



Final Hydraulic Modelling Report

Newstead Flood Study and Mitigation Strategy (M1751-2023)

Mount Alexander Shire Council

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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



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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 – This 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 hydraulic model build and calibration process undertaken as part of the study.

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.

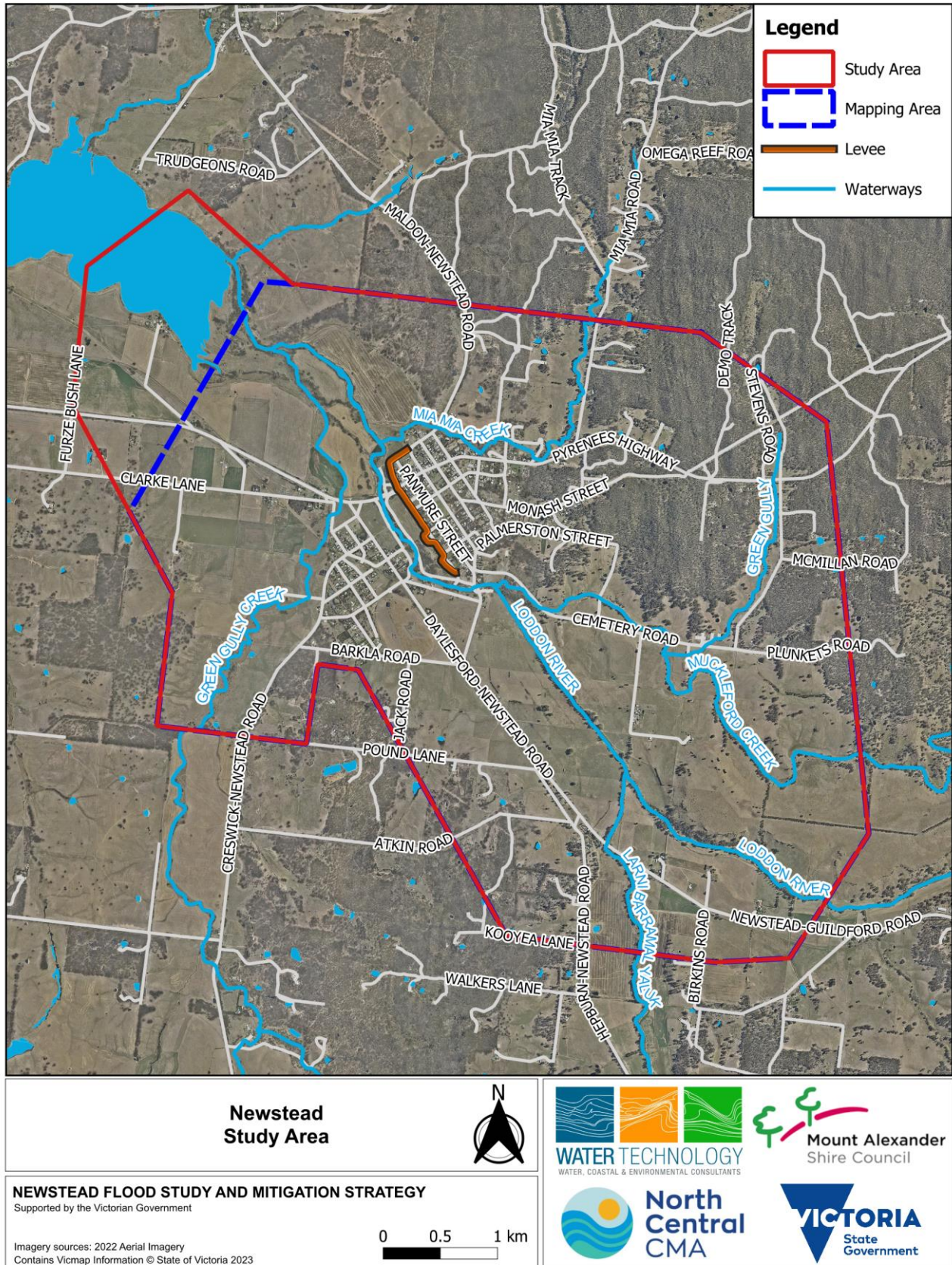


Figure 1-1 Newstead study area



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 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 the 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 hydrology calibration and validation approach was adopted for the study, whereby the hydrologic model was primarily calibrated to recorded flows at the Loddon River at Newstead gauge, and secondarily to other streamflow gauges within the catchment. Flows produced by the hydrology model were then applied to the hydraulic model and model parameters adjusted until agreement between surveyed and modelled flood levels was 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 gauge 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 for 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 hydrology model, taking into account the temporal and spatial patterns of design rainfall provided by ARR2019 and design depths provided by the Bureau of Meteorology for the catchment. Model parameters were adjusted to reconcile flows with the FFA results to ensure unbiased flows were produced for the design scenarios. The FFA and RORB modelling is detailed in the Hydrology Report⁵.

Based on the most recent climate change recommendations provided by ARR⁶, the Intensity-Frequency-Duration (IFD) data provided by the Bureau of Meteorology was adjusted to represent present day rainfall for the year 2024.

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

⁵ Water Technology, 2024 *Hydrology Report - Newstead Flood Study and Mitigation Strategy*, prepared for Mount Alexander Shire Council

⁶ DCCEE 2023, *Discussion Paper: Update to Climate Change Considerations chapter in Australian Rainfall and Runoff: A Guide to Flood Estimation Discussion Paper*, Department of Climate Change, Energy, the Environment and Water, Canberra, CC BY 4.0.



3 HYDRAULIC MODEL SETUP

3.1 Overview

A hydraulic model of Newstead was built using the TUFLOW modelling package. The model is intended for two uses: simulation of riverine flooding as a result of rainfall within the upper Loddon River catchment, and localised stormwater flooding as a result of rainfall over the Newstead township. While many model features are shared, some model features are specific to the stormwater component. The current report is focused on the hydraulic calibration modelling of riverine inundation events and model features specific to stormwater modelling will be detailed in later reports.

A summary of key model parameters has been provided in Table 3-1 below.

Table 3-1 Key TUFLOW 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)

3.2 Model boundaries and extent

Flow hydrographs extracted from the RORB model were applied to the TUFLOW hydraulic model via flow-time (QT) boundaries. The model considered inflows from the Loddon River, Muckleford Creek, Larni Barramal Yaluk, Mia Mia Creek, Green Gully Creek and Green Gully. The model extent was set to capture the project study area. The single outflow boundary was set to match gauged levels of the Cain Curran Reservoir head gauge for the calibration events. For design events, the peak level recorded at the gauge during the 2022 event was applied as a constant height of 208.475 mAHD.

The model extent and boundary locations are shown in Figure 3-1.

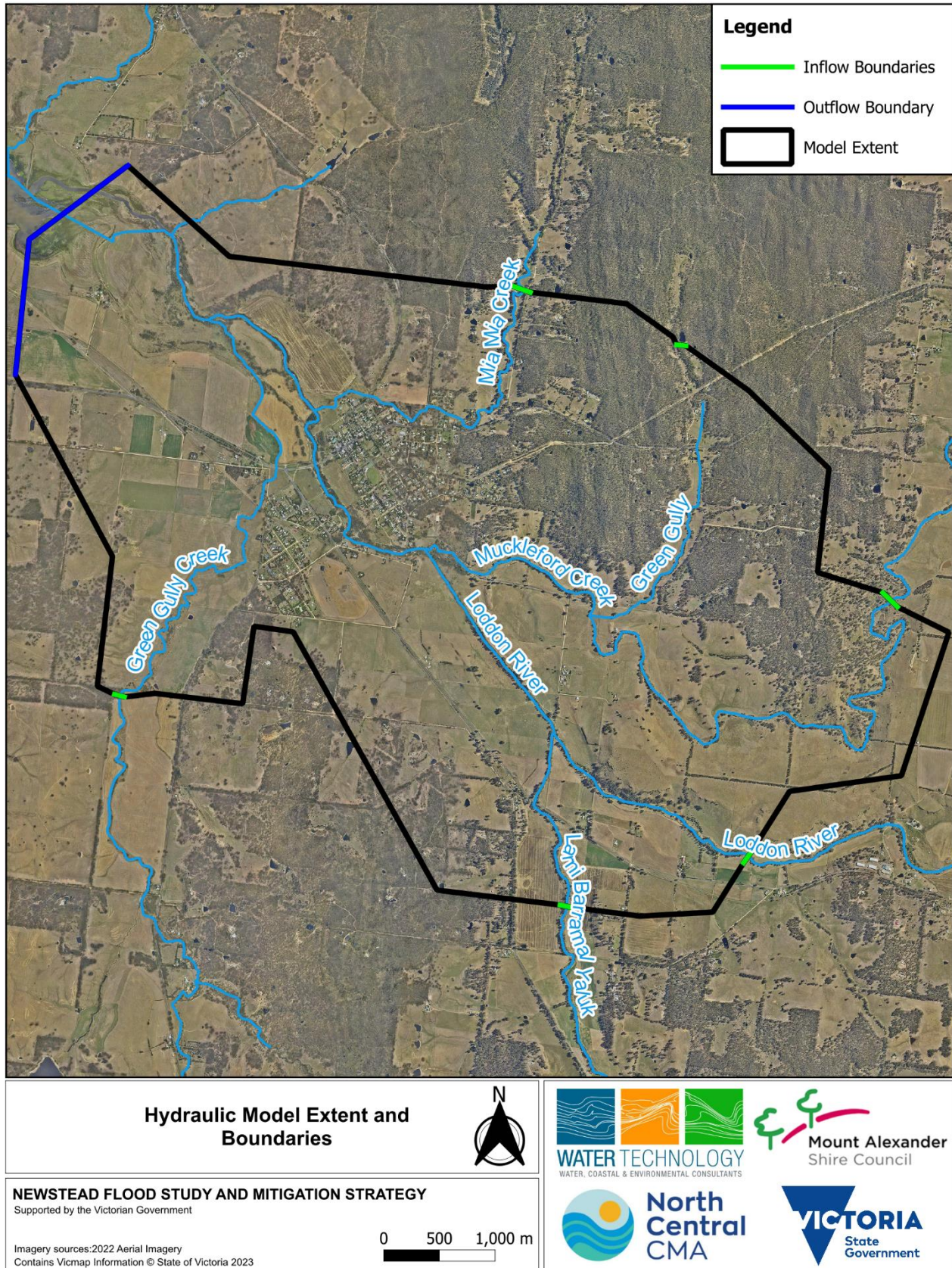


Figure 3-1 TUFLOW model extent and boundaries



3.3 Model topography

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. The cross sections depths were extrapolated to lower the bed level for the remaining river reach.

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).

Figure 3-2 shows a map of the model topography.

3.4 Hydraulic roughness

Hydraulic roughness within the 2-dimensional model domain was represented by the Manning's 'n' roughness coefficient. Manning's 'n' was determined using land use classifications as determined from the MASC planning layers and adjusted based on inspection of aerial imagery. Roughness coefficients were determined using industry standard/expected values such as those found in (Chow, 1959) and (Melbourne Water, 2023).

During the calibration process, roughness values were adjusted after analysis of results against available surveyed flood marks and other historic flood information. The adopted roughness coefficients are summarised in Table 3-2. Figure 3-3 shows a map of the adopted roughness values.

