The alignment at the southern end of the levee was modified to where possible minimise the extent of levee on private land, additionally the alignment was moved slightly closer to the Loddon River to offset the distance from existing dwellings.
- A final section along Mia Mia Creek has two options, to either follow Codrington Road or sit closer to Mia Mia Creek and provides protection to the town from Mia Mia Creek flooding.

A flood level difference map for the 1% AEP event is presented in Figure 5-11, comparing the mitigation option to the existing conditions.

The updated and raised levee alignment completely removes the flood extent inside the levee, while increasing flood levels outside the levee by up to 400 mm. This option results in a reduction of above floor flooding at 87 properties in the 1% AEP flood event.

Impacts outside the levee are similar to Option 3 but show larger increases in flood levels on the western side of the Loddon River. Again there are increased flood levels showing the breakout of flows from the railway cutting at Dundas Street. This leads to 14 additional; properties being inundated between Creswick–Newstead Road, Campbell Street and the railway line in a 1% AEP event. The flood mapping shows the breakout of flow is shallow through these properties flood depths less than 50 mm.

In the 1% AEP flood event, 32 dwellings have an increase in flood level, two properties show a change from below floor to above floor inundation in this event.

In the 2% AEP flood event, 17 dwellings have an increase in flood level, three properties show a change from below floor to above floor inundation in this event.

In the 5% AEP flood event, one dwelling changes from below to above floor flooding.

The larger increases in flood level on the western side of the Loddon River when compared to Mitigation Option 3 indicate the realignment of the levee closer to the river reduces the flow capacity. This option also requires significantly more volume of fill to create the levee as the levee is now placed in deeper sections of the floodplain.

