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WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Summary Report

Marnoo Flood Study

North Central CMA

27 June 2023

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Cover Image: Wallaloo Creek at Raluana Road, January 2011

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Dear Nathan,

Marnoo Flood Study

Water Technology is pleased to present the Marnoo Flood Study Summary Report. The report presents a summary of the technical reports produced as part of the project including the following:

- R01 – Data Review and Validation Report.
- R02 – Calibration Modelling Report.
- R03 – Design Hydrology and Hydraulic Modelling Report.
- R04 – Flood Damages and Mitigation Assessment Report.
- R05 – Flood Intelligence and Flood Warning Report.
- R06 – Municipal Flood Emergency Plan (MFEP) Documentation.
- **R07 – Summary Report (this report).**

Water Technology would specifically like to thank the Northern Grampians Shire Council, North Central CMA and the Marnoo community members who gave their time to provide their personal observations of flooding and provide feedback on the flood modelling. Strong contributions from key stakeholders and community members has resulted in improved outcomes from this study, which will assist with flood related land use planning, floodplain risk management, flood emergency response and raising community awareness of individual flood risk.

Yours sincerely

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1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by the North Central Catchment Management Authority (NCCMA), in partnership with Northern Grampians Shire Council (NGSC), to undertake the Marnoo Flood Study. The Marnoo Flood Study was supported by the Victorian Government. The investigation area covered the township of Marnoo and the surrounding local catchments, including Wallaloo Creek which flows past the township and its tributary Andersons Creek, as shown in Figure 1-1. A well-documented flood event took place in Marnoo in January 2011, it was the largest flood on record for many river systems in north central Victoria.

Marnoo was covered by the North Central CMA Rapid Flood Risk Assessment (HARC, 2020), producing hydrologic and hydraulic models and flood mapping. The Rapid Flood Risk Assessment model was not calibrated and a preliminary review of this work by Water Technology highlighted areas of potential improvement, mostly related to the complexity of the local catchment contribution from the east. The Marnoo Flood Study provides a detailed understanding of flood risk to the township of Marnoo and its residents, developing an understanding flooding behaviour to inform future land use, prospective mitigation options and emergency management actions.

The project reporting was broken up into a series of deliverables which are summarised in this report, including a brief overview of each of the previous reports submitted, and the recommendations developed throughout the study. Reporting produced as part of the study included:

- R01 - Data Review and Validation
- R02 – Calibration Modelling Report
- R03 – Design Hydrology and Hydraulic Modelling Report
- R04 – Flood Intelligence and Flood Warning Report
- R05 – Flood Damages and Mitigation Assessment Report
- R06 – Municipal Flood Emergency Plan (MFEP) Documentation
- **R07 – Final Summary Report – This report**

1.2 Study area

Marnoo is in Victoria's Wimmera region, approximately 35 km west of St Arnaud and 60 km east of Horsham and is situated on the banks of Wallaloo Creek. The Wallaloo Creek catchment and its main tributary Anderson Creek, begin approximately 25 km southeast of Marnoo between the Morrl Morrl and Mount Bolangum Nature Conservation Reserves. Wallaloo Creek and Anderson Creek meander northwest across mostly cleared agricultural land before joining approximately 2 km south of Marnoo. Wallaloo Creek joins the Richardson River approximately 7 km northwest of Marnoo. A catchment of approximately 180 km^2 drains through Marnoo. The entire catchment is located within the Northern Grampians Shire Council and the North Central CMA management areas.

The catchment within and upstream of the study area is largely cleared agricultural land with some vegetated areas along the waterways.

The study area is focused on the township of Marnoo and includes the following waterway structures:

- Road crossings at the following locations:
  - Wimmera Highway over Wallaloo Creek
  - Raluana Road bridge over Wallaloo Creek

- Donald-Stawell Road over Andersons Creek
- Road culverts and underground pit and pipe network
- The redundant railway east of the township and associated hydraulic structures.
- Grampians Wimmera Mallee Water (GWMWater) irrigation channels located east of the township.
- Several off-stream dams throughout the township.

1.3 Previous reporting (and context)

This report follows R01 to R06 and summarises the completed project. This summary report will not delve into technical detail, instead focussing on project outputs and deliverables produced by the study. Readers will be directed to individual reports should additional information be required. The chapters and sections of this report broadly follow the previous reporting from R01 to R06 with a summary of the key points in each detailed report.