Table 3-2 Hydraulic roughness values

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

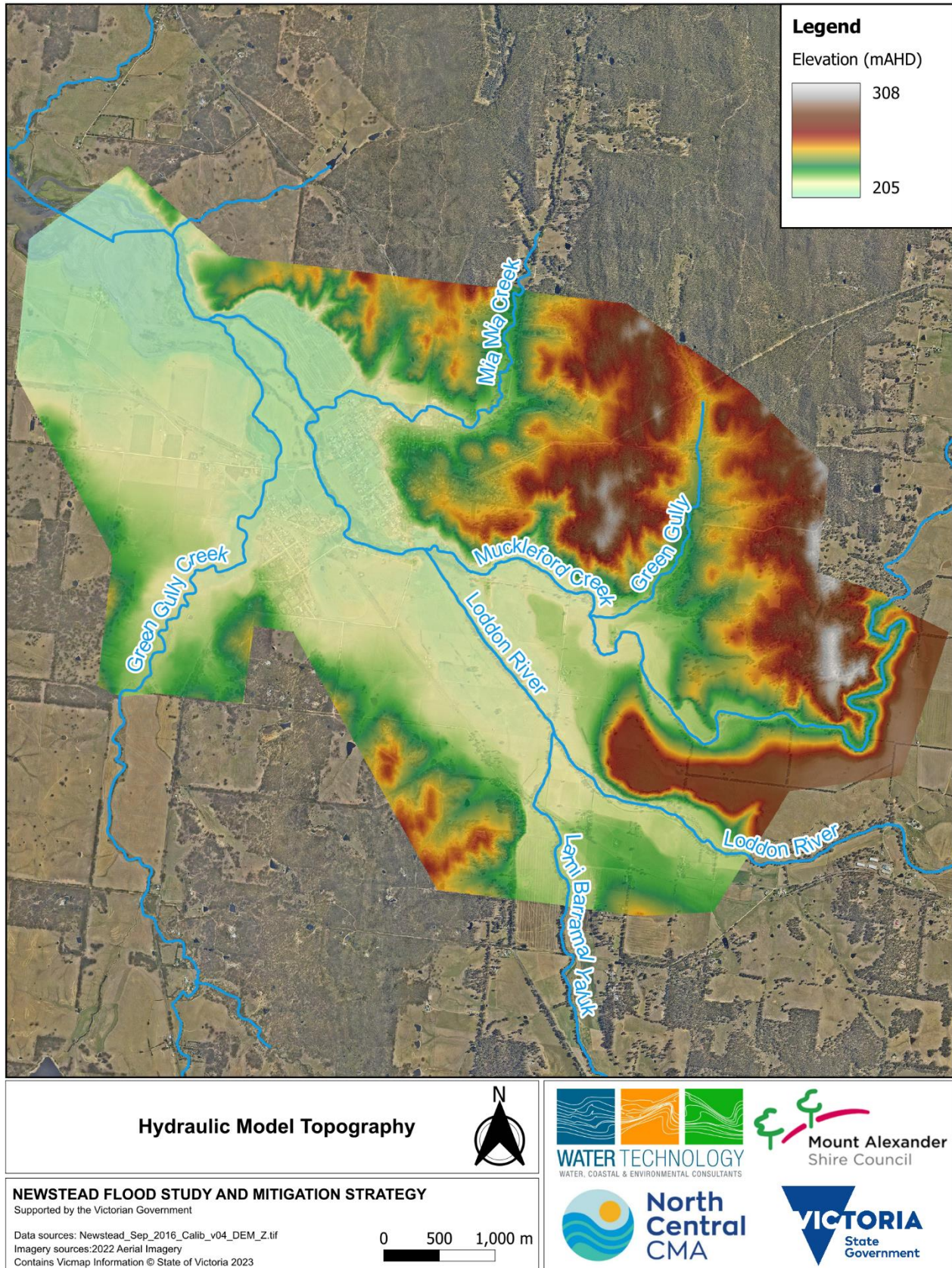


Figure 3-2 Model topography

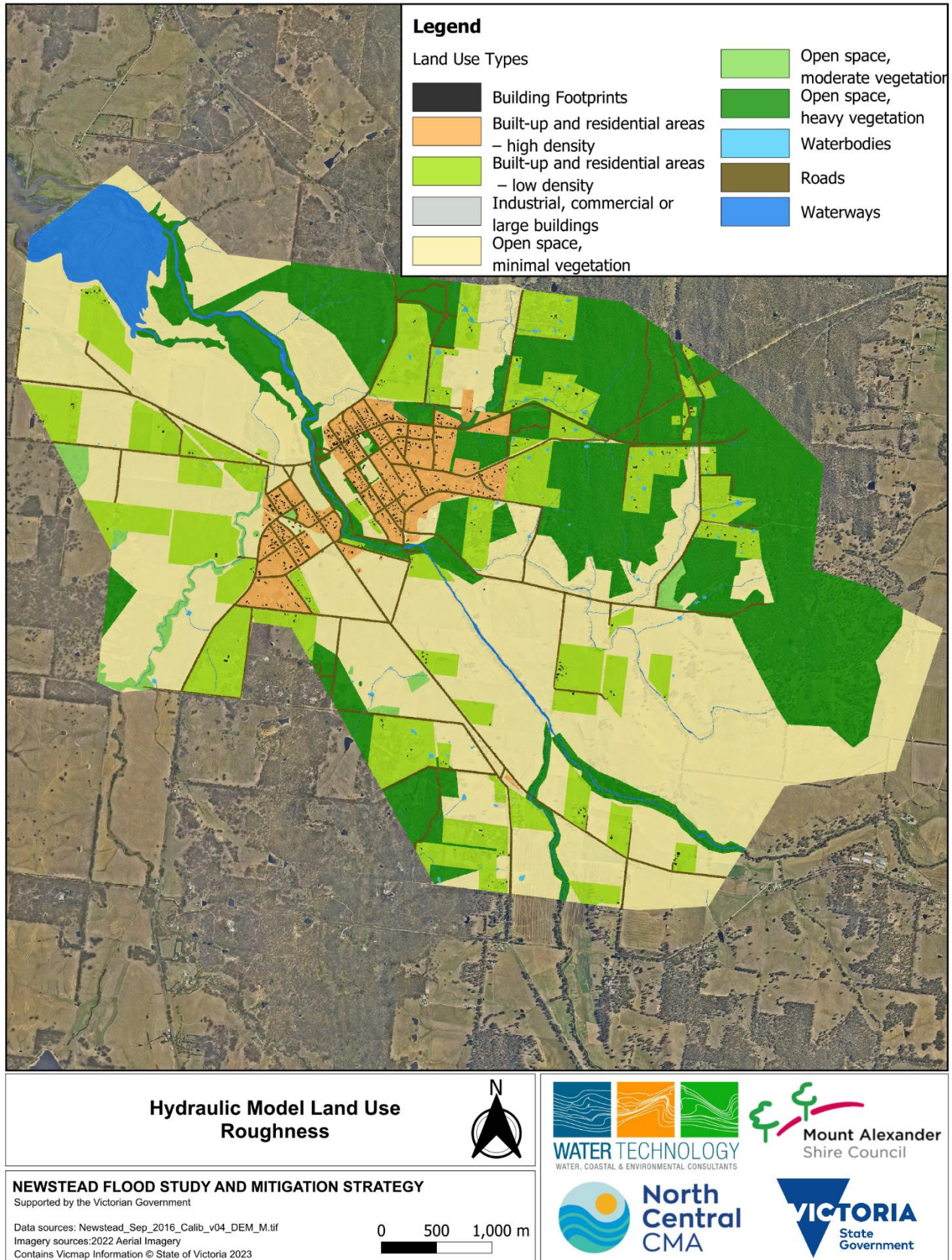


Figure 3-3 Hydraulic model roughness



3.5 Structures

3.5.1 Bridges

10 bridges were incorporated in the hydraulic model as 2D bridge flow constrictions to represent energy losses due to piers and bridge deck. The bridge dimensions were based on as-built drawings, survey data and site visit observations, see Table 3-3. Figure 3-4 shows the bridge locations.

Table 3-3 Modelled bridges

Map reference	Road	Waterway	Data source
B1	Pyrenees Highway	Loddon River	Drawing SN2502
B2	Pyrenees Highway	Green Gully Creek	Drawing SN9296
B3	Maldon-Newstead Road	Mia Mia Creek	Drawing SN4471
B4	Newstead-Guildford Road	Larni Barramal Yaluk	Surveyed
B5	Railway	Larni Barramal Yaluk	Surveyed
B6	Cemetery Road	Muckleford Creek	Surveyed
B7	Cemetery Road	Muckleford Creek	Surveyed
B8	Unnamed	Green Gully	Surveyed
B9	Railway	Green Gully Creek	Surveyed
B10	Unnamed	Green Gully Creek	Site visit

3.5.2 Culverts

11 culverts were incorporated in the hydraulic model as 1D structures directly connected to the 2D domain. Culvert dimensions were based on existing datasets, survey data and site visit observations, see Table 3-4. Figure 3-4 shows the culvert locations.

Table 3-4 Modelled culverts

Map reference	Road	Waterway	Dimension and type
C1	Pyrenees Highway	Green Gully	1800 mm pipe culvert
C2	Pyrenees Highway	Drainage	300 mm pipe culvert
C3	Pyrenees Highway	Drainage	1000 mm pipe culvert
C4	Pyrenees Highway	Drainage	1350 x 1300 mm box culvert
C5	Pyrenees Highway	Drainage	400 mm pipe culvert
C6	Cameron Road	Mia Mia Creek	375 mm pipe culvert
C7	Cameron Road	Mia Mia Creek	375 mm pipe culvert
C8	Cemetery Road	Green Gully	3300 x 2400 mm box culvert
C9	Cemetery Road	Drainage	300 mm pipe culvert
C10	Hepburn - Newstead Road	Drainage	450 mm pipe culvert
C11	Railway	Drainage	900 mm pipe culvert



3.5.3 Pit and pipe network

The small number of stormwater pits in central Newstead were surveyed by Price Merrett and included in the modelling. Assumptions were made for inverts and pipe dimensions based off LiDAR and pipe sizes. Open pipe ends not connected to a pit were modelled as directly connected to the 2D domain via a SX boundary. The pipe network is of limited importance in the hydraulic modelling only including riverine inflows, but will be assessed in a stormwater model later in the current project. The floodgate through the levee located at the end of Panmure Street was modelled as closed in all calibration events and therefore no backflow from the Loddon River made it's way into the stormwater network.

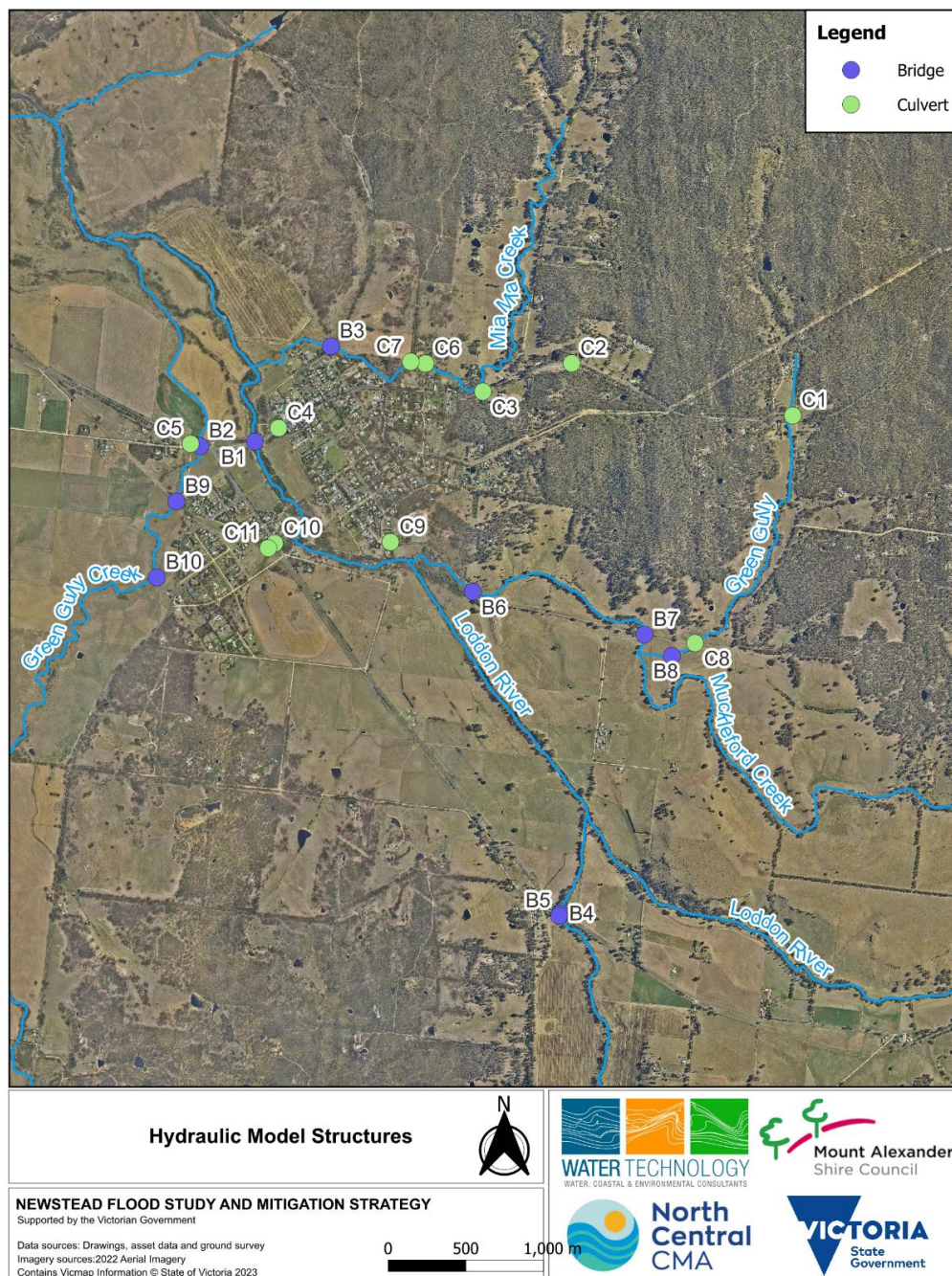


Figure 3-4 TUFLOW model structures



4 HYDRAULIC CALIBRATION

4.1 Approach

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. Given the recent nature of these events, the model topography and structures are more likely to be accurately represented, and anecdotal evidence is likely more reliable. Although included in the hydrology model calibration detailed in the Hydrology Report⁵, the November 2010 and January 2022 flood events were not included in the hydraulic calibration due to a lack of calibration data aside from gauge records.

4.2 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. Hence, the levee height was increased at low points in the hydraulic model to prevent overtopping.

4.2.1 Model inflow

Figure 4-1 shows the inflow hydrographs for each of the model inflow locations.

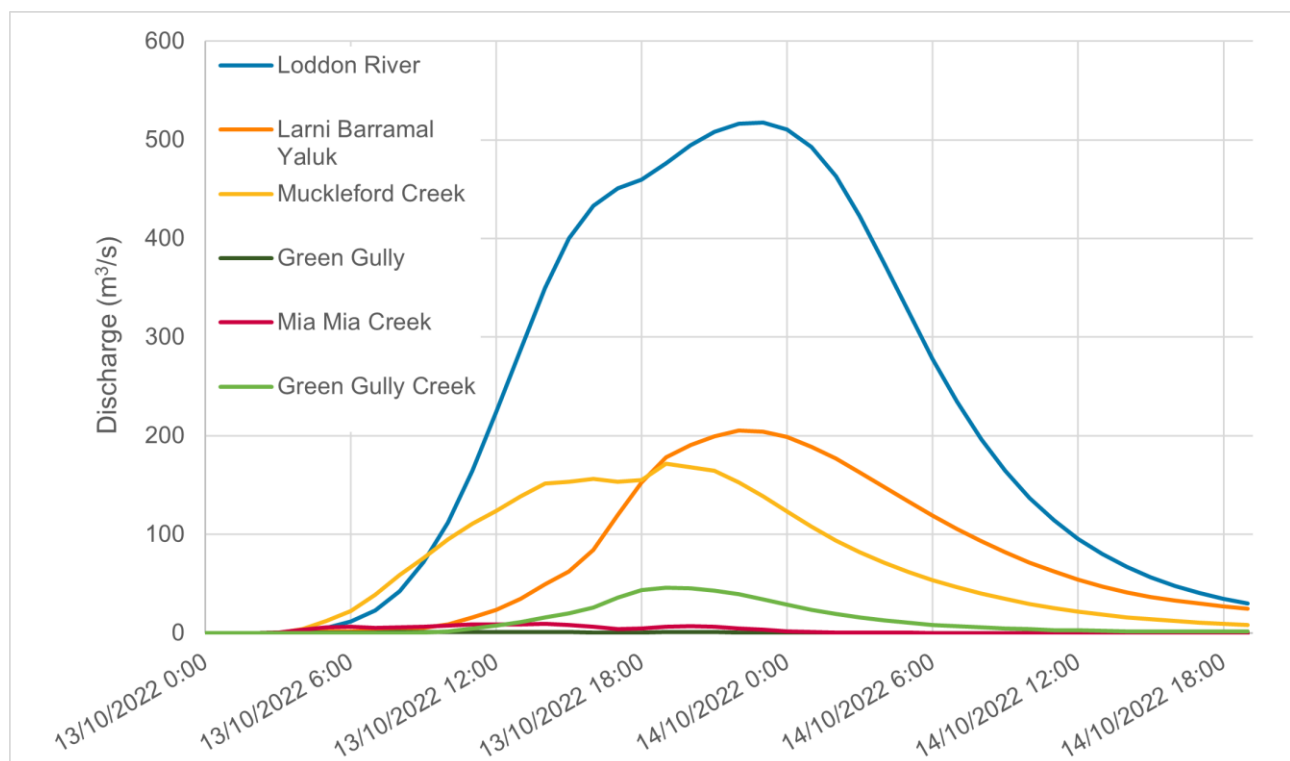


Figure 4-1 October 2022 hydraulic model inflow hydrographs

4.2.2 Calibration data

The following calibration data sources were available from the October 2022 event:

- Loddon River at Newstead gauge recorded hydrograph and flood level
- 14 surveyed flood levels (NCCMA and Price Merrett)
- Photos provided by council staff members depicting flooding at the Pyrenees Highway
- Several anecdotal records specific to the October 2022 event, relating to inundation at specific locations/properties as further described in Section 4.2.3.3.