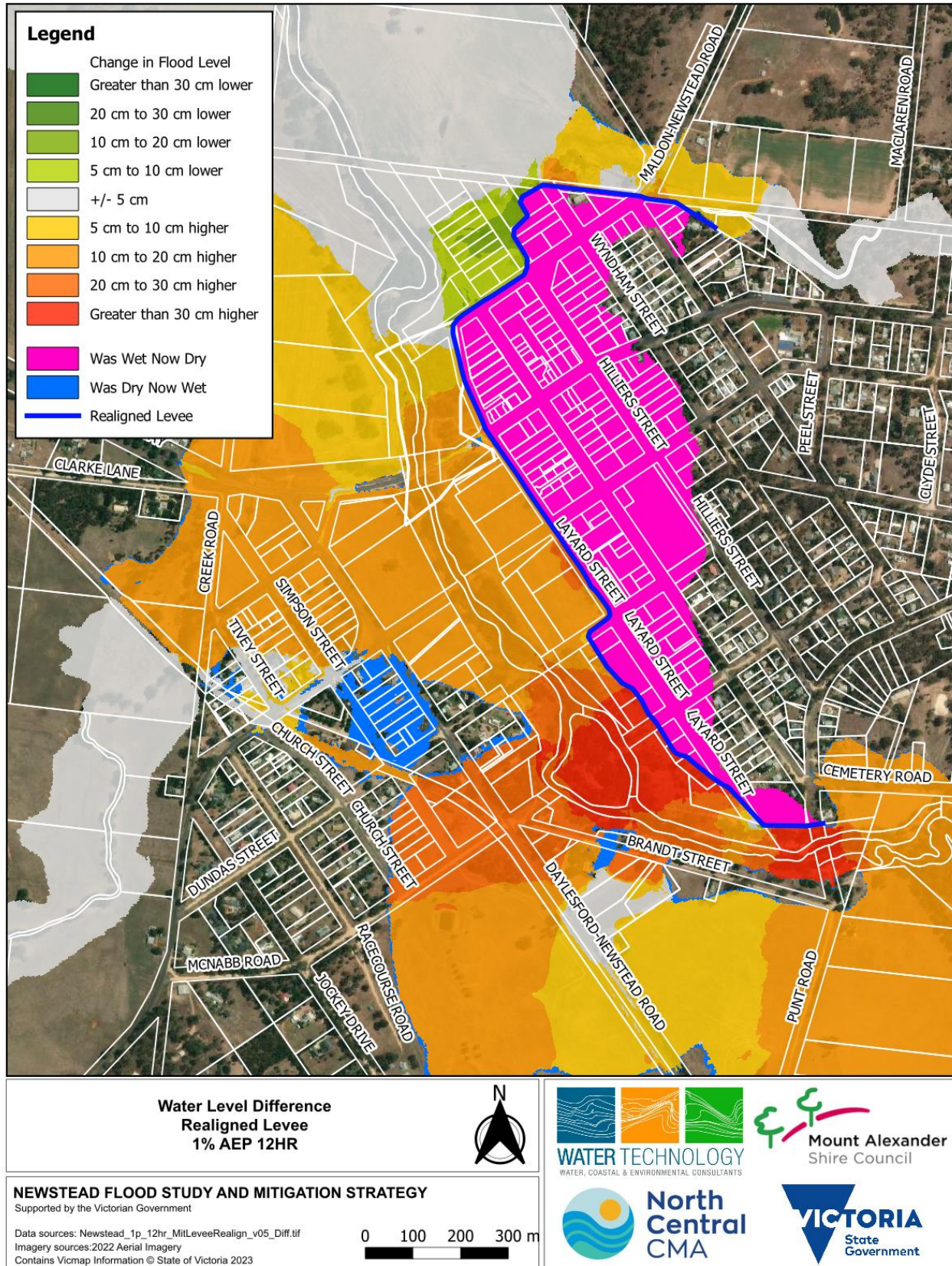


Figure 5-11 1% AEP flood level difference – Raised, extended and realigned levee



5.5.10 Mitigation Option 7: Green Gully Creek culvert assessment

Flood modelling and anecdotal evidence from past flood events identified The Pyrenees Highway being overtopped at Green Gully Creek. Hydraulic modelling of existing conditions shows the road becomes impassable at events greater than a 10% AEP and is overtopped in more regular events.

In considering this option, a desktop assessment was undertaken to estimate the capacity of the existing crossing at Green Gully Creek. The assessment indicated that the current culvert arrangement can convey around 25 m³/s. Total flow from the upstream Green Gully Creek catchment during the 20% and 10% AEP events are presented in Figure 5-12.

The effectiveness of the option is limited in extreme flood events, however it does offer the ability to maintain access from Newstead west towards Maryborough in events upto a 10% AEP or extends the time the road is trafficable in rarer events by several hours. Further investigation and consultation with DTP would be required to identify the impacts of increased culverts or raising the road profile on the flood behaviour upstream and downstream of the road.

Any raising the Highway road profile is likely to result in increased levels on properties upstream, and a comprehensive assessment would be needed to understand the extent of these effects.