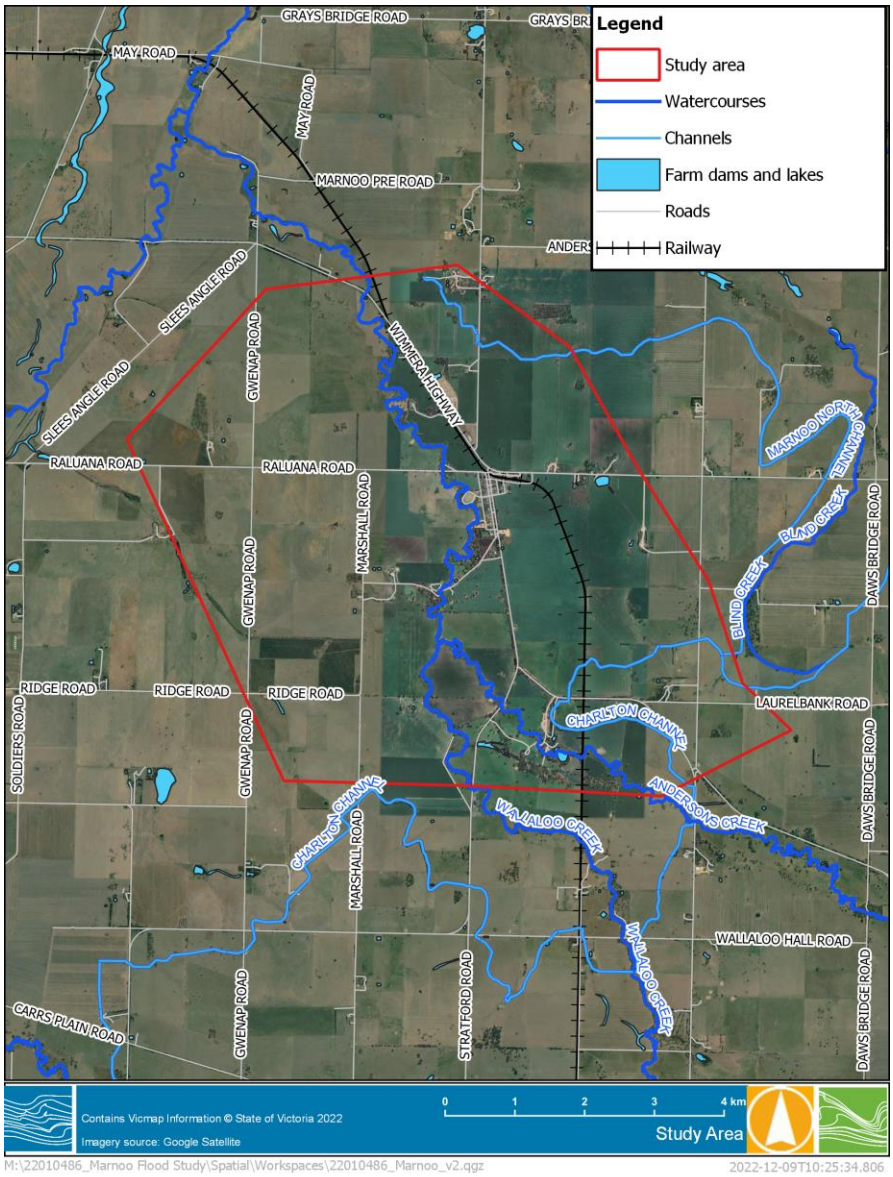

Figure 1-1 Study area

2 DATA REVIEW AND VALIDATION

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

- Previous flood studies and reports covering the area
  - Donald Flood and Drainage Management Plan (GHD, 2014)
  - North Central CMA Rapid Flood Risk Assessment (HARC, 2020)
- Historical flood events and accompanying anecdotal evidence
  - Anecdotal evidence was the best available data for historical floods – no gauged flood heights were uncovered as part of the study.
  - Evidence was gathered for the January 2011 event, which was selected for validation modelling based on the information available.
- Recorded streamflow
  - The catchment has no streamflow gauges.
- Recorded rainfall
  - Including both daily and sub-daily rainfall.
- Road and drainage infrastructure
  - Survey data was supplied by council with gaps infilled for minor structures by site visits.
- Topographic data
  - Multiple LiDAR data sets were available and were verified against survey captured for the project.

The initial community consultation session also formed part of the data collation aspect of the project, together with phone and email correspondence with Marnoo residents. Information relevant to the study was gathered however was limited to anecdotal evidence of flood behaviour in historic events.

The Data Collation Report (R01) also confirmed and detailed the modelling methodology for the following stages of the project.

3 CALIBRATION MODELLING

3.1 Overview

The Calibration Report (R02) describes in detail the hydrologic (RORB) and hydraulic (TUFLOW) model builds and parameter selection adopted for the study. The report also details the validation modelling of the historic event (January 2011). 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 RORB summary

3.2.1 Model build

The RORB model developed during the Rapid Flood Risk Assessment (2020) was reviewed and modified to produce inflows in both Wallaloo Creek and Andersons Creek upstream of Marnoo. The changes led to minor modifications to reach lengths and additional print points. A baseflow inflow location was removed based on prior calibration in which this flow was zero.

The final RORB model included 26 sub-catchments encompassing a total catchment area of approximately 180km^2, with the hydraulic study area located towards the lower end of the catchment, see Figure 3-1. The reaches were all defined as 'natural' and impervious fractions were left unchanged from the previous model, ranging from 0 to 0.04768.

3.2.2 Model parameters

The RORB parameters used in the Rapid Flood Risk Assessment (2020) were adopted in the current study, see Table 3-1. Kc was calculated using the average flow distance (D_{av}) in the reach network and a coefficient for Victorian catchments as recommended by Pearse et al (2002). As the catchment delineation was slightly modified in the current study, there was a minor decrease of the kc value in comparison to the previous model. The losses used in the Rapid Flood Risk Assessment (2020) were originally derived from the Donald Flood and Drainage Management Plan (GHD, 2014).

Table 3-1 RORB parameters

Parameter	January 2011
Kc	25.52
m	0.8
Initial losses	18.8 mm
Continuing losses	1.1 mm/hr

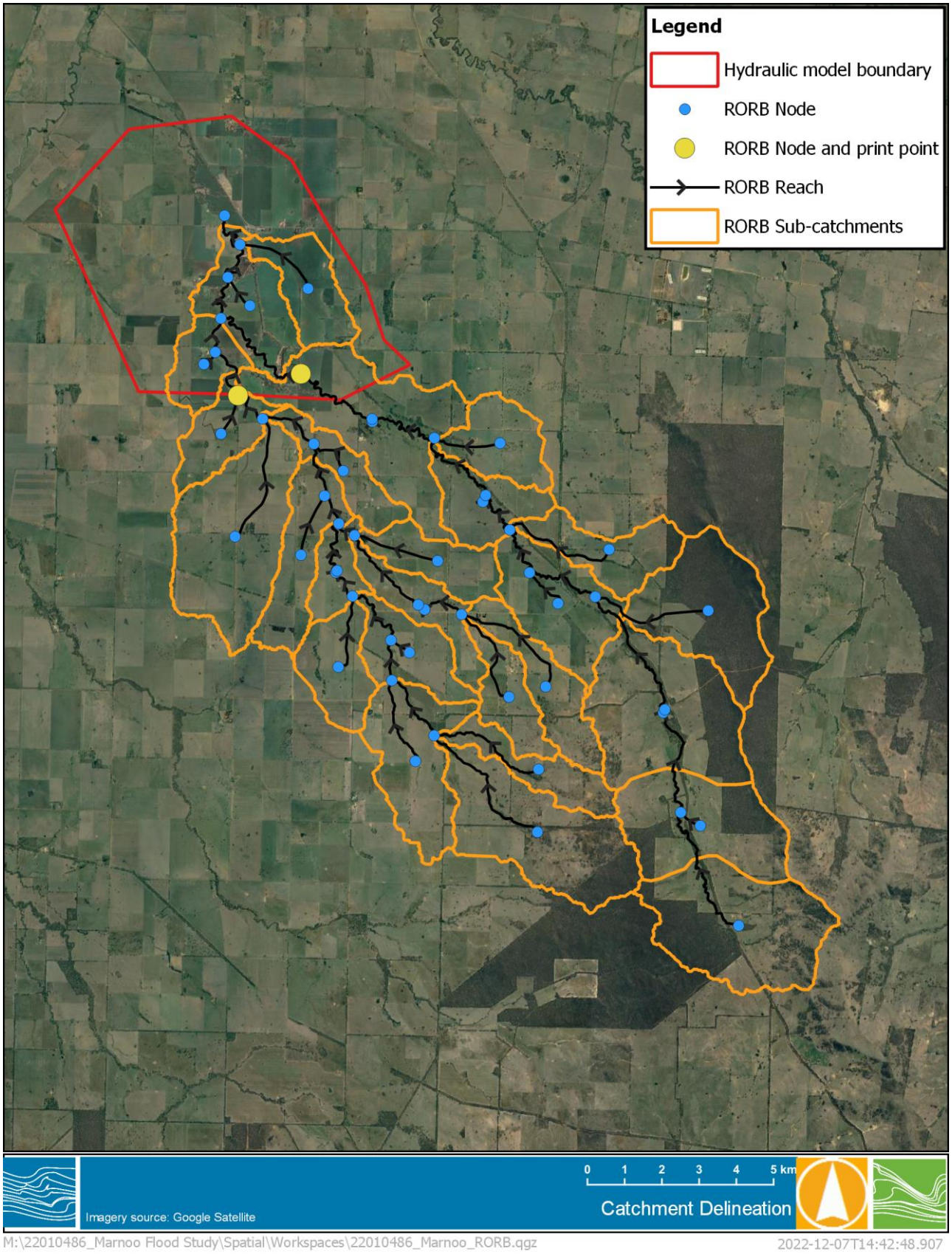

Figure 3-1 RORB model layout

3.2.3 Rainfall

3.2.3.1 Historic events

The RORB model was run for the January 2011 flood event. Daily records informed the spatial pattern and total rainfall across the catchment with the sub-daily record informing the temporal pattern of the event. A spatial distribution of rainfall was generated using nine rainfall gauges surrounding Marnoo with data recorded during the 2011 event. The temporal pattern for the event was generated using the Navarre (Avon no 3) (079086) gauge. The January 2011 event was modelled from 2100 hours on January 9 to 2100 hours on January 15 to capture the two rainfall bursts occurring during the storm event.