4.2.3 Calibration results

4.2.3.1 Streamflow gauge and surveyed flood levels

The calibration modelling represents the event well, with almost all flood marks modelled within 0.2 m of the surveyed level. In particular, the modelled peak level at the Loddon River at Newstead gauge was within 0.02 m of that observed. The modelled peak flood level at the gauge occurred at around 0000 hours on 14 October, 1 hour after the recorded peak at 2300 hours on 13 October, see Figure 4-2. The surveyed and modelled flood levels are shown in Table 4-1, with differences greater than 0.1 m highlighted. The modelled maximum flood depth and the location of the surveyed flood levels for the October 2022 event is shown in Figure 4-3 and Figure 4-4.

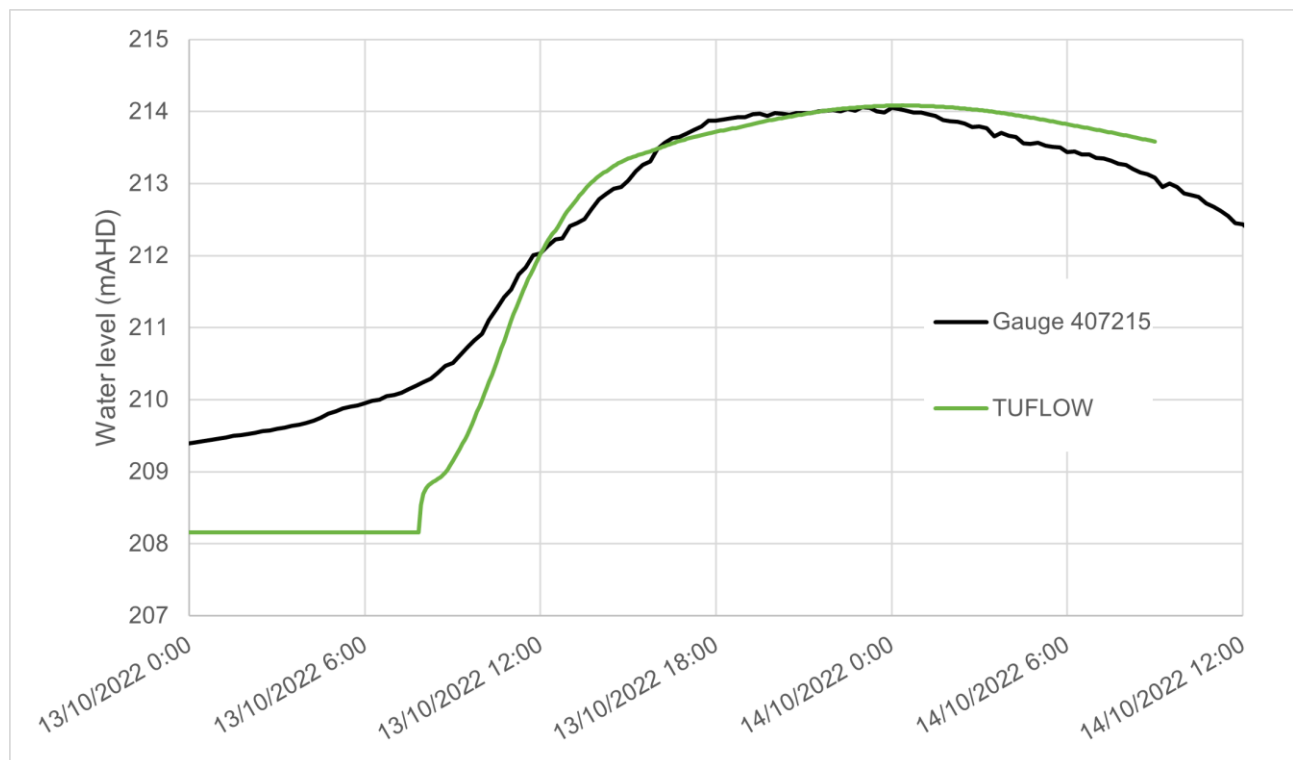


Figure 4-2 October 2022 comparison between modelled and gauged hydrographs at the Loddon River at Newstead gauge



Table 4-1 Modelled VS gauged and surveyed flood levels for October 2022 calibration

Gauge/Surveyed location	Gauged or surveyed peak flood level (m AHD)	Modelled peak flood level (m AHD)	Difference (m)
Loddon River at Newstead gauge	214.06	214.08	0.02
North of eastern abutment of Pyrenees Hwy Bridge	213.46	213.53	0.07
South of Pyrenees Hwy between Tivey St and Dundas St	213.77	213.95	0.18
Clark Ln and Pyrenees Hwy intersection	212.9	Outside modelled extent	
1 Tivey St	213.76	213.64	-0.12
5 Tivey St	213.81	213.76	-0.05
1 Simpson St - front of dwelling	213.73	213.78	0.05
1 Simpson St - at road	213.69	213.81	0.12
11 Tivey St - at Simpson Rd	213.80	213.84	0.04
Creswick-Newstead Rd and Hepburn-Newstead Rd intersection	213.90	214.17	0.27
18 Campbell St - front of dwelling	215.52	215.44	-0.08
18 Campbell St - rear of dwelling	215.35	215.45	0.10
18 Campbell St - rear of dwelling	215.35	215.45	0.10
18 Campbell St - at railway	215.70	215.53	-0.17
McNabb St and Hepburn-Newstead Rd intersection	214.66	215.46	0.80

Greater discrepancies can be expected for non-gauge flood peak levels, with gauge levels considered high reliability and other non-gauge levels considered lower reliability since they were captured post event and rely on anecdotal information from residents. Where the model differs more than 0.2 m compared to the surveyed level are further discussed:

- The point located south of the Pyrenees Highway between Tivey St and Dundas St is likely representing a ground level at the edge of the flood extent. Given the point is located within 5 m of the flood extent boundary the result is acceptable.
- The point located at the Clark Ln and Pyrenees Hwy intersection is likely erroneous as the measured level is located below the road surface level.
- Resident records state that the dwelling at 1 Tivey St was protected by sandbags. The modelled flood extent does reach the dwelling and the flood level discrepancy is acceptable.
- Given the proximity of the two points located at 1 Simpson St a difference in flood level is unlikely. Given the close match of the model to the level measured at the dwelling the point at the road is considered of less importance.
- The point located at the Creswick-Newstead Rd and Hepburn-Newstead Rd intersection is likely representing a ground level at the edge of the flood extent. Given the point is located within 10 m of the flood extent boundary the result is acceptable.



- The point located on the railway near 18 Campbell St relates to an anecdotal record stating that the railway overtopped. The level of overtopping is likely estimated, and given the close match to other flood levels at 18 Campbell St this measured level is likely erroneous.
- The point located at the McNabb St and Hepburn-Newstead Rd intersection was also deemed to be erroneous given its proximity to and large difference in height from other surveyed points which were represented well in the model. This point is suspected to be a road height rather than a flood mark.