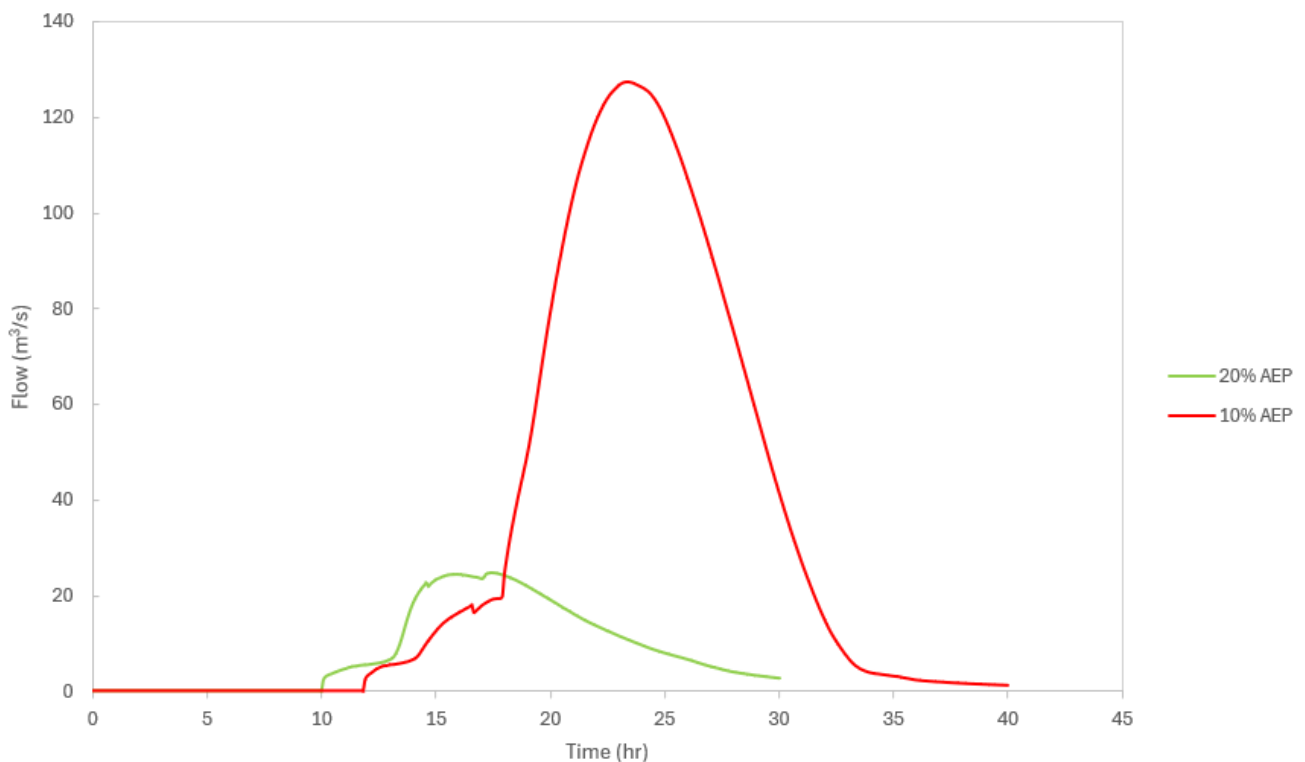


Figure 5-12 Total flow upstream of Green Gully Creek culvert crossing



5.5.11 Mitigation Impacts

A summary of the impacts of each option considered are presented in Table 5-2.

Table 5-2 Summary of the impacts

Option	Reduction in above floor flooding	Impacts on western side of town	Notes
1	5	Reduction in flood levels (150mm)	Not likely to be achievable to the extent modelled due to environment/waterway health considerations.
2	33	100-150mm increase	Levee is outflanked at several locations.
3	67	150mm increase + increased extent. 19 dwellings with increased flood levels in 1% AEP event.	Flooding above floor inside levee occurs from Mia Mia Creek
4	5	Reductions in flood level 150-300mm	Entire removal of bridge and approach embankments.
5	67	Generally less than 50mm. Far less than Option 3.	Flooding above floor inside levee from Mia Mia Creek still occurs. As per Option 1, Not likely to be achievable to the extent modelled due to environment/waterway health considerations.
6	87	200-300mm increase + increased extent. 32 dwellings with increased flood levels in 1% AEP event.	Full protection inside the levee but greater impacts on western side. Significant increase in cost compared to Option 3
7	N/A	Likely to be isolated to around the roadway	Has not been modelled. Does provide additional evacuation/access route time towards Maryborough in events up to 10% AEP of several hours. Provides minimal to no benefit in 1% AEP events

5.6 Mitigation Damages

Similar to the existing conditions, a flood damage assessment was undertaken for the following three options:

- Mitigation Option 2: Raised Levee.
- Mitigation Option 3: Raised and Extended Levee.
- Mitigation Option 6: Raised, Extended and Realigned Levee.

The flood damage assessment determined the monetary flood damage for the range of modelled design events (i.e. 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1% and 0.05% AEP events and the PMF floods). The damage occurring in each of the modelled events has been used to calculate an AAD for the study area. A summary of the flood damage assessment in a 1% AEP event for the three options is shown in .



The expected damage in a 1% AEP event for Option 2 is \$8,739,227, compared to \$12,716,693 under existing conditions a reduction of \$3,977,466.

The expected damage in a 1% AEP event for Option 3 is \$6,337,102, a reduction of \$6,379,591.

The expected damage in a 1% AEP event for Option 6 is \$4,895,810, a reduction of \$7,820,883.

Table 5-3 Mitigation Options 1% AEP Average Annual Damages (AAD) Summary

	1% AEP			
	Existing	Option 2	Option 3	Option 6
Residential Buildings Flooded Above Floor	81	52	27	11
Commercial Buildings Flooded Above Floor	18	14	5	0
Properties Flooded Below Floor	475	518	475	411
Total Properties Flooded	574	584	507	422
Direct Potential External Damage Cost	\$5,638,070	\$5,628,762	\$5,209,727	\$4,667,417
Direct Potential Residential Damage Cost	\$8,298,899	\$4,244,124	\$2,075,687	\$963,571
Direct Potential Commercial Damage Cost	\$1,317,542	\$398,305	\$47,979	\$0
Total Direct Potential Damage Cost	\$15,254,511	\$10,271,191	\$7,333,393	\$5,630,988
Total Actual Damage Cost (0.8*Potential)	\$12,203,609	\$8,216,953	\$5,866,714	\$4,504,790
Infrastructure Damage Cost	\$513,084	\$522,275	\$470,388	\$391,019
Rural Cost	N/A	N/A	N/A	N/A
Total Cost	\$12,716,693	\$8,739,227	\$6,337,102	\$4,895,810



5.6.1 Cost-benefit analysis

Based on the modelling presented above and discussions with MASC, it was determined to assess a cost-benefit analysis for the three options; The selected options were Option 2: Raised Levee, Option 3: Raised and Extended Levee and Option 6 Raised, Extended and Realigned Levee.