3.2.3.2 Design Events

Design rainfall depths for the range of AEPs and durations were downloaded from the Bureau of Meteorology's IFD (Intensity-Frequency-Duration) Design Rainfall Data System[1]. Given the size of the catchment, spatial variation in design rainfall was considered by deriving the spatial pattern in accordance with the method shown in section 6.5.4 of ARR2019 Book 2 Chapter 6.

Pre-burst rainfall was accounted for by subtracting the median pre-burst depth from the storm initial loss, as provided by the ARR datahub, verifying against nearby calibrated models to produce the burst initial loss according to the below equation:

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

3.3 TUFLOW summary

3.3.1 Model parameters and design

The TUFLOW model design and parameter selection is described in detail in R02 – Calibration 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 3-2. The TUFLOW model extent and boundary areas are shown in Figure 3-2.

Table 3-2 Key TUFLOW model parameters

Parameter	Value/Approach
Model build	2020-10-AF-iSP-w64
Model precision	Single Precision
Grid cell size	3 metres
Sub grid sampling	Not adopted
Solution scheme	HPC
Inflows	Source-area boundaries for in-channel hydrographs and rainfall excess
Outflow	Height-flow slope of 1% based on waterway slope
Hydraulic Roughness	Manning's 'n', varies with land use
1-Dimensional elements	Culverts and pipes linked to 2-D domain

[1] http://www.bom.gov.au/water/designRainfalls/revised-ifd/

Parameter	Value/Approach
Topography	2009-10 Victorian State Wide Floodplains 1m LiDAR and 2006 GWMWater Wimmera Mallee Pipeline 2m LiDAR with the floodplains dataset used in preference outside of the creek channel.
Extent	The model extent was set such that the entire floodplain in Marnoo and the entire eastern catchment would be captured and main flow boundaries would be a sufficient distance from the town to have no influence on model results within the town.
Roughness	Assigned based on land use and previous modelling, see Table 3-3.
Hydraulic Structures	Culverts and pipes were represented as 1D elements linked to the 2D domain. Bridges were represented as layered flow constrictions within the 2D domain based on survey captured by NG Shire Council.

Table 3-3 Hydraulic roughness

Land use / Topographic description	Roughness coefficient (Manning's n)
Open space, minimal vegetation	0.04
Open space, moderate vegetation	0.08
Open space, heavy vegetation	0.12
Open space in residential areas at Marnoo	0.05
Built-up and residential areas at Marnoo – higher density	0.25
Built-up and residential areas at Marnoo – lower density	0.15
Commercial areas at Marnoo	0.35
Industrial areas	0.30
Car park/pavement/roads	0.02
Open water	0.04

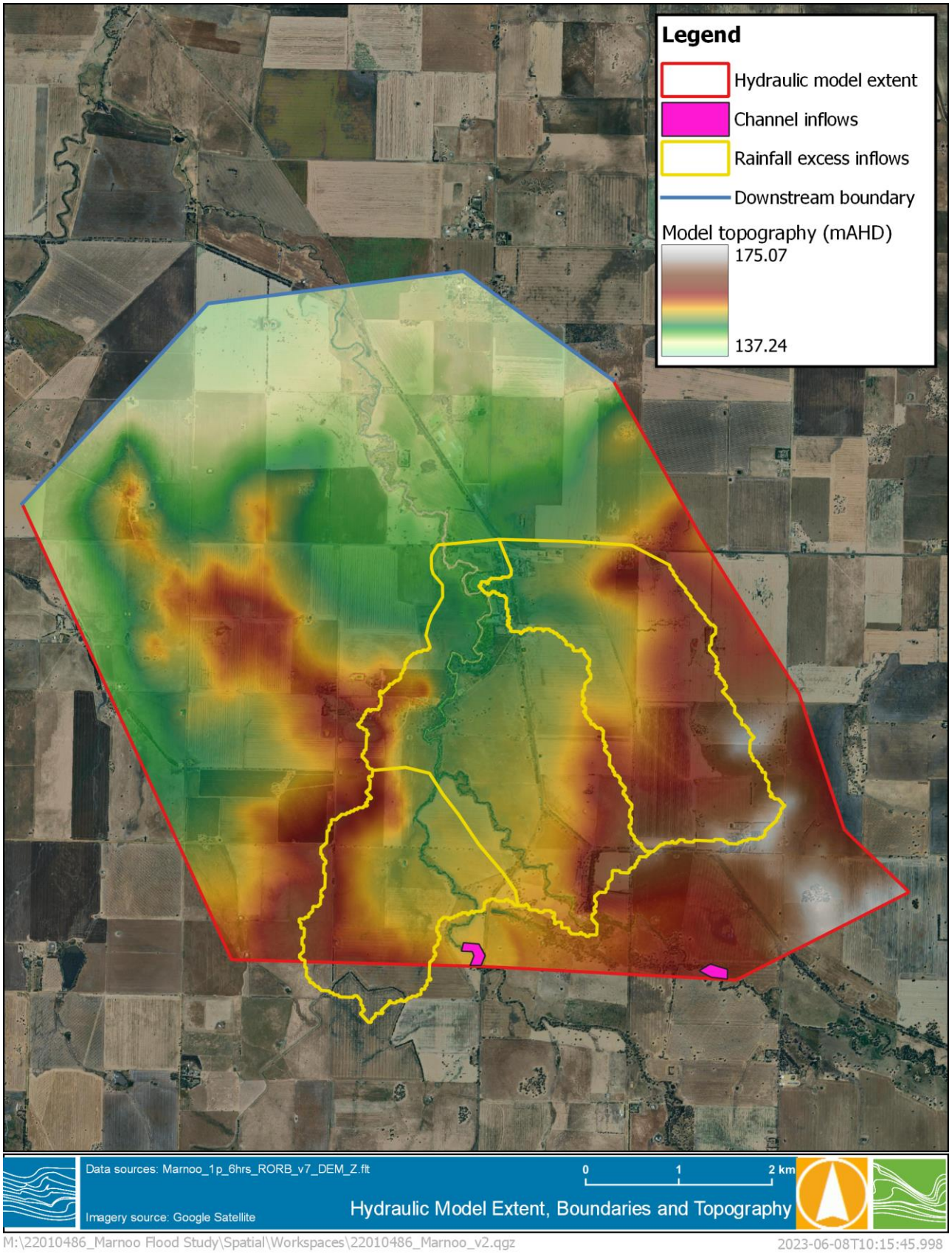

Figure 3-2 Hydraulic model extent, topography and boundaries

3.4 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 January 2011. The model results were compared to anecdotal evidence obtained during the initial community consultation session in July 2022 and presented to community members at the second community consultation session held in March 2023.

The following calibration data sources were available from the January 2011 event:

- 21 photographs showing inundation extent at different locations in Marnoo taken by a Marnoo resident. It should be noted that the photos were taken after the peak flood level.
- 24 photographs showing inundation extent in the southern Park Lane area taken by a Marnoo resident. The quality of these photographs is not as high as for the above photographs.
- A surveyed peak water level mark at 38 Park Lane.
- Anecdotal recollections stating that:
  - The sporting grounds oval was inundated but the cricket pitch located at the centre of the oval was above the water level.
  - The Marnoo clubrooms located next to the sporting grounds was inundated above floor level with a water level approximately 50-100 mm above floor.
  - The pub located at 7 Newall Street experienced above floor inundation.
  - Worst affected were the four properties located on 34 to 42 Newall Street; however, none of them experienced above floor inundation.
    - 42 Newall Street experienced inundation to just below the floor level. The residents opened the back gate to let water through which may have contributed to keeping inundation levels below floor level.
    - 36-38 Newall Street also experienced inundation close to floor level.