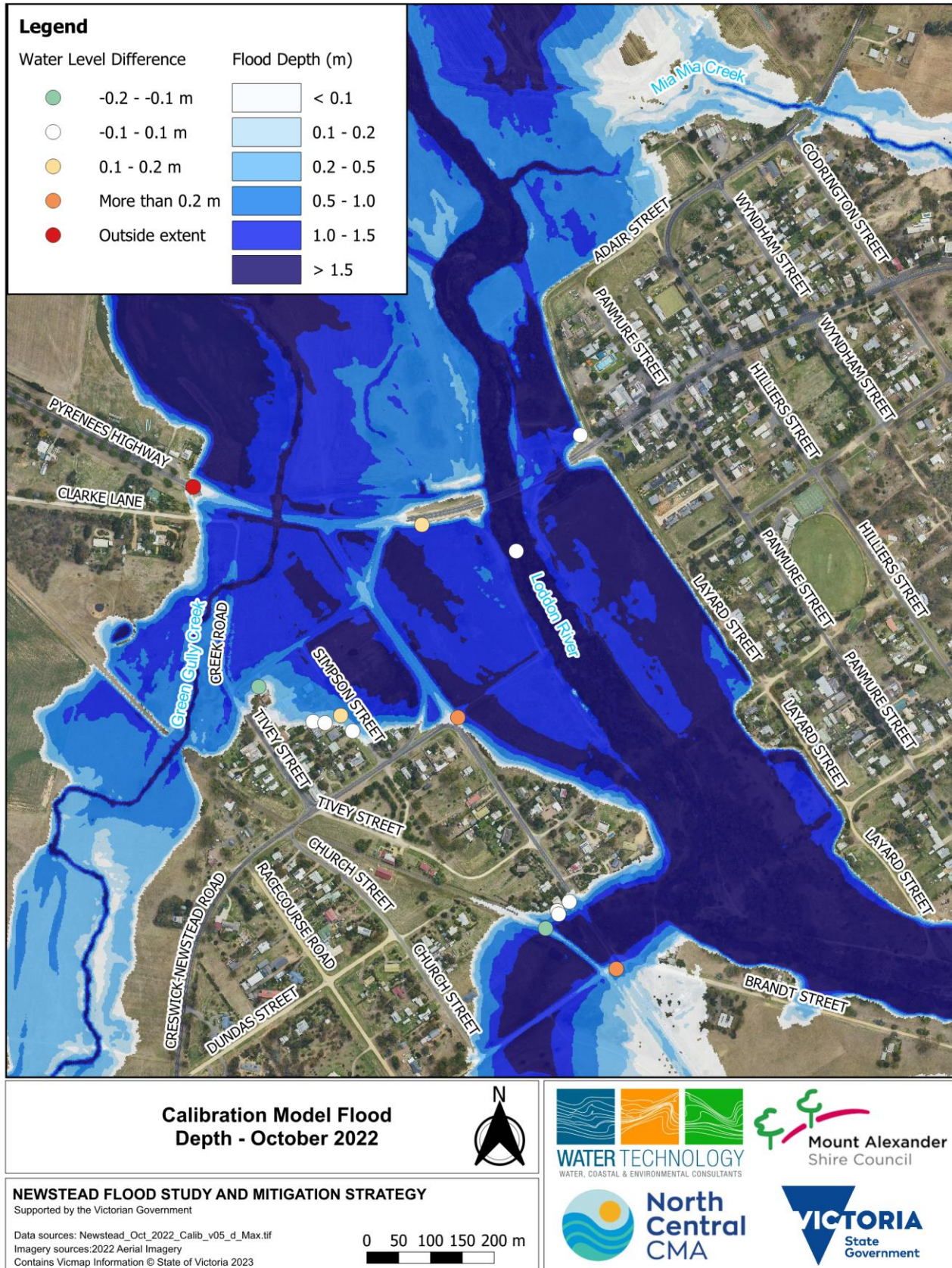


Figure 4-3 Calibration model flood depth within Newstead – October 2022

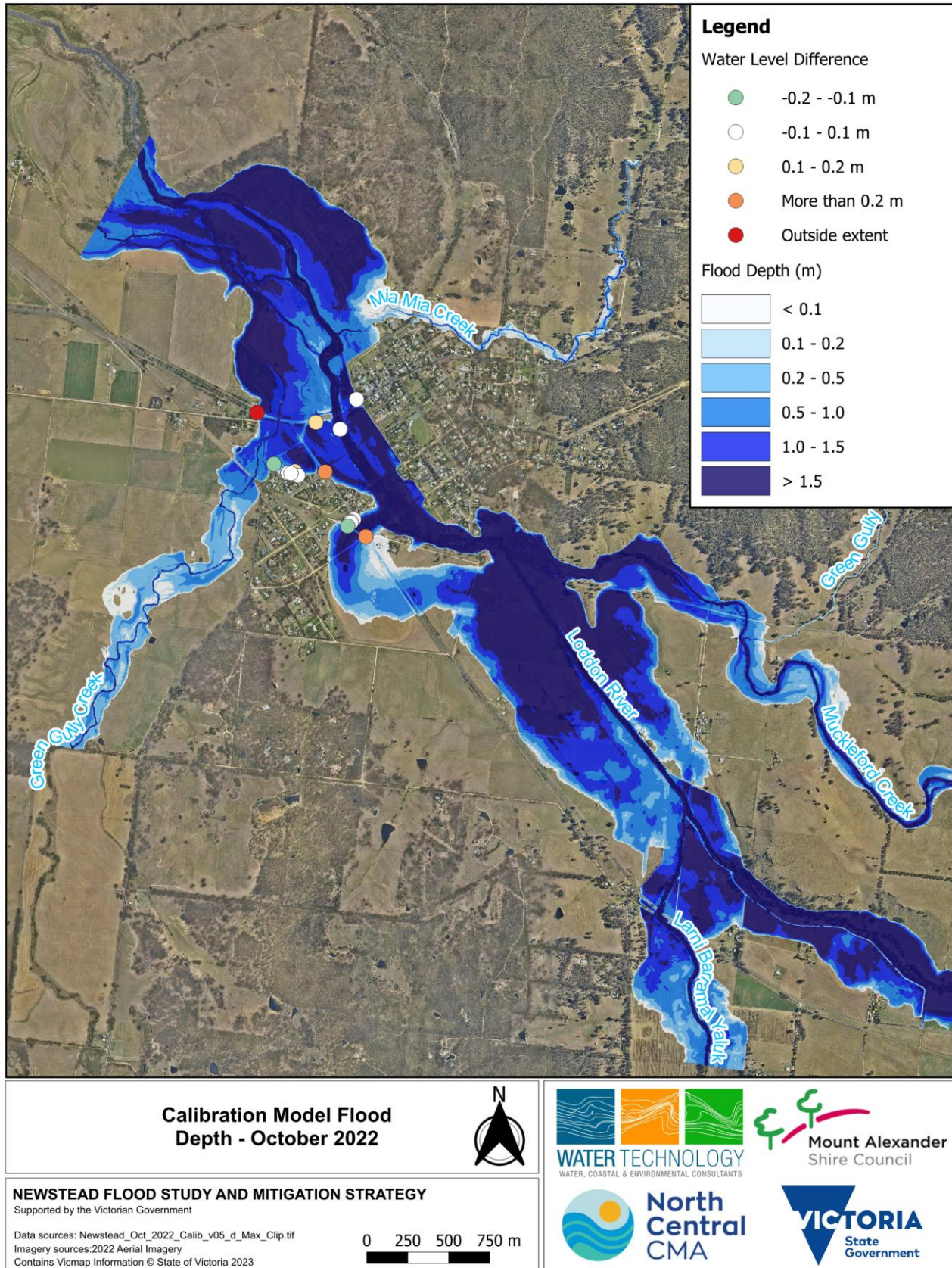


Figure 4-4 Calibration model flood depth – October 2022



4.2.3.2 Photos

Photos were available at the Pyrenees Highway west of the Loddon River, taken at 1535 hours on 13 October and 0705 hours on 14 October, see Figure 4-5 and Figure 4-6 respectively. The flood peak occurred between these times, meaning neither would have captured the flood peak. The flood depths captured in the photos are about 0.4 m lower than the peak flood level. However, the model results at these time steps show a flood depth of around 0.1 m higher than the estimated depth in the photo at 1535 hours on 13 October and 0.2 m higher compared to the photo at 0705 hours on 14 October, indicating that the model performs well also before and after the peak flood, see Figure 4-5 and Figure 4-6.



Figure 4-5 Pyrenees Highway west of the Loddon River, facing west, 1535 hours on 13 October 2022.



Figure 4-6 Pyrenees Highway west of the Loddon River, facing east, 0705 hours on 14 October 2022.



4.2.3.3 Anecdotal records

Table 4-2 lists the anecdotal evidence available for the October 2022 event from Council, CMA and the community, and commentary on how the model performed in comparison to the results presented in Figure 4-4. Overall, the model results generally reflects with the anecdotal evidence, with some discrepancies that can be attributed to uncertainties in the stated records.

Table 4-2 Anecdotal records available for October 2022 calibration

Description	Model comparison
The flood level beneath the Pyrenees Highway bridge across the Loddon River reached approximately 0.3 m below the bridge deck soffit (~213.4 mAHD)	Modelled level at the bridge is ~213.8m AHD, which agrees with gauge level 100 m upstream. The reported flood level may have been observed before or after the flood peak.
The Maldon Newstead Road bridge across Mia Mia Creek was the only road into Newstead not impacted by flood waters	Model results agree with this. This is true for the roads within the model extent.
The Cairn Curran Reservoir filled and reached upstream of the Pyrenees Highway	The gauged peak level in Cairn Curran Reservoir was ~208.5 mAHD, well below the gauged peak level at Newstead of 214.06 mAHD, indicating limited impact of the reservoir levels in Newstead. This is further supported by sensitivity testing, see Section 7.3.
Muckleford Creek was a major contributor of the flooding, being the largest ever observed	The modelled October 2022 levels in Muckleford Creek are ~0.7 m above September 2016, however Muckleford Creek only makes up 12% of the flow in the Loddon River at Newstead.
Green Gully Creek was smaller than in other major events and peaked at around 0030 to 0100 hours on 14 October.	The modelled October 2022 levels in Green Gully Creek are ~0.5 m above September 2016. The reported flood level may have been observed before or after the flood peak. The modelled flood peak in Green Gully Creek at Pyrenees Highway occurred at around 0000 hours on 14 October.
18 Campbell Street – Goat house was inundated and flood levels reached up to 0.2 m below floor level of the house (~215.51 mAHD)	The modelled level reached 215.48 mAHD which is a good fit.
1 Simpson Street – flood peak occurred at approximately 2330 on 13 October to 0000 hours on 14 October.	The modelled flood peak at this location occurred around 0000 hours on 14 October.



Description	Model comparison
1 Tivey Street – house was close to flooding but was protected by sandbags	Modelling agrees.
65 Petersons Road – Flooding did not cross Petersons Road and the maximum depth in the paddocks south of the road was approximately 0.15 m deep	Modelling indicates that Petersons Road was overtopped by up to 0.15 m, with flood depths in the paddocks south of the road reaching up to 1 m. The reported flood level may have been observed before or after the flood peak. The levee located along the Loddon River immediately south of 65 Petersons Road is represented in the hydraulic model and is not overtopping. The flooding observed in this area is caused by water backing up from Loddon River and Muckleford Creek further downstream.
3 Brandt Street – Loddon River flooding never reaches the house	Modelling agrees.
Lot 2, 9 McNabb Street – Experienced up to 1 m of inundation against an external retaining wall	This is related to stormwater inundation as this location is well outside the modelled flood extent.
1a and 2a Wyndham Street – Flood levels reached up to 285 mm at the northwestern end of the property at 1900 hours on 13 October	The location of 1a Wyndham Street has not been identified. Modelled flood depths at the northwestern end of 2a Wyndham Street reached 20 mm. Modelled flood depths on the adjacent 2b Wyndham Street reached maximum 600 mm but was around 250-300 mm across most of the lot. These lots appear to be used as a single property and could be the property referred to in the record.
Railway overtopped near Campbell Street	Modelling agrees.

4.3 September 2016 validation

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 saturated catchments 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 assessment.

The September event was modelled as a validation event, using the model parameters adopted for the October 2022 event model.



4.3.1 Model inflow

Figure 4-1 shows the inflow hydrographs for each of the model inflow locations.

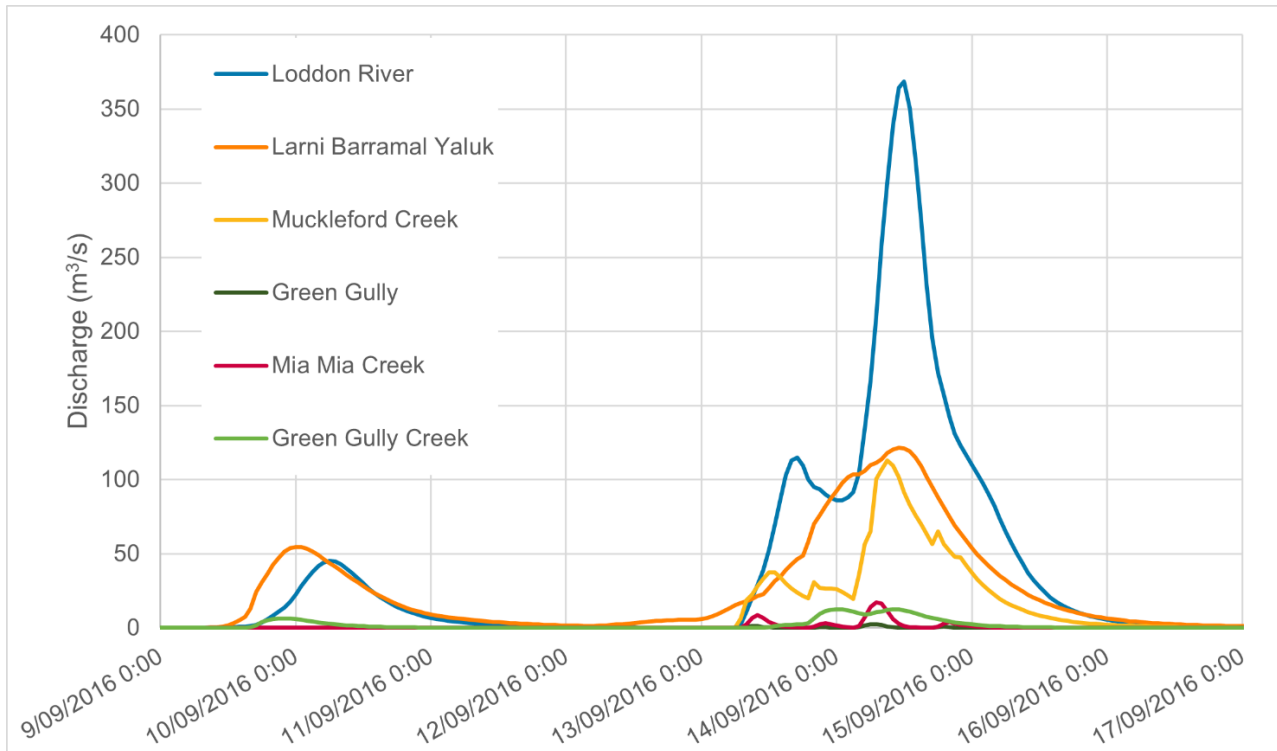


Figure 4-7 September 2016 hydraulic model inflow hydrographs

4.3.2 Calibration data

The following calibration data sources were available from the September 2016 event:

- Loddon River at Newstead gauge recorded hydrograph and flood level
- Numerous photos provided by community members depicting flooding at various locations along the Loddon River
- Anecdotal records stating that all road entries to Newstead were cut off by flood waters in September 2016.

4.3.3 Calibration results

4.3.3.1 Streamflow gauge

Table 4-3 shows that the modelled peak level at the Loddon River at Newstead gauge was within 0.07 m of that observed. Although not as close as the October 2022 event model, this is still considered a close match. The modelled peak flood level at the gauge occurred at around 1430 hours on 14 September, 45 minutes after the recorded peak at 1345 hours on 14 September, see Figure 4-8. The modelled maximum flood depth for the September 2016 event is shown in Figure 4-9.



Table 4-3 Modelled VS gauged flood level for September 2016 calibration

Gauge/Surveyed location	Gauged or surveyed peak flood level (m AHD)	Modelled peak flood level (m AHD)	Difference (m)
Loddon River at Newstead gauge	213.64	213.71	0.07

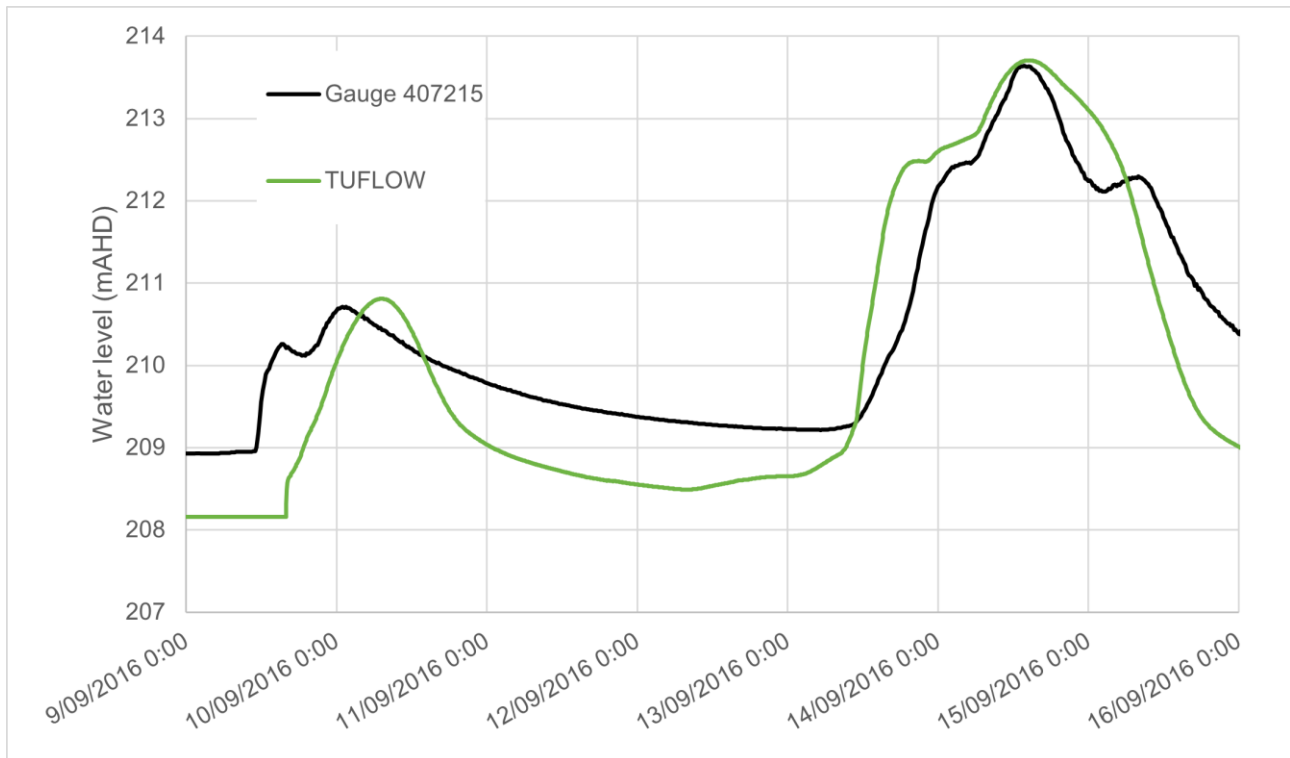


Figure 4-8 September 2016 comparison between modelled and gauged hydrographs at the Loddon River at Newstead gauge