The resultant AAD for Option 2 was \$836,934 per year, providing an annual reduction of \$114,307. The resultant AAD for Option 3 was \$764,965 per year, providing an annual reduction of \$218,261. The resultant AAD for option 6 was \$707,385 per year, providing an annual reduction of \$243,856. The reduction in AAD is a result of fewer properties being inundated above floor in almost all events.

For Mitigation Option 6, there are in total 87 less properties flooded above floor in the 1% AEP event. There is also a reduction in properties flooded below floor in most of the analysed events, and a significant reduction in costs associated with infrastructure damage for all events except for the PMF event.

A high-level cost estimate was developed based on cost estimates developed by Price Merrett. A 30% contingency was included in the total cost estimates for each option to account for unforeseen contingencies, along with a 10% Engineering Fee and 12% Administration Fee. Other assessments including Cultural and Heritage, Environmental, Flood Impact and Geotechnical Report fee estimates have been lumped together. The cost/benefit was assessed in terms of the net present value of the option. A 50-year project timeline was adopted with a discount rate of 6% and an annual maintenance fee of \$4,000.

5.6.2 Summary

Several mitigation options were tested in the Newstead hydraulic model, focusing on reducing damage and hazard associated with the flooding from the Loddon River impacting central Newstead. Impacts of each mitigation option were demonstrated, with raising, extending and realigning the levee deemed as the option which provides the greatest protection to the township.

Flood damages, in the form of Average Annual Damages (AAD), were assessed for Newstead based on flood modelling of three options undertaken as part of the Study. Construction cost estimates were assessed against the reduction in AAD from the existing case to inform net present value analysis.

- Mitigation Option 2: Raised Levee was the cheapest option but has the smallest reduction in damages and above floor flooding.
- Mitigation Option 3: Raised and Extended Levee reduced above floor flooding by 67 properties but still has above floor flooding inside the levee (from Mia Mia Creek) but has some increased flood levels on the western side of the town.
- Mitigation Option 6: Raised, Extended and Realigned Levee reduced above floor flooding by 88 properties but was the most expensive option and results in larger increases to the western side of the town.

The report recommends that a Mitigation Option 6 be explored further as the preferred option. This would include opportunities to reconfigure the alignment in the southern end of the levee to where possible reduce the volume of fill material required as well as investigate opportunities to reduce the increased flood levels on the western side of the town.

5.7 Planning scheme mapping

The Victoria Planning Provisions (VPPs) contain several controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), the Urban Floodway Zone (UFZ) and the Environmental Significance Overlay (ESO). Inclusion of flood



mapping in the planning scheme is a key non-structural mitigation measure to prevent flood risk from increasing into the future.

Currently there are no flood-related planning overlays in Newstead. Flood-related planning overlays should be developed as direct outcomes from this study. Updating the planning scheme mapping allows development applications within the floodplain to be assessed in line with current national, state, regional and local policies. The ultimate effect of this will be to discourage inappropriate development within the floodplain, reducing the number of future buildings and occupants exposed to flood risk.

Draft planning scheme mapping has been produced in line with the project brief and discussions with North Central CMA. The draft flood related overlays have been developed based on two climate change scenarios: the 1% behaviour for the year 2100, as projected under Shared Socioeconomic Pathways SSP3 and SSP5 respectively. Flood modelling of the scenarios was undertaken in line with Australian Rainfall and Runoff 2019 (V4.2) and is detailed in R04 – Final Hydraulic Modelling Report. The most appropriate controls considered for application in Newstead include the Land Subject to Inundation Overlay (LSIO), the Floodway Overlay (FO) and the Special Building Overlay (SBO).

- **Land Subject to Inundation Overlay (LSIO)** – defines the floodplain fringe and lower hazard areas within the 1% AEP flood extent

Purpose: Land Subject to Inundation Overlays are planning scheme controls that apply to land affected by flooding associated with waterways, natural flow paths and drains. Such areas are commonly known as floodplains. The LSIO is used to identify flood fringe areas of the floodplain where flooding depths and velocities are typically lower.

- **Floodway Overlay (FO)** – defines the high hazard portion of the floodplain

Purpose: Floodway Overlays apply to land that's identified as carrying active flood flows associated with waterways, natural flow paths and drains. The overlay is characterised by areas impacted by deep and or fast flowing floodwaters during the 1% AEP flood event.