Figure 3-3 shows the modelled flood depth for the January 2011 event. The modelled water levels agreed well with the recollections at all locations. The modelled flood extent agreed well with the extent indicated in photos provided by residents, taking into account the photos may have been taken after the peak flood level occurred.

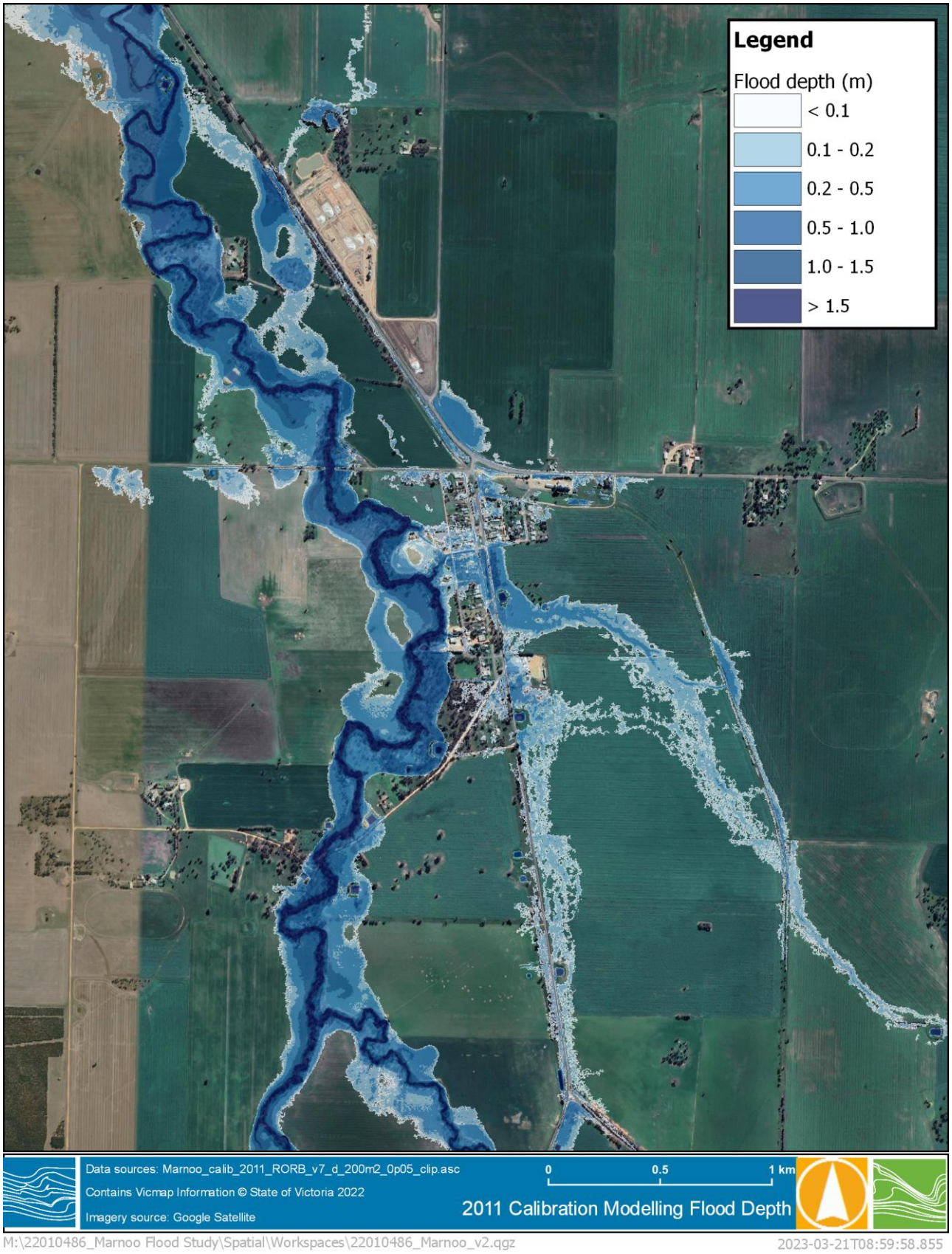

Figure 3-3 2011 calibration modelling flood depth

4 DESIGN MODELLING

4.1 Hydrology

The RORB hydrologic model was ran for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.1%AEPs and PMF events. Critical event hydrographs for Wallaloo Creek, Andersons Creek and rainfall excess at the eastern catchment for the design events (excluding the PMF) are shown in Figure 4-1 to Figure 4-3.