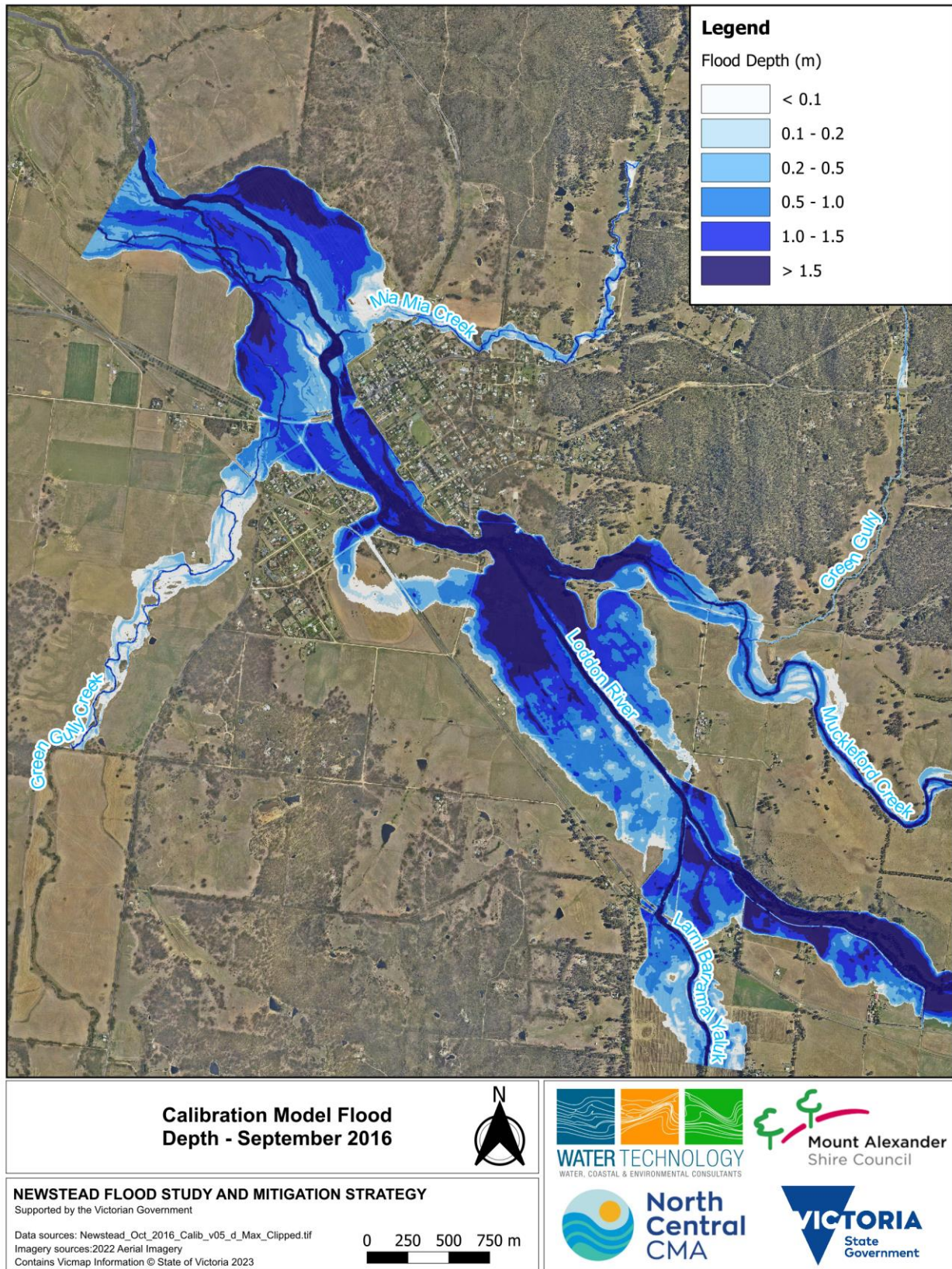


Figure 4-9 Calibration model flood depth – September 2016



4.3.3.2 Photos

Photos were available at a number of locations within Newstead. A selection of photos are shown in Figure 4-10 to Figure 4-14 and compared to the modelled peak flood depth.



Figure 4-10 56 Punt Road captured at around 1400 hours on 14 September 2016. Agrees well with modelled peak flood extent.

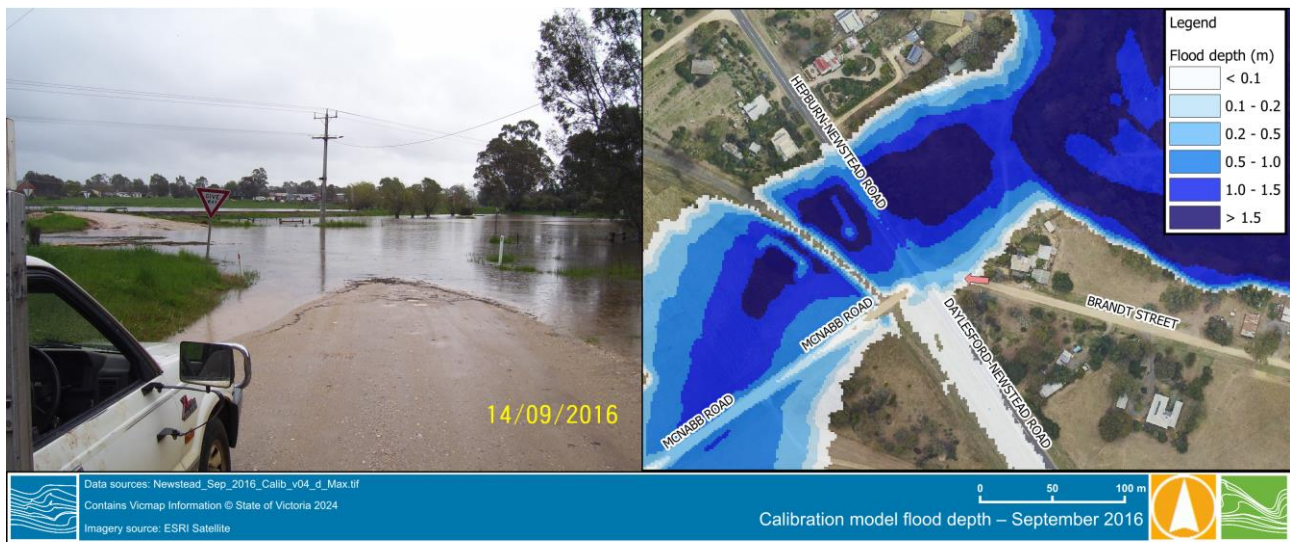


Figure 4-11 Brandt St/Hepburn-Newstead Rd intersection, captured at around 1400 hours on 14 September 2016. Agrees well with modelled peak flood extent.



Figure 4-12 Creswick-Newstead Rd/Hepburn-Newstead Rd intersection, captured at around 1400 hours on 14 September 2016. Agrees well with modelled peak flood extent.



Figure 4-13 McNabb Rd, captured at around 1200 hours on 14 September 2016. Agrees well with modelled peak flood extent considering timing.



Figure 4-14 Railway bridge over Larni Barramal Yaluk, captured at around 1130 hours on 14 September 2016. Agrees well with modelled peak flood extent and level (modelled level is approximately 0.5 m below bridge soffit).

4.4 Discussion

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.



5 HYDRAULIC DESIGN EVENT MODELLING

5.1 Hydrology modelling

Design flows in the waterways entering the hydraulic model were determined using a hydrology model (RORB) as described in the Hydrology Report⁵. An ensemble approach was adopted as outlined in ARR2019⁴ and a brief summary of the methodology is presented below:

- Design intensity-frequency-duration rainfall data was obtained for the catchment centroid. Due to the size of the catchment, spatial variation of design rainfall was applied.
- The ensemble approach modelled 10 available Murray Basin temporal patterns for each storm duration.
- To account for the varying catchment size of the different tributaries to be mapped, tributaries were grouped based on similar catchment size and Areal Reduction Factors (ARF) were adopted 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.
- Design losses were determined by reconciliation of the modelled peak flows at the Loddon River at Newstead gauge with the results of a Flood Frequency Analysis (FFA). 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.
- Climate change factors were 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), in line with the Book 1 Chapter 6 update to ARR2019⁴. Near-term climate change was adopted for the hydraulic design modelling described in this report to represent the current day flood risk. Losses were also scaled according to the latest guidance.
- The critical duration and temporal pattern resulting in the median peak flow in each waterway was then adopted as the design flow.

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

Table 5-1 shows the near-term (2030) peak 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. As described in R02 – Hydrology Report, design modelling was undertaken using areal and point temporal patterns as well as varying ARF to produce accurate flows from each catchment. The results show that the critical duration varies between each of the tributary catchments, with the critical duration shorter for the smaller catchments. There is also variation in the temporal pattern generating the median peak flow at each inflow location. Upon closer inspection of each temporal pattern peak flow, the difference in peak flow between temporal patterns is negligible. This information was used to limit the number of model simulations (critical durations and temporal patterns) used in the design hydraulic modelling. * Peak flows for Mia Mia Creek, Green Gully Creek and Green Gully were achieved using point temporal patterns

Table 5-2 shows the model simulations (critical durations and temporal patterns combinations) adopted in the hydraulic model, to ensure the correct peak flow was achieved in each inflow waterway.



Table 5-1 Design flows, critical durations and representative temporal patterns for near-term (2030) climate change scenario at hydraulic model inflow locations

AEP	Loddon River (m³/s)	Larni Barramal Yaluk (m³/s)	Muckleford Creek (m³/s)	Green Gully Creek (m³/s)*	Mia Mia Creek (m³/s)*	Green Gully (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
PMF	5123	1885.5	1863.8	517.7	226.4	36.7
	12 hrs TP09	12 hrs TP09	12 hrs TP09	6 hrs TP02	2 hrs TP07	1.5 hrs TP01

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

Table 5-2 Modelled design events – Near term climate change

AEP	Modelled events					
20%	18 hrs TP09	12 hrs TP10			3 hrs TP06	
10%	18 hrs TP09		9 hrs TP08		3 hrs TP05	



AEP	Modelled events					
5%	18 hrs TP09	12 hrs TP09	9 hrs TP09		3 hrs TP04	
2%	18 hrs TP09	12 hrs TP09	9 hrs TP06		3 hrs TP01	
1%	18 hrs TP03	12 hrs TP09	9 hrs TP06		3 hrs TP08	
0.5%	18 hrs TP03	12 hrs TP09	9 hrs TP06		3 hrs TP08	
0.2%	18 hrs TP03	12 hrs TP09		6 hrs TP07	3 hrs TP08	1.5 hrs TP02
0.1%	18 hrs TP03	12 hrs TP09		6 hrs TP02	3 hrs TP08	1.5 hrs TP02
0.05%	18 hrs TP03	12 hrs TP09		6 hrs TP07	3 hrs TP08	1.5 hrs TP02
PMF		12 hrs TP09		6 hrs TP02	2 hrs TP07	1.5 hrs TP01

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

Table 5-3 shows the critical durations and temporal patterns adopted in the hydraulic model for the long term climate change scenario, which was assessed for the 1% and 10% AEP events.

Table 5-3 Modelled design events – Long term climate change

AEP	Modelled events					
10%	18 hrs TP09	12 hrs TP01	9 hrs TP07		2 hrs TP06	1.5 hrs TP05
1%	18 hrs TP03	12 hrs TP09		6 hrs TP02		1.5 hrs TP01

5.4 Probable Maximum Flood

The Probable Maximum Precipitation (PMP) was interpolated between depths estimated by the Generalised Short Duration Method (GDSM) and the Generalised Southeast Australia Method (GSAM). The rainfall depths were modelled in RORB utilising the 'rare' temporal patterns obtained from the ARR datahub and distributed spatially in line with the 0.1% AEP event. And initial loss of 0 mm and a continuing loss of 1 mm/hr was applied as a further conservative assumption. All ten temporal patterns were simulated in the ensemble for the PMF. The maximum flow for each inflow location was selected as the representative design events, see * Peak flows for Mia Mia Creek, Green Gully Creek and Green Gully were achieved using point temporal patterns



Table 5-2.



6 RESULTS

Design flood modelling for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1% and 0.05% AEP events and the PMF event was undertaken using the calibrated hydraulic model. Flood modelling outputs will be used for the improvement of flood emergency response intelligence information. Flood maps will be used as guidance for the development of planning controls for future land use development.

The final flood maps for each event were created by enveloping the maximum results (depths, water surface, velocity) of all the model simulations for each AEP event. The model simulations are based off the critical durations and the median temporal patterns combinations summarised in * Peak flows for Mia Mia Creek, Green Gully Creek and Green Gully were achieved using point temporal patterns

Table 5-2. The flood extents for the full range of modelled AEP events for each catchment area are shown in Figure 6-2, and the 1% AEP maximum depth results are shown in Figure 6-3. Figure 6-4 shows the water level profile for each modelled AEP along the Loddon River from the model outlet up to the confluence of Loddon River and Larni Barramal Yaluk. Figure 6-5 shows the water level profile for each modelled AEP along the Newstead levee. The Newstead levee starts overtopping in a 5% AEP event, which can also be seen in the flood mapping in Appendix A.

Long term impacts of climate change (year 2100) were assessed for the 1% and 10% AEP events. The 1% AEP flood level and extent with climate change is almost identical to the near term climate change 0.1% AEP event and the 10% AEP flood level and extent with climate change is between a near term climate change 5% and 2% AEP event.

Flood depth maps for the full range of AEPs and the PMF event are provided in Appendix A and GIS deliverables (grids and extents) have been provided to MASC and NCCMA.

Flood hazard mapping was prepared in line with ARR2019 and the Australian Disaster Resilience Guideline 7-3 Flood Hazard⁷ The hazard classifications are based on the peak depth, velocity and product of depth and velocity. The classifications are shown in Figure 6-1.