- **Special Building Overlay (SBO)** – defines the portion of the floodplain within the Newstead Township that is located inside the levee

Purpose: Special Building Overlays are to ensure that future developments allow the free passage of floodwaters, minimise flood damage, and are safe with flood hazard and local drainage conditions.

The LSIO and FO layers have been developed in line with the North Central CMA criteria, as shown below:

- LSIO – area inundated in a 1% AEP flood extent.
- FO – area inundated meeting the following criteria:
 - Land where the 1% AEP flood depth is likely to reach or exceed 0.5 metres, and/or
 - Land where the 1% AEP flood hazard factor (the produce of depth and velocity) is likely to reach or exceed 0.4 m²/s.
- SBO - area inundated in a 1% AEP flood extent located inside the Newstead Township levee.

Two draft maps of the proposed overlays are shown in Figure 5-13 and Figure 5-14.

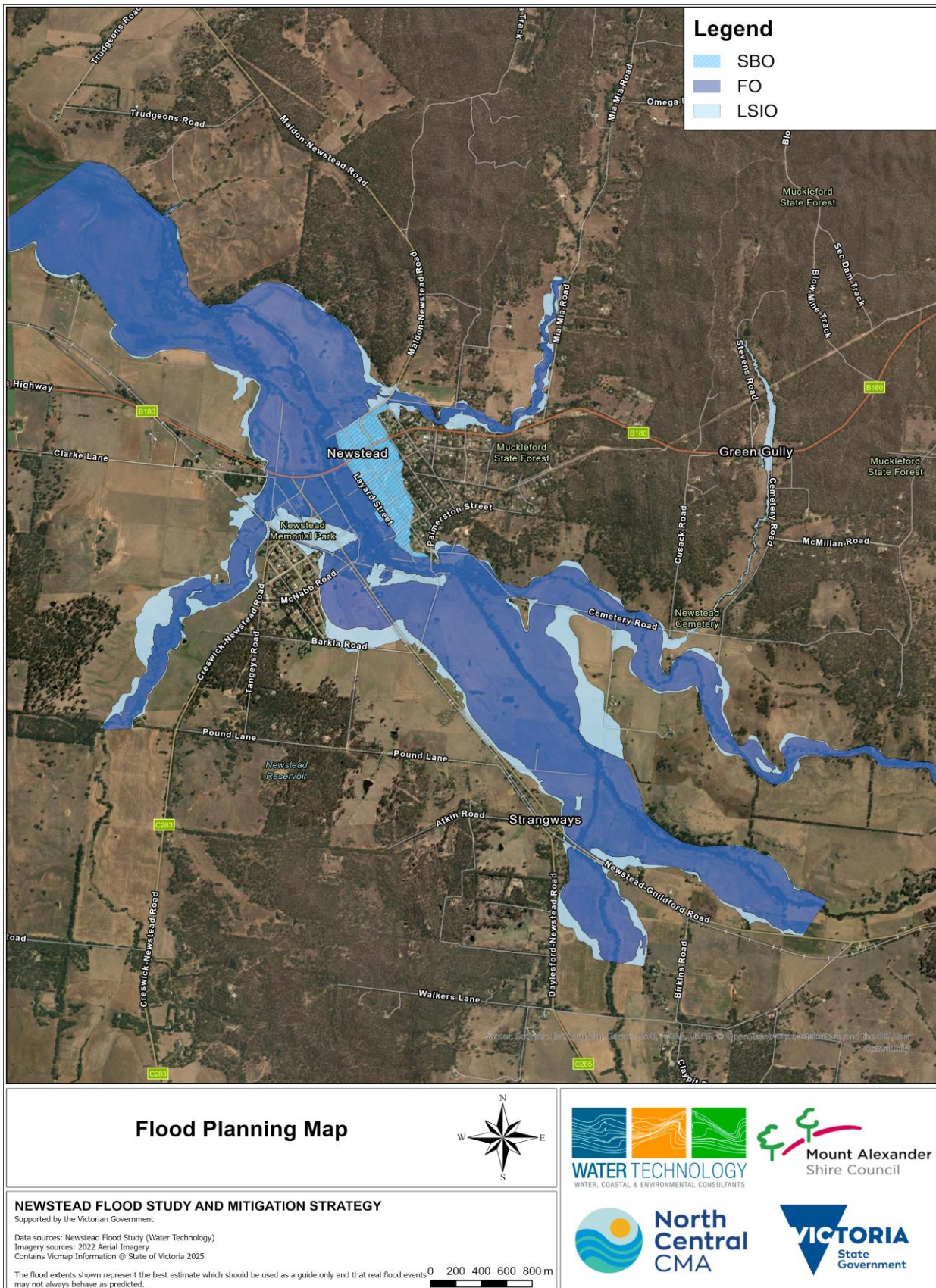


Figure 5-13 Draft Flood Related Planning Overlays developed using the 2100 SSP5 event