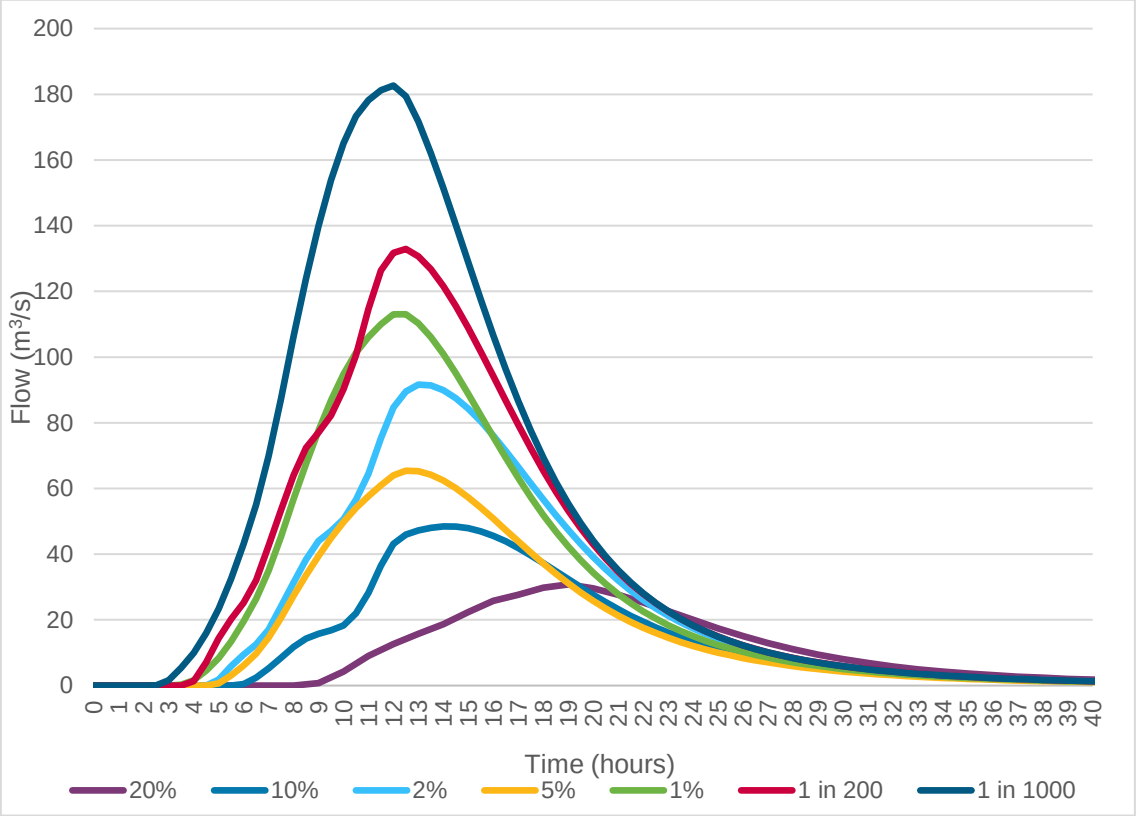

Figure 4-1 Design hydrographs, Wallaloo Creek at Donald-Stawell Rd

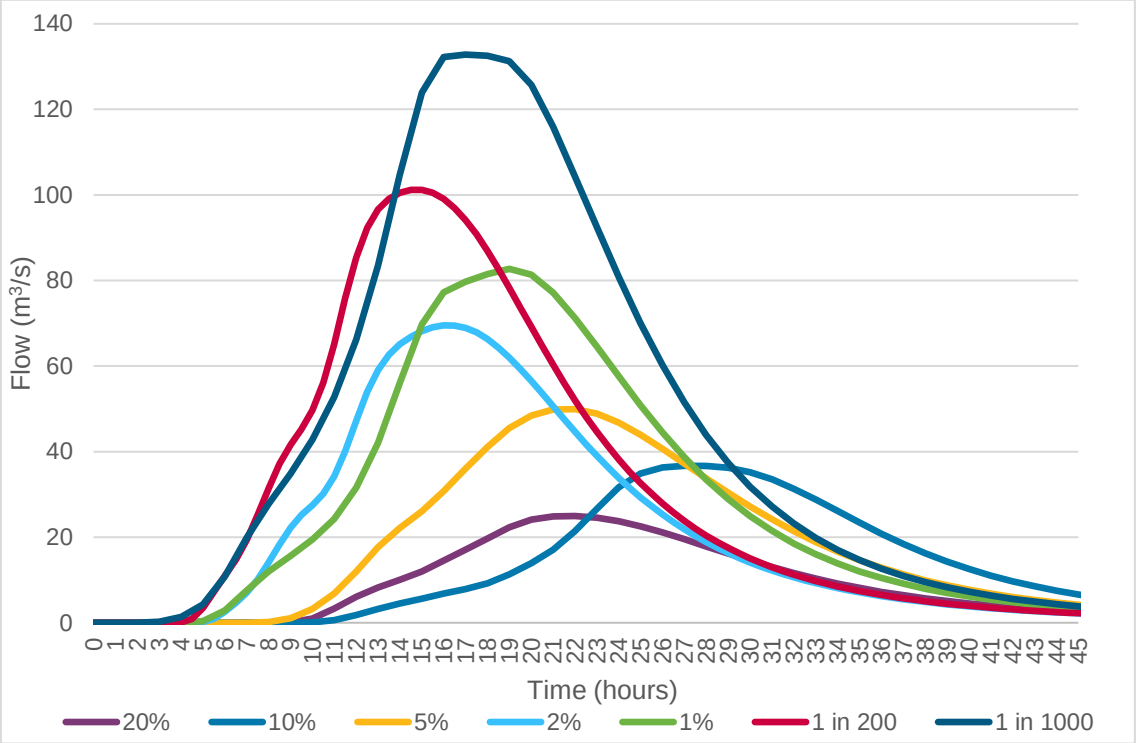

Figure 4-2 Design hydrographs, Andersons Creek 1.5 km upstream of Donald-Stawell Rd

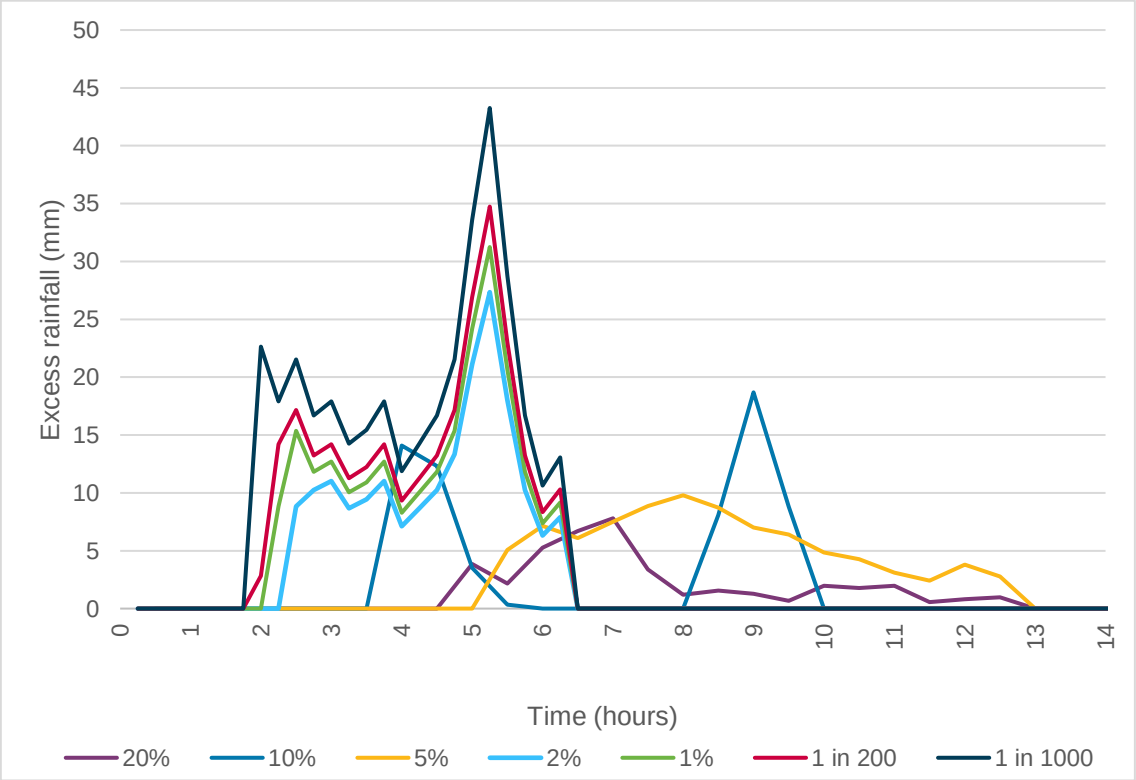

Figure 4-3 Design rainfall excess hydrographs, sub-catchment east of Marnoo

The impact of increased rainfall intensity associated with climate change was investigated for the 10% and 1% AEP events, with two scenarios modelled for both AEPs:

- Projected flows to 2100 under RCP4.5
- Projected flows to 2100 under RCP8.5

The resultant impact on flows at the Raluana Road bridge are shown in Table 4-1. The 1% AEP flows under an RCP8.5, 2100 scenario are shown to increase by 19.3% and comparably are between present day 0.1% and 0.5% AEP flows. The 10% AEP flows for the same climate scenario are increased by 45.6% and compare to an even magnitude just above present day 5% AEP flows.

Table 4-1 Climate change assessment summary

1% AEP (12 hr duration)	RCP4.5 2100	RCP8.5 2100
IFD rainfall (mm)	90	90
% increase	6.34	23.33
Projected rainfall depth (mm)	95	111
Peak flow at bridge (m^3/s)	177.6	200.0
Increase in flow (%)	5.9	19.3
10% AEP (12 hr duration)	**RCP4.5 2100**	**RCP8.5 2100**
IFD rainfall (mm)	56	56
% increase	6.34	23.33
Projected rainfall depth (mm)	60	69
Peak flow at bridge (m^3/s)	88.4	117.1
Increase in flow (%)	10.0	45.6

4.2 Hydraulics

Hydrographs extracted from the RORB model at locations corresponding to the source-area inflow locations shown in Figure 3-2 were applied to the TUFLOW model. Peak flood depths for the 1% AEP and the 2100 1% AEP under RCP8.5 are shown in Figure 4-4 and Figure 4-5.