⁷ Australian Disaster Resilience Guideline 7-3 Flood Hazard, 2017, Australian Institute Disaster Resilience

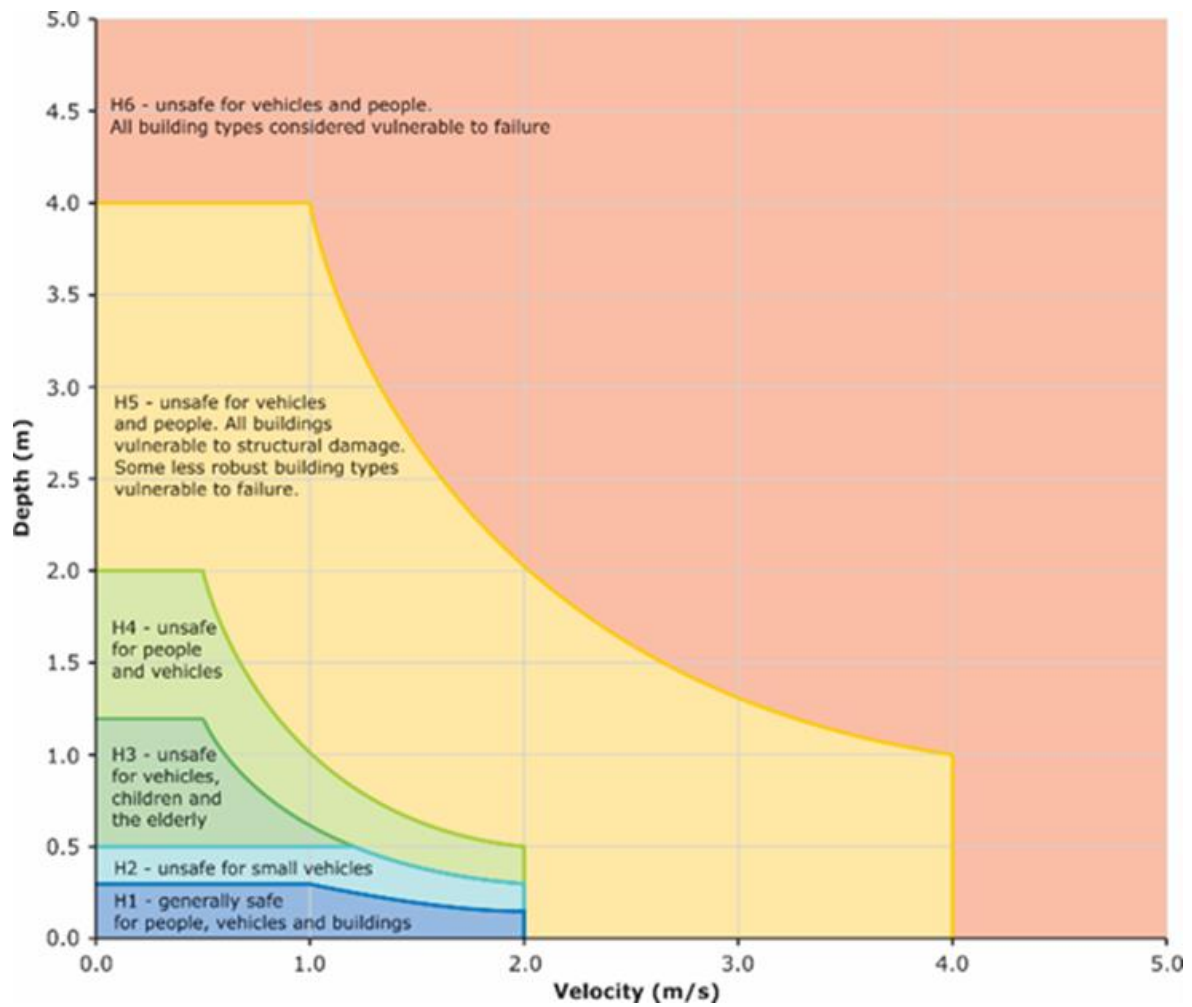


Figure 6-1 Flood hazard classifications

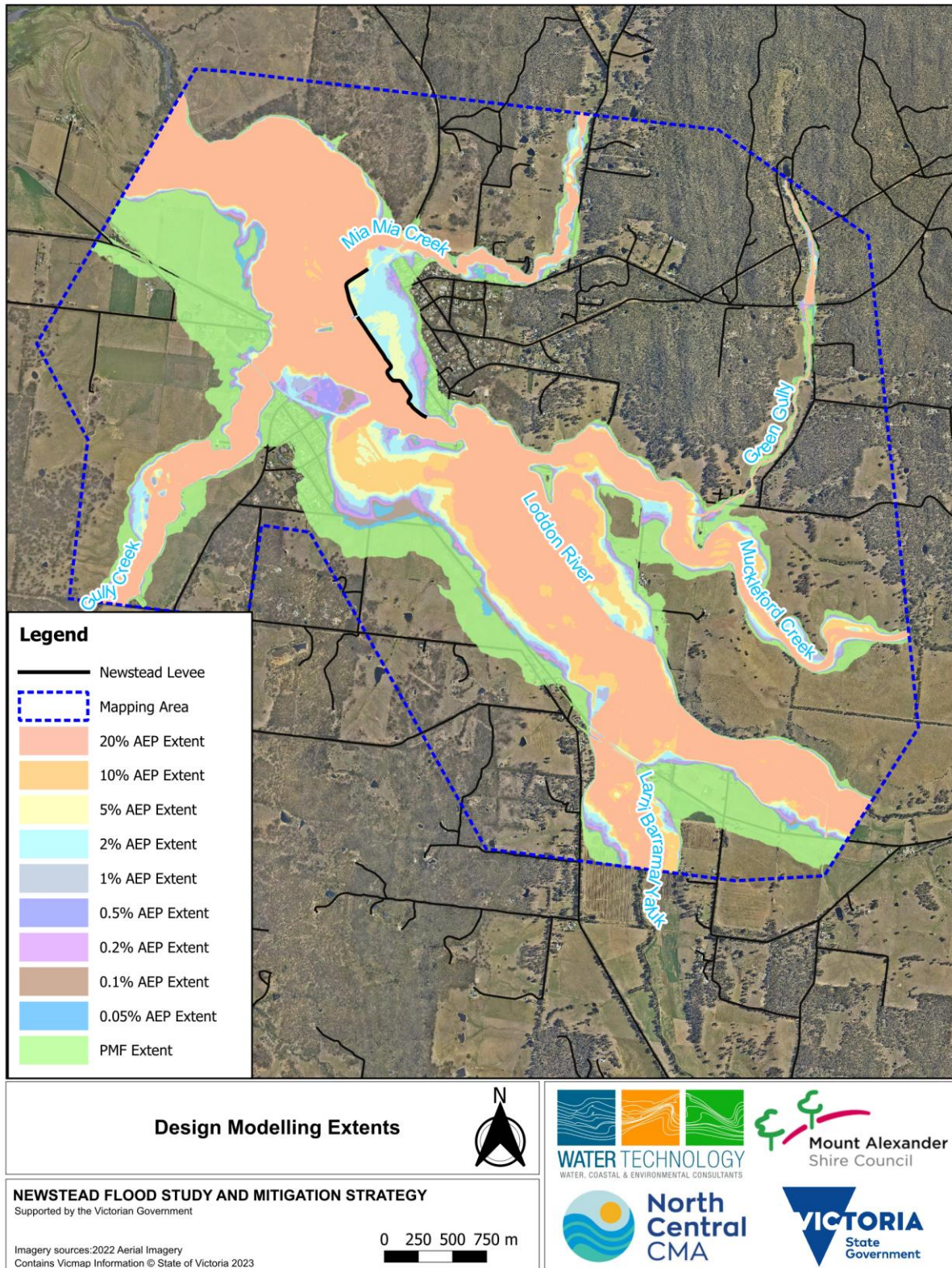


Figure 6-2 Design modelling flood extents

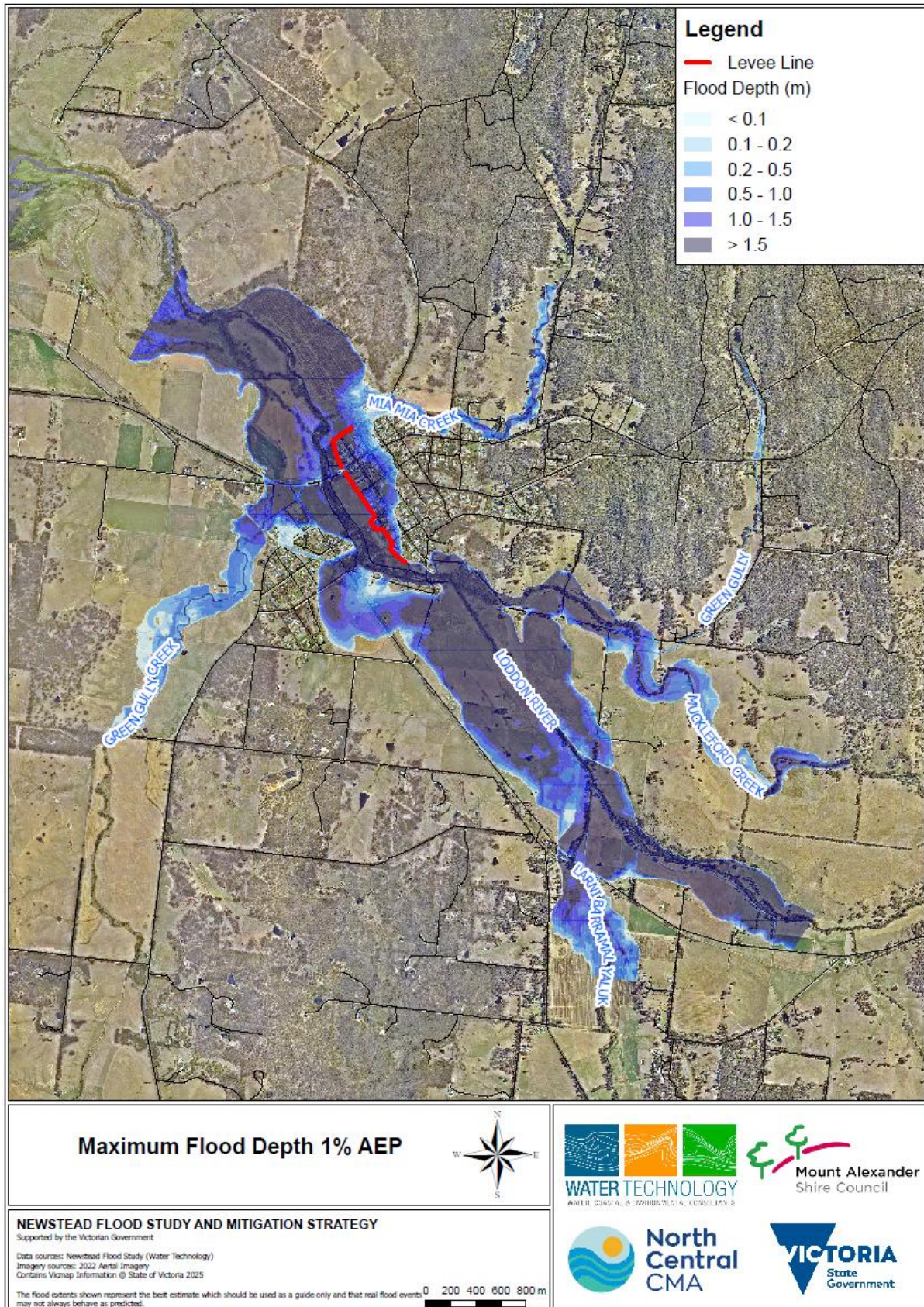


Figure 6-3 1% AEP flood depth

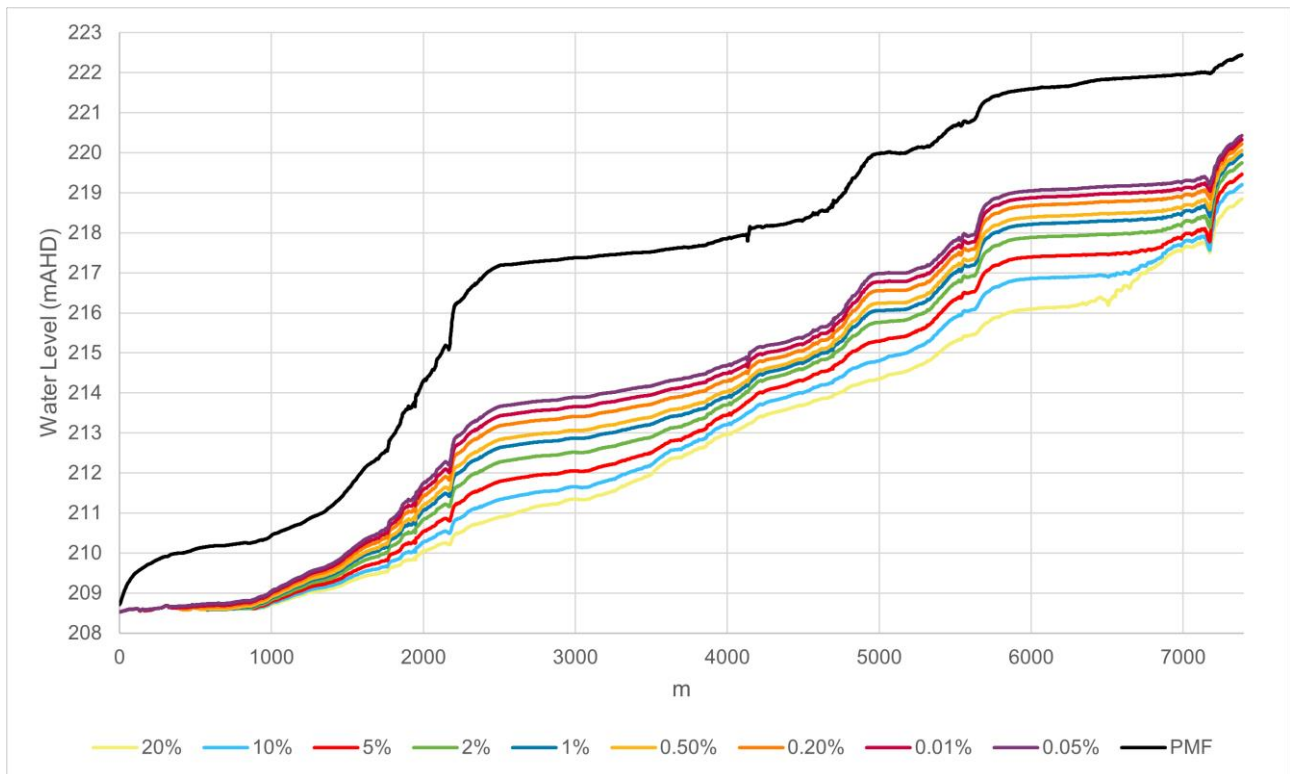


Figure 6-4 Water level profiles along the Loddon River

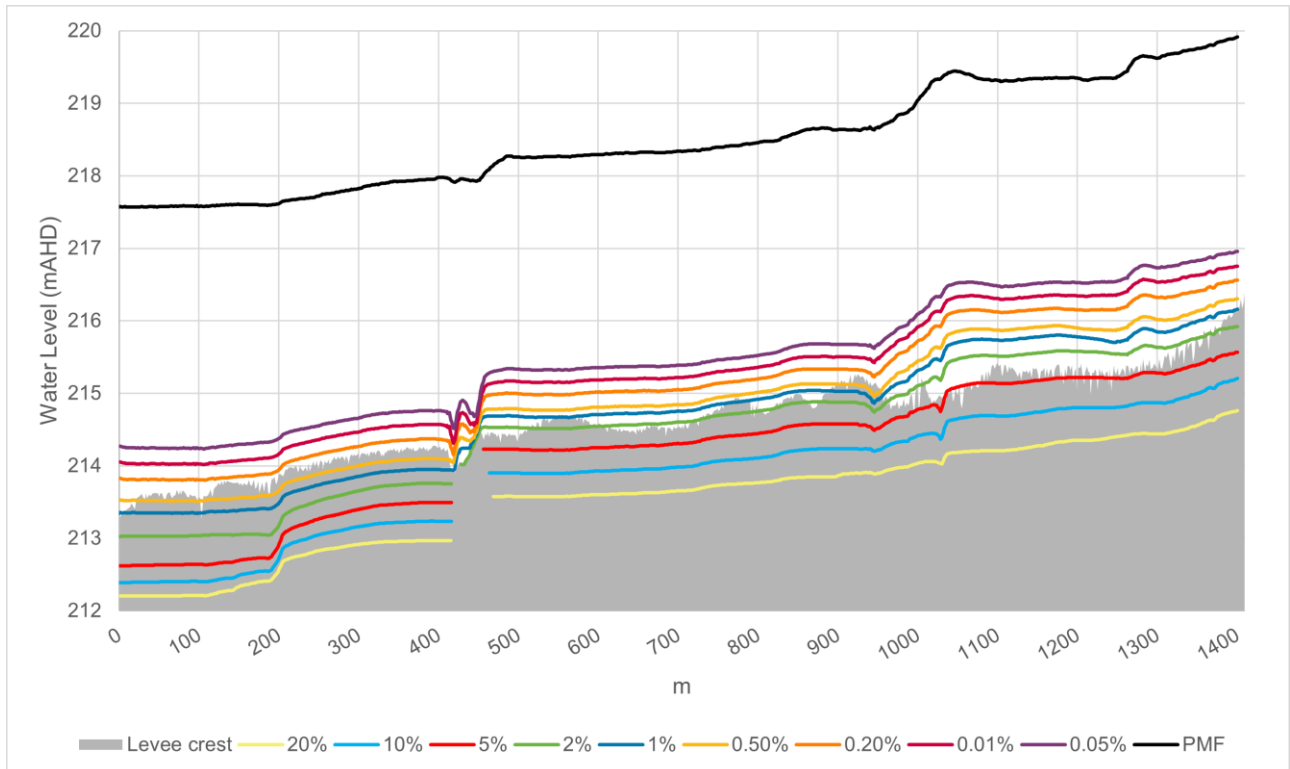


Figure 6-5 Water level profiles along the Newstead levee



7 SENSITIVITY ANALYSIS

Sensitivity testing of flood models consists of altering an input or parameter and comparing results to the base case, revealing the sensitivity of the model results to that input or parameter. Sensitivity testing of the model was undertaken for a range of parameters and inputs as described below. Sensitivity testing of the model was completed for the 1% AEP event 12 hour duration only, since this is the critical duration at Newstead. Flood level difference plots compared to the design mapping is shown for each sensitivity test undertaken.

7.1 Roughness coefficients

Sensitivity to surface roughness within the hydraulic model was tested by lowering and raising the Manning's 'n' roughness. The roughness values adopted for the design modelling were achieved during the calibration process, after analysis of results against available surveyed flood marks and other historic flood information. However, the floodplain roughness may vary depending on the time of the year due to for example variations in vegetation and cropping of fields, which in turn may influence flood levels. The design roughness values in the model were multiplied by 0.8 and 1.2 for the low and high tests respectively. Figure 7-1 and Figure 7-2 show the difference in water level in Newstead for each test. The results show large differences along the entire Loddon River floodplain, and slight changes to the flood extent near the Newstead township. Flood levels inside the Newstead levee increased by up to 0.38 m in the high roughness scenario, and decreased by up to 0.68 m in the low roughness scenario. The model area is characterised by native bushland and open space used for grazing rather than cropping. Hence, large variations in vegetation cover throughout the year is unlikely. The sensitivity analysis is overestimating the likely impacts caused by surface roughness changes more so than a catchment where cropping is more extensively found on the floodplain and significant changes in the surface roughness may occur due to the land use type. Additional input regarding vegetation coverage changes throughout the year will be sought during community consultation sessions.

7.2 Structure blockage