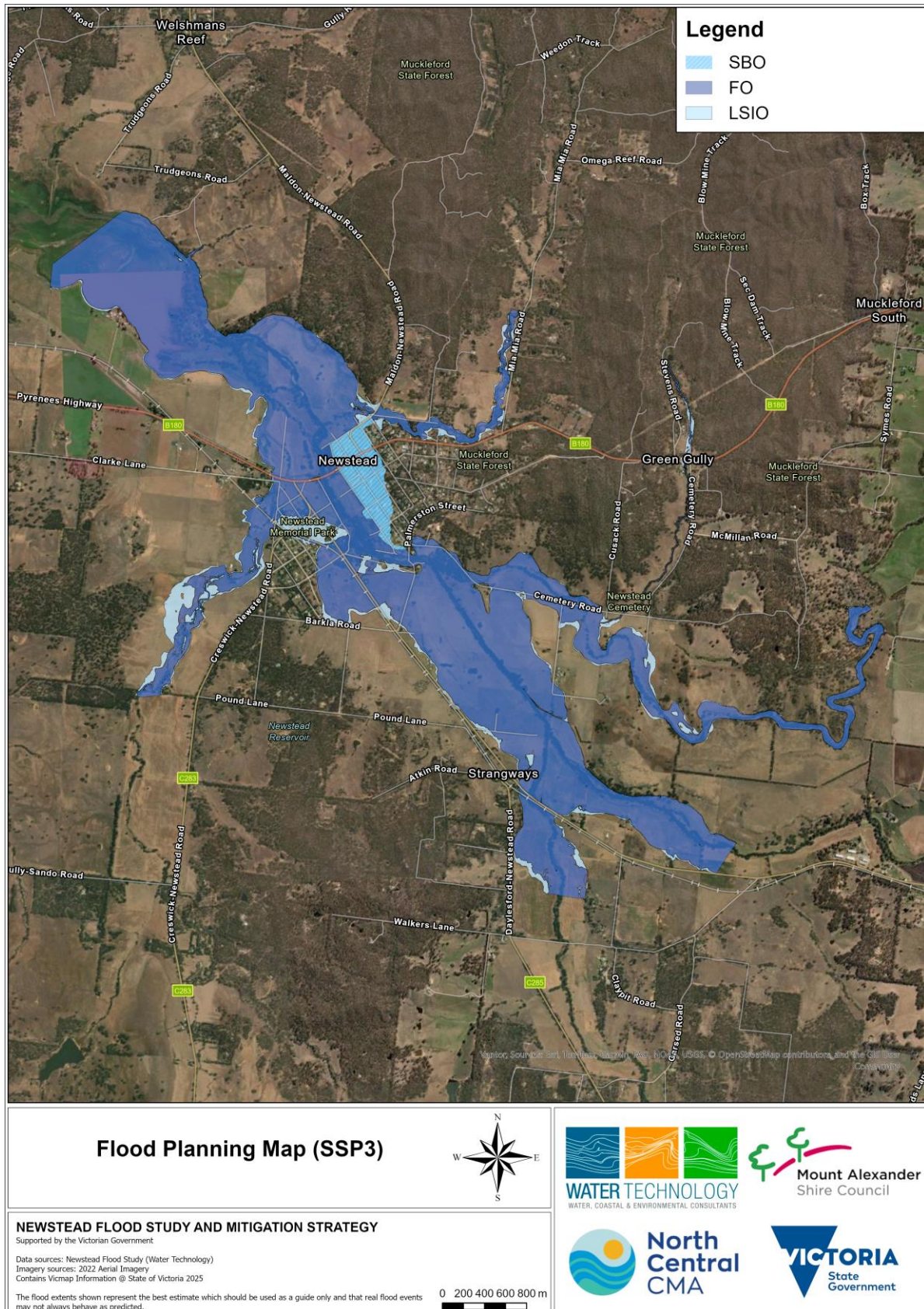


Figure 5-14 Draft Flood Related Planning Overlays developed using the 2100 SSP3 event



6 FLOOD INTELLIGENCE AND WARNING

6.1 Overview

Flood intelligence and flood warning outputs utilise the 1% AEP + climate change under SSP5 for 2030. This was considered the most appropriate scenario given the date of the study and current climate change advice, determined in consultation with the project technical reference group.