Figure 4-6 shows the difference in flood levels between the existing conditions 1% AEP event and the 2100 1% AEP under RCP8.5. In the township, flood levels are shown to increase in the order of 0.05 to 0.2 m with larger increases in and around Wallaloo Creek. Flood level increases in the overland flow path from the east are limited to approximately 0.05m.

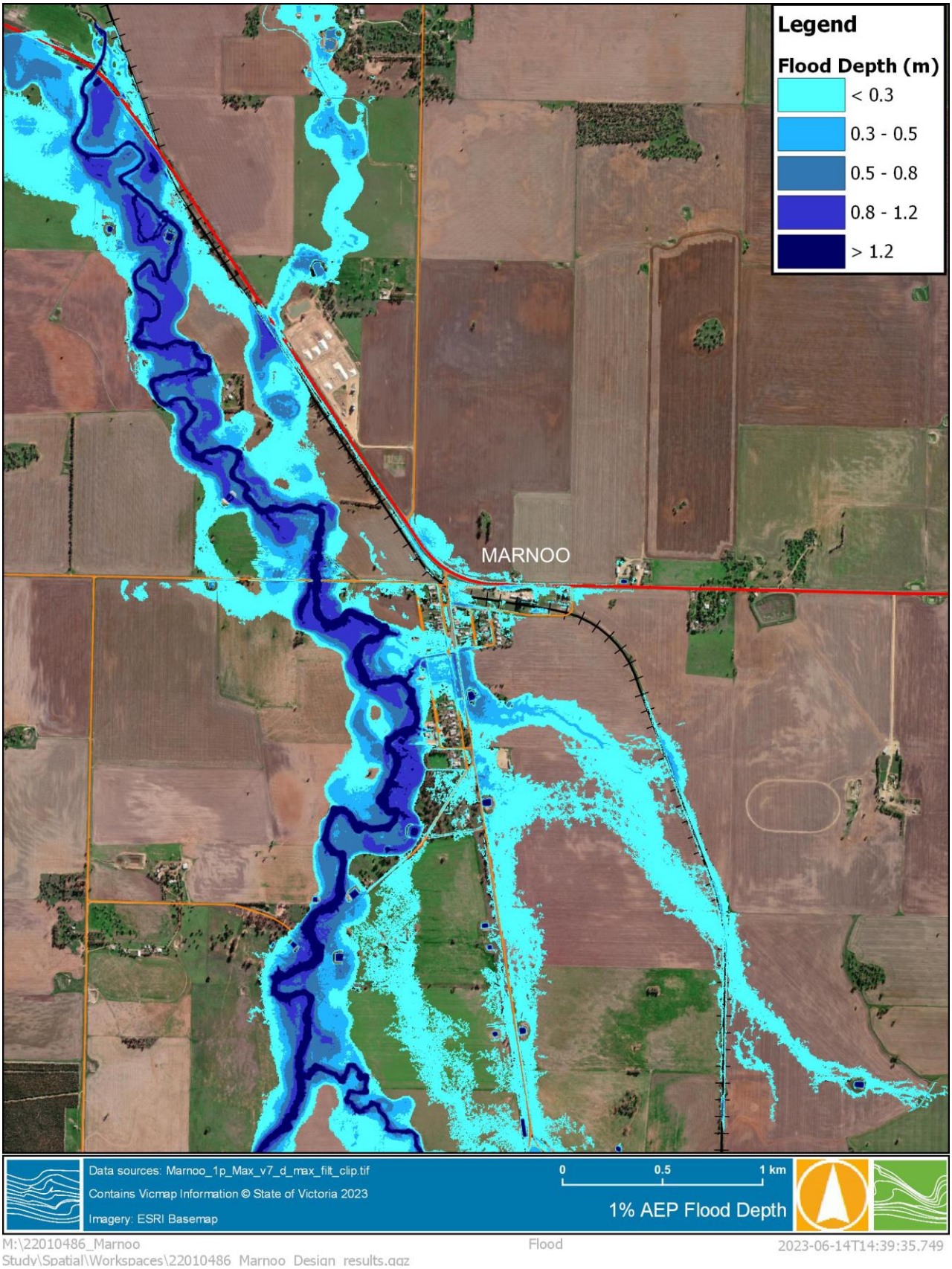

Figure 4-4 1% AEP flood depth

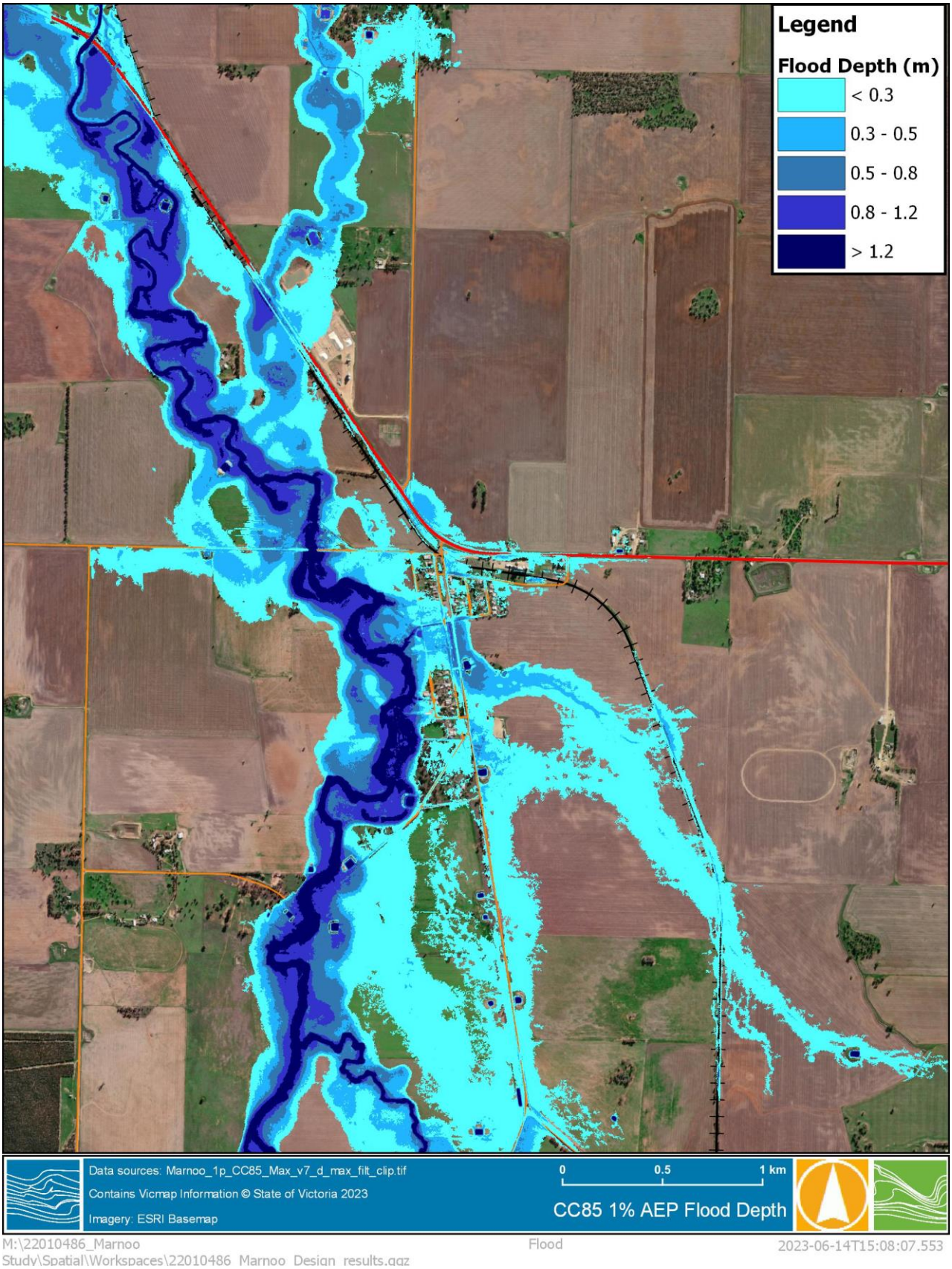

Figure 4-5 1% AEP RCP8.5 2100 depth

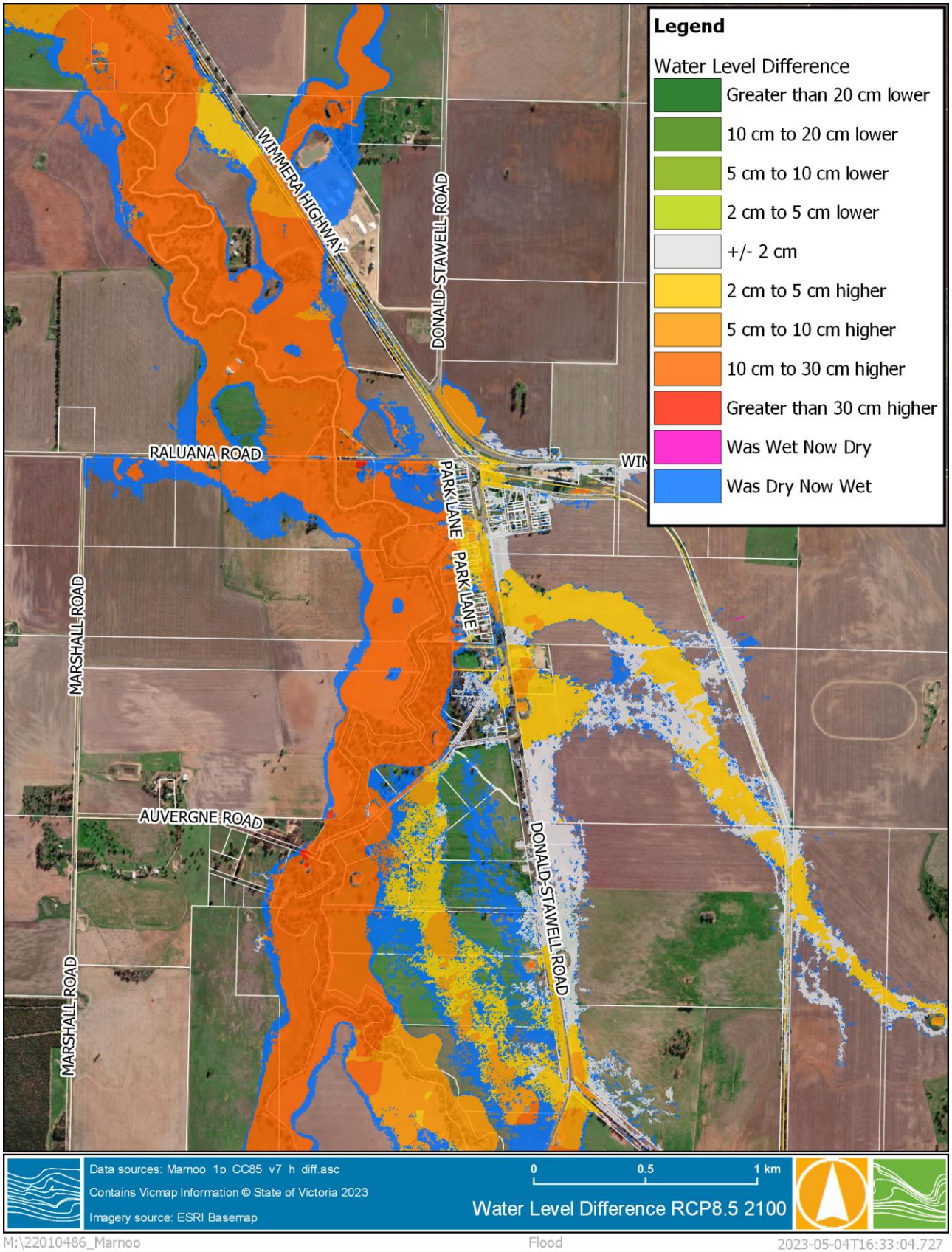

Figure 4-6 1% AEP water level difference – climate change RCP8.5 2100

4.3 Sensitivity testing

Model sensitivity testing was conducted on the hydrologic and hydraulic models for the following parameters:

- Losses (hydrology)
- Hydraulic roughness
- Structure blockage
- Boundary conditions (slope)

The models were shown to be sensitive to initial loss, hydraulic roughness and bridge blockage. Reducing initial loss from 18.8 to 0 mm caused a 26.4% increase in flows for the 1% AEP event.

Alterations to hydraulic roughness impacted flood levels in and around the waterways, but had less of an impact for the overland flow path. Flood levels in the waterways increased by up to 0.1 m in the township in the high roughness scenario. The low roughness scenario resulted in lowered flood levels with just over 0.1 m in the same area.

Applying 50% of blockage to bridge openings and 100% of blockage to the railings caused increased flood levels upstream of each bridge. Levels and extents were also increased in the overland flow path north of Andersons Creek downstream of the bridge, due to more water being pushed across the road north of the bridge. Upstream of the Raluana Road bridge, flood levels were increased by up to 0.2 m, with more water pushed across the road to the west of the bridge.

5 FLOOD INTELLIGENCE AND WARNING

5.1 Overview

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

- Summary table of flood behaviour, impacts and roads inundated, see Section 5.2.
- Average flood peak travel time estimations, see Section 5.3.
- "Flood/No Flood" tool, providing a rough link between observed rainfall and flood magnitude, see Section 5.4.
- Flash flooding monitoring capability

These products have been included in a draft update to the Northern Grampians Municipal Flood Emergency Plan in addition to the Flood Intelligence and Warning Report (R04). The flood impacts summary table, flood peak travel time estimates and Flood/No Flood tool have been reproduced herein for reference.