A blockage assessment was undertaken in accordance with ARR2019 guidelines considering inlet blockage for major culverts and bridges in the model. The catchment upstream of each structure was characterised in terms of debris availability, mobility and transportability, resulting in the overall catchment debris potential. Consideration was also given to whether the structure was located downstream of other structures which would capture a majority of the debris, decreasing the debris potential downstream of such structures. Two blockage scenarios were modelled, one scenario using the debris potential as described, and one scenario ignoring the impact of upstream structures. The final blockage factor adopted for each structure is listed in Table 7-1 and Table 7-2, with structure locations show in Figure 3-4. Note that the bridge blockage was applied to the openings (i.e. underneath the deck), with 100% blockage applied to the bridge railings for all modelled bridges.

Table 7-1 Structure blockage factors - culverts

Map reference	Road	Waterway	Blockage – Scenario 1	Blockage – Scenario 2
C1	Pyrenees Highway	Green Gully	25%	25%
C2	Pyrenees Highway	Drainage	No flow in 1%AEP	
C3	Pyrenees Highway	Drainage	No flow in 1%AEP	
C4	Pyrenees Highway	Drainage	25%	25%
C5	Pyrenees Highway	Drainage	25%	25%
C6	Cameron Road	Mia Mia Creek	50%	50%
C7	Cameron Road	Mia Mia Creek	25%	50%



Map reference	Road	Waterway	Blockage – Scenario 1	Blockage – Scenario 2
C8	Cemetery Road	Green Gully	25%	25%
C9	Cemetery Road	Drainage	No flow in 1%AEP	
C10	Hepburn - Newstead Road	Drainage	25%	25%
C11	Railway	Drainage	25%	25%

Table 7-2 Structure blockage factors - bridges

Map reference	Road	Waterway	Blockage – Scenario 1	Blockage – Scenario 2
B1	Pyrenees Highway	Loddon River	10%	10%
B2	Pyrenees Highway	Green Gully Creek	25%	50%
B3	Maldon-Newstead Road	Mia Mia Creek	0%	10%
B4	Newstead-Guildford Road	Larni Barramal Yaluk	0%	0%
B5	Railway	Larni Barramal Yaluk	10%	10%
B6	Cemetery Road	Muckleford Creek	25%	50%
B7	Cemetery Road	Muckleford Creek	50%	50%
B8	Unnamed	Green Gully	25%	50%
B9	Railway	Green Gully Creek	25%	50%
B10	Unnamed	Green Gully Creek	50%	50%

Figure 7-3 and Figure 7-4 show the differences in water level in Newstead obtained using the blockage factors. The results show localised increases to flood levels directly upstream at some of the blocked structures, but no changes in flood extent and no changes downstream of the structures. The distance between the Loddon River bridge (in Newstead) piers provides a low blockage factor, resulting in minor impacts to flood levels in this area.

7.3 Boundary conditions

The model has a single outflow boundary located in the Cain Curran Reservoir. For design events, a constant height of 208.475 mAHD was adopted. This corresponds to the October 2022 flood peak water level recorded at the Cairn Curran head gauge, which is just above the Full Supply Level of 208.46 mAHD as stated by Goulburn-Murray Water. A sensitivity test was undertaken adopting the Cairn Curran downstream gauge peak level from 2022 of 182.507 mAHD. Changing the downstream boundary level causes the peak water level at the boundary to drop to the ground level of 205.5 mAHD and lowered water level in an area directly upstream of the boundary. However, the results indicate that the influence of the downstream boundary is limited to 1.2 km upstream of the boundary, or 2 km downstream of Newstead, see Figure 7-5.