In line with the project brief, the following flood intelligence products were produced:

- Flood/No flood tool – rainfall intensity and flooding indicator.
- Flood peak calculator – river gauge level correlations.
- Flood peak travel time calculator/warning time available.
- Modelled/calibrated hydrographs at gauging stations.
- Prepare draft documentation for insertion into the Mount Alexander Flood Emergency Plan (MFEP), this includes:
 - Flood intelligence card
 - Property and road inundation tables, mapping and data (inundation depth and time) for all properties and roads impacted by flooding.
 - Proposed updates to other outdated information in the MASC MFEP relating to Newstead (Appendix A, B and C)

6.2 Flood peak travel time

Definitive information on the time it takes for flooding to develop (i.e. to arrive at a location) following the onset of heavy rain and the time it takes for the flood peak to be reached is highly variable. The magnitude and timing of a flood is dependent on several factors including the attributes of the rainfall/storm event and antecedent conditions. **Timing of flooding in the Newstead township is however likely to be within 11 to 54 hours.**

Table 6-1 Flood peak travel timing

From	To	Typical travel time
Start of rainfall (catchment)	Start of Loddon River rising in Newstead	11 hours to 4 days
Start of Loddon River rising in Newstead	Peak Loddon River level at Newstead	11 to 54 hours
Peak Loddon River level at Vaughan	Peak Loddon River level at Newstead	0 to 5 hours
Peak Muckleford Creek level at Muckleford	Peak Loddon River level at Newstead	2 to 5 hours
Peak Larni Barramal Yaluk level at Yandoit	Peak Loddon River level at Newstead	0 to 6 hours

6.3 Flood/No Flood tool

The Intensity Frequency Duration (IFD) design rainfall data used in the development of Mount Alexander Flood Emergency Plan (MFEP) can be utilised along with forecast and observed rainfall data as an early warning tool. The data can be used to identify the likely magnitude of flooding and resulting consequences based on the predicted rainfall depths of an event. The flood/no flood tool is presented in Figure 6-1 and discussed in detail in the Municipal Flood Emergency Plan (MFEP) Documentation (R06).



6.4 Municipal Flood and Storm Emergency Plan Flood Intelligence Table

A set of summary tables were developed for Newstead, to be read from top to bottom, with each subsequent larger magnitude event reporting on the incremental changes in consequences across different regions of the study area. This is presented in the Newstead Flood Intelligence Documentation.

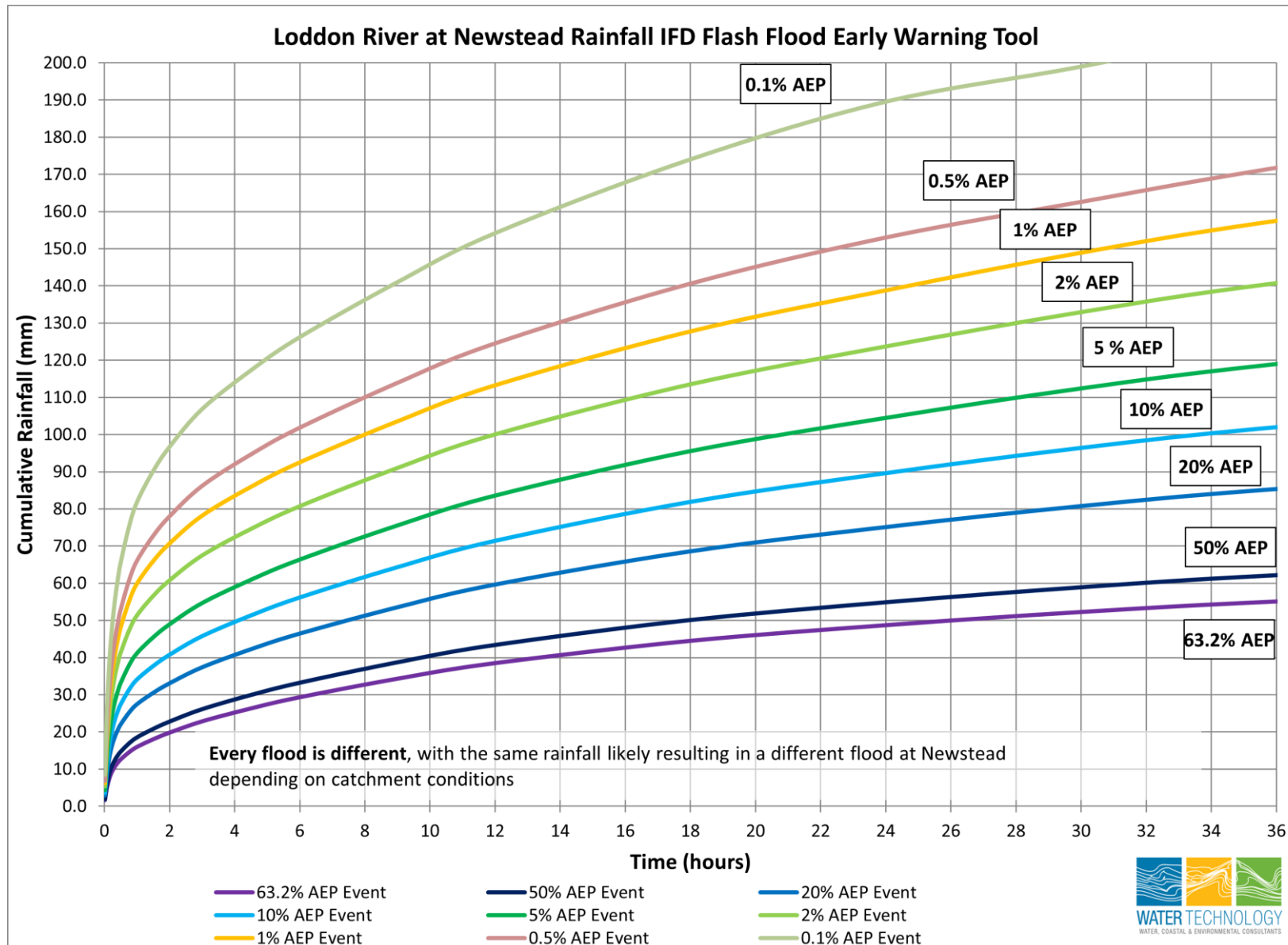


Figure 6-1 Loddon River at Newstead Flood/No flood tool



7 SUMMARY

The Newstead Flood Study has produced detailed flood modelling of Loddon River upstream of Newstead and its tributaries. The mapping produced by this study is fit for the purposes of flood emergency planning and response alongside statutory and strategic planning in the town. The study has also investigated the current flood impacts in terms of average annual damages and the potential for structural mitigation to reduce those damages. Flood intelligence products have been produced for insertion into the Mount Alexander Flood Emergency Plan (MFEP), these are detailed in the MFEP Documentation Report.

Recommendations from the Newstead Flood Study have been separated into the agencies responsible:

- **Mount Alexander Shire Council**
 - Endorse the flood study with the aim of adopting the flood study recommendations.
 - Share mapping and findings of the current study with the Newstead community including newcomers.
 - Undertake a planning scheme amendment to update the flood related planning overlays to reflect the flood risk mapping produced by this project.
 - Review the information within the Flood Intelligence and Flood Warning Report to undertake an update of the Mount Alexander Shire Council MFEP.
 - Investigate opportunities install a level gauge with historic flood levels near the Newstead levee to provide a robust reference for communications during emergencies.
 - Investigate funding mechanisms of the preferred mitigation option including detailed design and consideration of an alternative alignment to reduce the construction cost.
 - Undertake a review of the current response, maintenance and operations documentation with Council staff.
- **North Central Catchment Management Authority**
 - Endorse the flood study and use the flood mapping data to inform floodplain risk management decisions.
 - Upload the Victoria Flood Database mapping data and the excel spreadsheet of property inundation to FloodZoom.
 - Investigate opportunities to install telemetered rainfall gauges within the catchment and stream gauges at Castlemaine and the Mia Mia Creek and Green Gully Creek catchments.
 - Discuss with BoM to review the current Flood Class Levels at Newstead.
- **Victoria State Emergency Service:**
 - Continue to engage the community through flood awareness programs such as FloodSafe.
 - Update the Newstead Local Flood Guide and assist Council in updating the MFEP.
- **VicRoads**
 - Investigate opportunities to reduce the frequency of overtopping the Pyrenees Highway at Green Gully Creek
 - Add “Floodway” signs on major roads susceptible to flooding, particularly Pyrenees Highway with depth markers where appropriate.

Future flood events in Newstead should be monitored carefully and compared to the results of this study, with flood levels marked and surveyed where possible. Where flood behaviour appears to disagree with the findings of the study, the reason for the discrepancy should be investigated and an update to the study should be considered.

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