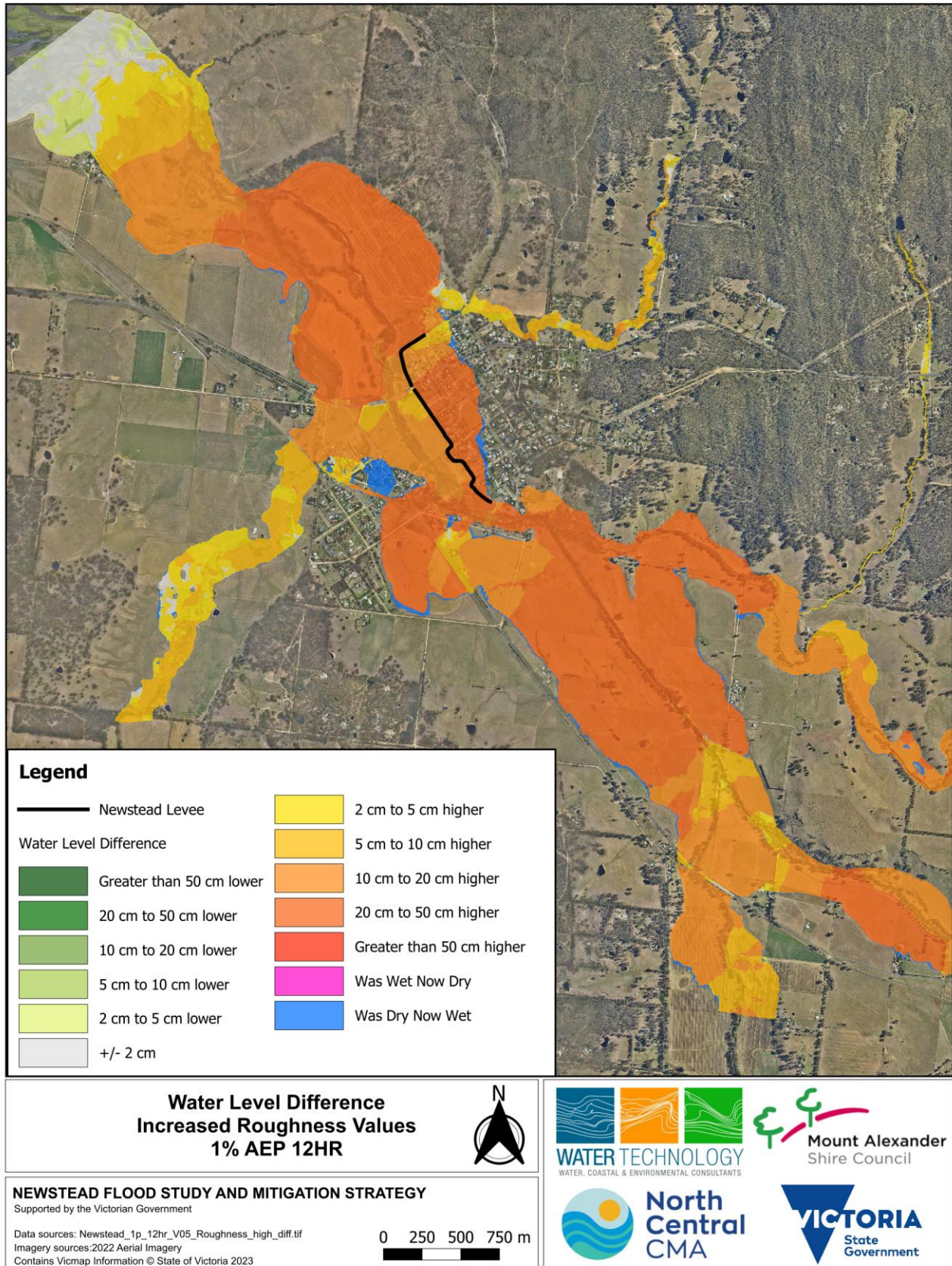


Figure 7-1 1% AEP water level difference – increased roughness values

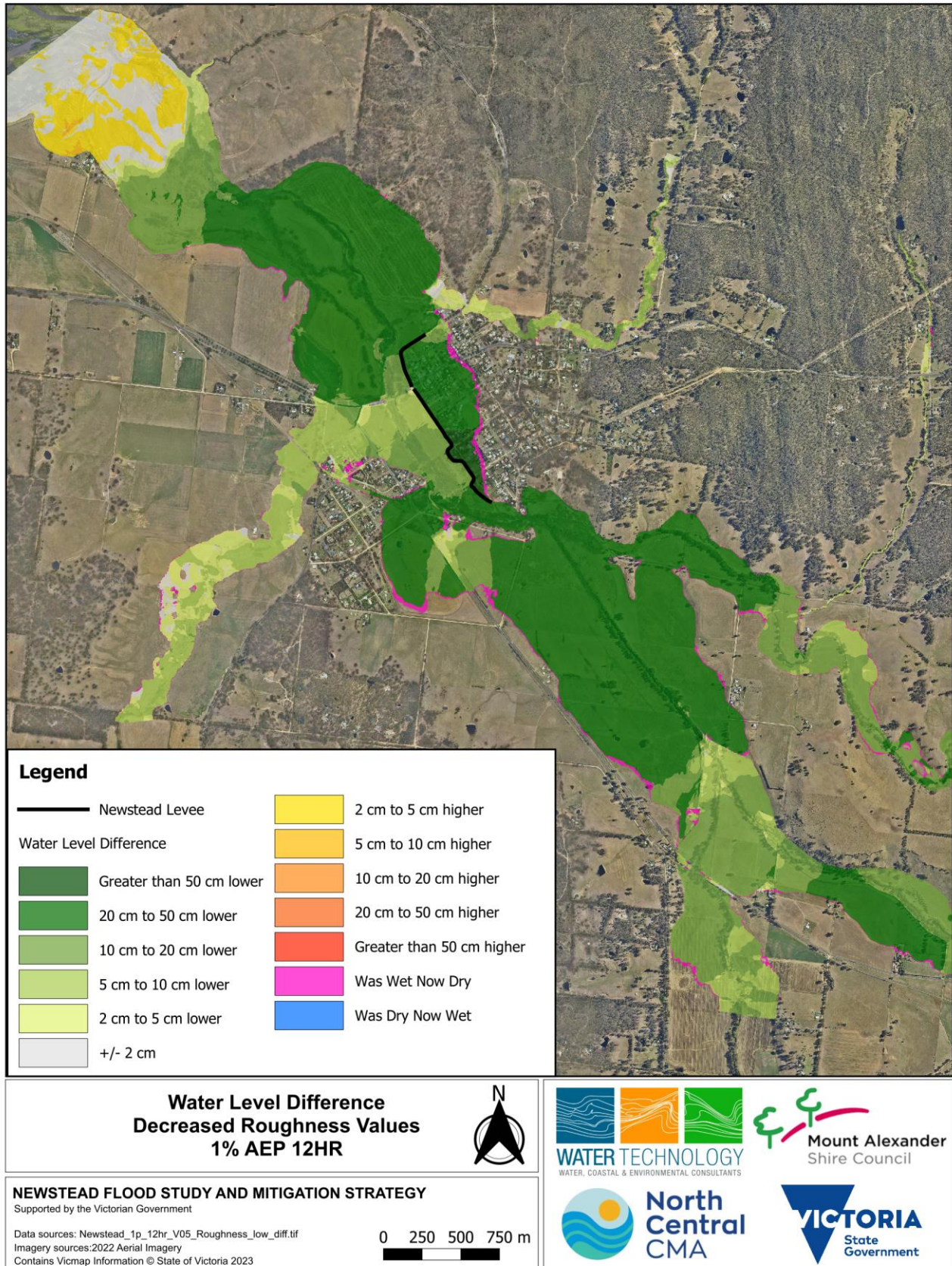


Figure 7-2 1% AEP water level difference – decreased roughness values

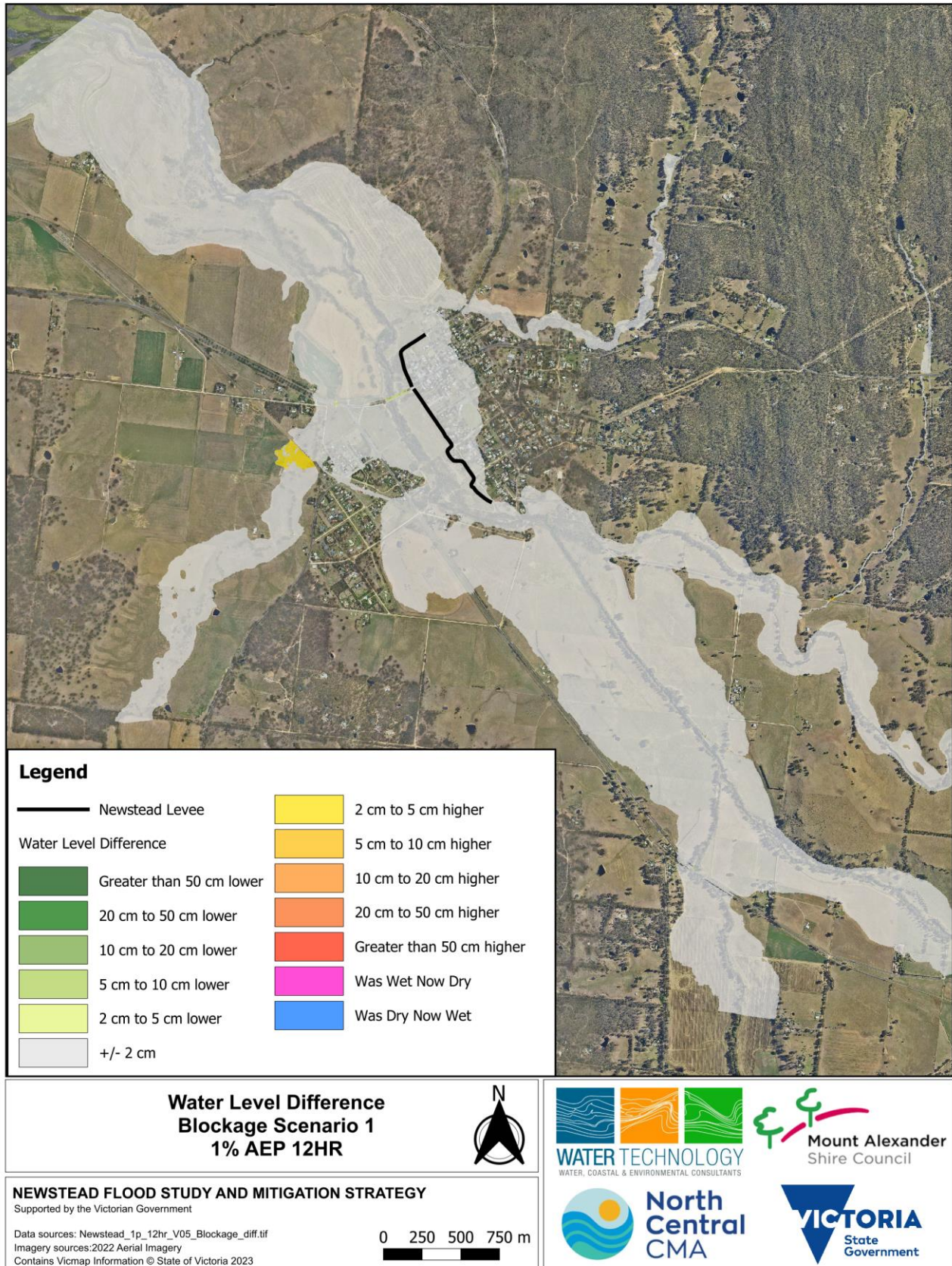


Figure 7-3 1% AEP water level difference – structure blockage scenario 1

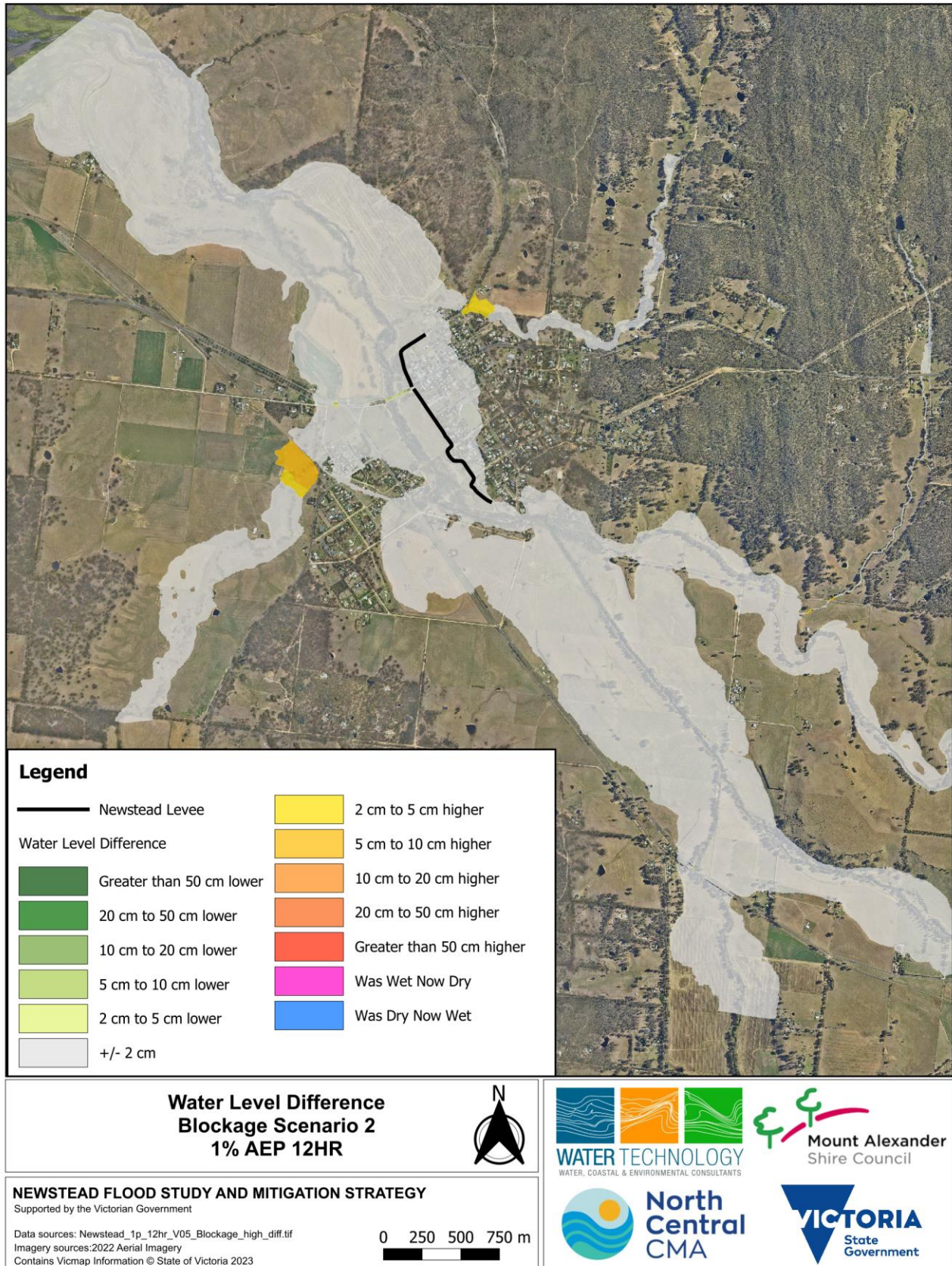


Figure 7-4 1% AEP water level difference – structure blockage scenario 2

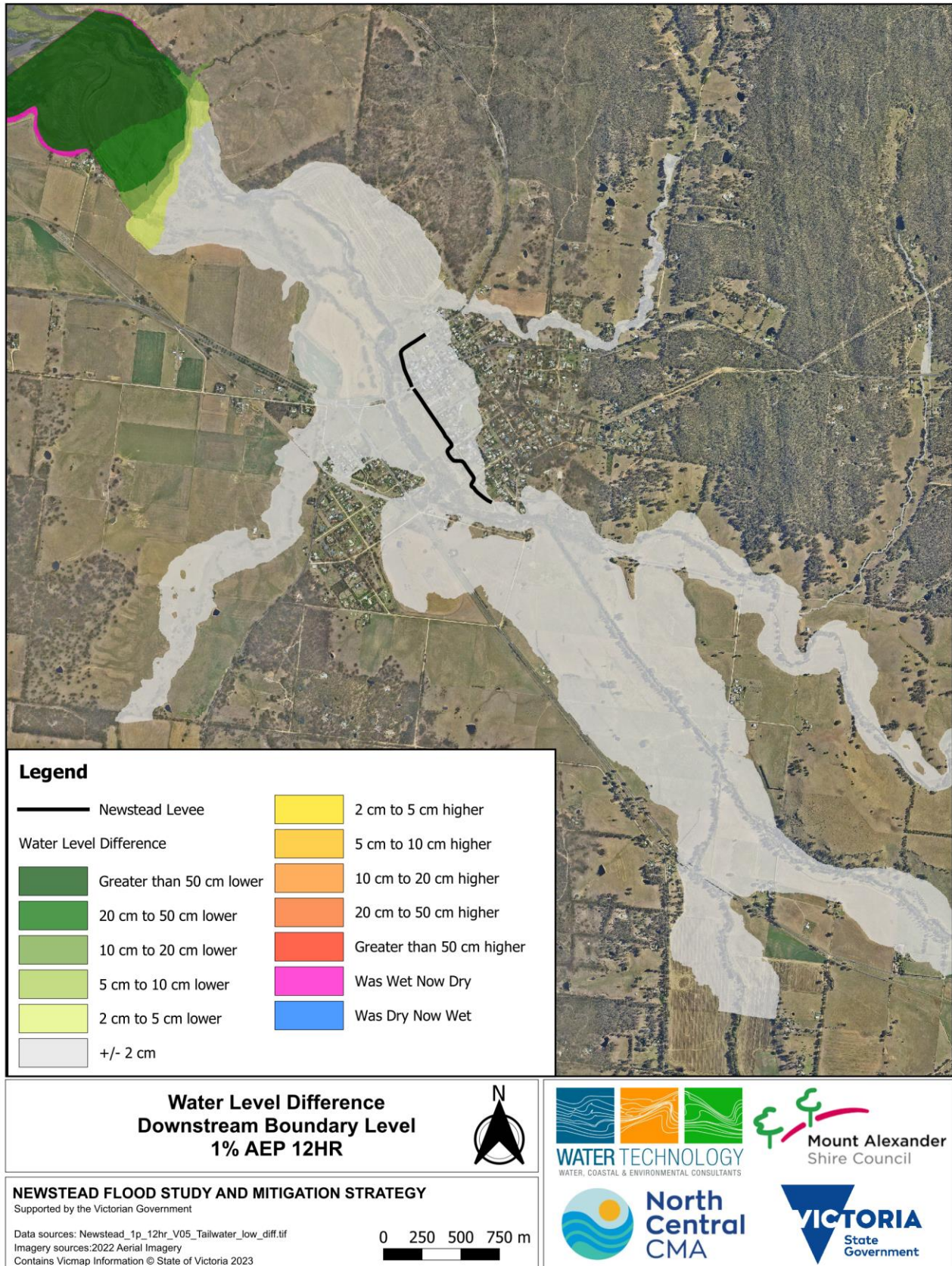


Figure 7-5 1% AEP water level difference – decreased downstream boundary level



8 SUMMARY AND NEXT STEPS

The hydraulic model calibration and validation process has shown the TUFLOW model developed for the study is suitable to replicate a range of flood events including large floods such as the October 2022 event and longer duration events such as September 2016. Modelling results show a suitable match to the available calibration data sources and the model is fit for purposes of design modelling.

Design modelling and sensitivity testing of the calibrated hydraulic model has been completed and detailed in this report. Design flood mapping outputs have been provided digitally along with this report.

The models have been simulated for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05% AEP and PMF events. The 10% and 1% AEP events were simulated with projected climate change increased rainfall intensity under SSP5 for the year 2100.

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.

Flood mapping was produced in line with industry standards and the current ARR guidelines. The mapping is fit for the purposes of informing land use planning within the study area through the development of draft overlays for a future planning scheme amendment. As part of this study, model outputs will be used to assess average annual flood damages for the township and the models utilised to assess potential structural mitigation options. Flood intelligence products will be developed to inform emergency management planning and response including updated content for the Municipal Flood Emergency Management Plan.



APPENDIX A FLOOD MAPPING





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