5.2 Flood impacts summary

Table 5-1 Flood impacts summary

Flood event	Characteristics – Flood behaviour	Roadways inundated
20% AEP *~38 mm of rainfall in 6 hours* *~47 mm of rainfall in 12 hours* *~53 mm of rainfall in 18 hours*	Ponding from Andersons Creek breakout occurs upstream of Donald – Stawell Road flowing south along the road and north towards Bolangum - Inn Road. Auvergne Road floodway fully submerged with hazardous depths and velocities. Breakouts from Wallaloo Creek north of Raluana Road, filling the floodplain and ponding upstream of Wimmera Highway, with a breakout branch flowing northwest instead of under the Wimmera Highway bridge. Overland flow path from eastern catchment ponding upstream of corner of Newall Street and Park Road, with culvert flow inundating the township south of Park Road to hazardous depths.	• Auvergne Rd (~3m) • Newall St West (<0.3m) • Park Ln (<0.3m) • Park Rd (<0.5m) • Station St (<0.3m)

Flood event	Characteristics – Flood behaviour	Roadways inundated
10% AEP *~52 mm of rainfall in 9 hours* *~56 mm of rainfall in 12 hours* *~63 mm of rainfall in 24 hours*	Wallaloo Creek breaks out of banks along entire modelled reach. Hazardous depths across floodplain. Further breakouts observed near Wimmera Highway Bridge. Overland flow paths widened. 1 Newall Street (GWMWater pump station), 22 and 30 Newall Street (Car mechanics) and 23 Newall Street (toilet block) inundated above floor.	• Auvergne Rd (>3.5m) • Newall St West (<0.5m) • Park Ln (<0.3m) • Park Rd (>0.5m) • Station St (>0.5m) • Bolangum Inn Rd (<0.1m) • Newall St East (<0.3m)
5% AEP *~54 mm of rainfall in 6 hours* *~66 mm of rainfall in 12 hours* *~74 mm of rainfall in 24 hours*	Generally as above with slightly deeper, faster flowing water. Hazardous depths across floodplain and parts of overland flow path from the east.	• Auvergne Rd (>3.5m) • Newall St West (<0.5m) • Park Ln (~0.3m) • Park Rd (>0.5m) • Station St (>0.5m) • Bolangum Inn Rd (<0.1m) • Newall St East (<0.3m)
2% AEP *~66 mm of rainfall in 6 hours* *~79 mm of rainfall in 12 hours*	Wallaloo Creek floodplain widened near township to inundate sporting field. Hazardous depths across floodplain. Ponding upstream of Raluana road Bridge overtops Raluana Road 100 to 200 m west of the bridge. Further breakouts observed towards the east south of the Wimmera Highway Bridge, overtopping Wimmera Highway 1.5 km south of the bridge. Ponding of Andersons Creek upstream of Donald – Stawell Road breaks out and overtops the road at the Bolangum-Inn Road intersection, with a flow path forming towards Auvergne Road. **42 Newall Street (residential) inundated above floor.**	• Auvergne Rd (~4m) • Newall St West (>0.5m) • Park Ln (<0.5m) • Park Rd (>0.5m) • Station St (>0.5m) • Bolangum Inn Rd (<0.3m) • Newall St East (<0.3m) • Donald – Stawell Rd (<0.1m) • Mclennan St (<0.3m) • Raluana Rd (~0.1m) • Wimmera Hwy (<0.1m)

Flood event	Characteristics – Flood behaviour	Roadways inundated
1% AEP *~76 mm of rainfall in 6 hours* *~90 mm of rainfall in 12 hours* *~100 mm of rainfall in 18 hours*	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain and parts of overland flow path from the east. Further breakouts observed south of Raluana Road Bridge, overtopping Raluana Road 400 m west of bridge. Overland flow path from Bolangum – Inn Road intersection towards Auvergne Road widened. Mckinnon Street roadside drain and part of Newall Street roadside drain inundated, inundating access to **Marnoo Primary School** carpark, however with lowest hazard classification. 28 Park Lane (sporting ground clubrooms) inundated above floor. **34 Newall Street (residential) inundated above floor.**	• Auvergne Rd (>4m) • Newall St West (>0.5m) • Park Ln (<0.5m) • Park Rd (>0.5m) • Station St (~0.7m) • Bolangum Inn Rd (<0.3m) • Newall St East (<0.3m) • Donald – Stawell Rd (~0.1m) • Mclennan St (<0.3m) • Raluana Rd (<0.3m) • Wimmera Hwy (<0.3m) • Mckinnon St (<0.3m)
0.5% AEP *~84 mm of rainfall in 6 hours* *~100 mm of rainfall in 12 hours*	Generally as above with slightly deeper, faster flowing water. Hazardous depths across floodplain and parts of overland flow path from the east. **40 Newall Street (residential) inundated above floor.**	• Auvergne Rd (>4m) • Newall St West (>0.5m) • Park Ln (>0.5m) • Park Rd (>0.5m) • Station St (~0.7m) • Bolangum Inn Rd (<0.3m) • Newall St East (<0.3m) • Donald – Stawell Rd (<0.3m) • Mclennan St (<0.3m) • Raluana Rd (~0.3m) • Wimmera Hwy (<0.5m) • Mckinnon St (<0.3m)

Flood event	Characteristics – Flood behaviour	Roadways inundated
0.1% AEP *~106 mm of rainfall in 6 hours* *~126 mm of rainfall in 12 hours* *~141 mm of rainfall in 18 hours*	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain and parts of overland flow path from the east. Further breakouts of Wallaloo Creek observed near township, with floodplain over 800 m wide. Raluana Road overtopping 180 to 350 m east of bridge as well as in previously observed locations. Widespread inundation of **Marnoo Primary School** grounds, however with lowest hazard classification. 17 Newall Street (former general store) inundated above floor. **38 Park Lane (residential) inundated above floor.**	• Auvergne Rd (>4.5m) • Newall St West (>0.5m) • Park Ln (>0.5m) • Park Rd (>0.5m) • Station St (~0.8m) • Bolangum Inn Rd (<0.3m) • Newall St East (<0.3m) • Donald – Stawell Rd (<0.3m) • Mclennan St (<0.3m) • Raluana Rd (<0.5m) • Wimmera Hwy (>0.5m) • Mckinnon St (<0.3m)

5.3 Flood peak travel time

Table 5-2 Flood peak travel timing

Location from	Location to	Typical travel time	Comments	Duration
Wallaloo Creek				
Start of rainfall (catchment)	Marnoo	12 - 40 hours	To peak – may be longer depending on rainfall pattern	Generally <40 hours
Eastern catchment				
Start of rainfall (catchment)	Marnoo	1 - 20 hours	To peak – may be longer depending on rainfall pattern	Generally <20 hours

5.4 Flood/No Flood tool

See Figure 5-1.

5.5 Municipal Flood Emergency Plan tables

A set of summary tables were developed for Marnoo, 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 Municipal Flood Emergency Plan (MFEP) Documentation (R06).

5.6 Monitoring capability for flash flooding

The Flood Intelligence and Flood Warning Report (R04) documented the monitoring capability within the Wallaloo catchment. Currently, there is no formal flood warning system in place for the Wallaloo Creek catchment. Additionally, there are no streamflow or sub-daily rainfall gauges within the catchment. Due to this, official flood warning capability for the catchment and township is limited to the issue of a Flood Watch and/or Severe Weather Warning for the Wimmera River area. Note a flood watch is not necessarily guaranteed to be issued prior to flooding.

Flood data monitoring for Marnoo would be improved by the placement of a rain gauge within the catchment, in consideration of the impact of overland flooding from the local catchment. A sub-daily rain gauge within Marnoo would enable monitoring capability for flash flooding in the township and lower areas of the catchment, and monitoring data can be used together with the Flood/ No Flood tool presented above. However, based on the quick catchment response associated with flash flooding, the rain gauge may not provide warning time sufficient to enact response actions other than evacuation or shelter in place. Also, the costs associated with installation and maintenance of a gauging station would likely exceed the benefits.

A more cost effective option may therefore be to install a gauge without telemetry, or to have the site ready for deployment of a Portable Automatic Logging System (PALS) to monitor rainfall during expected storm events. One potential issue with the PALS option is the demand for PALS units during events for which heavy rainfall is forecast. PALS ownership and deployment arrangements should therefore be confirmed prior to pursuing this option as it is unlikely Marnoo would be considered a priority site.

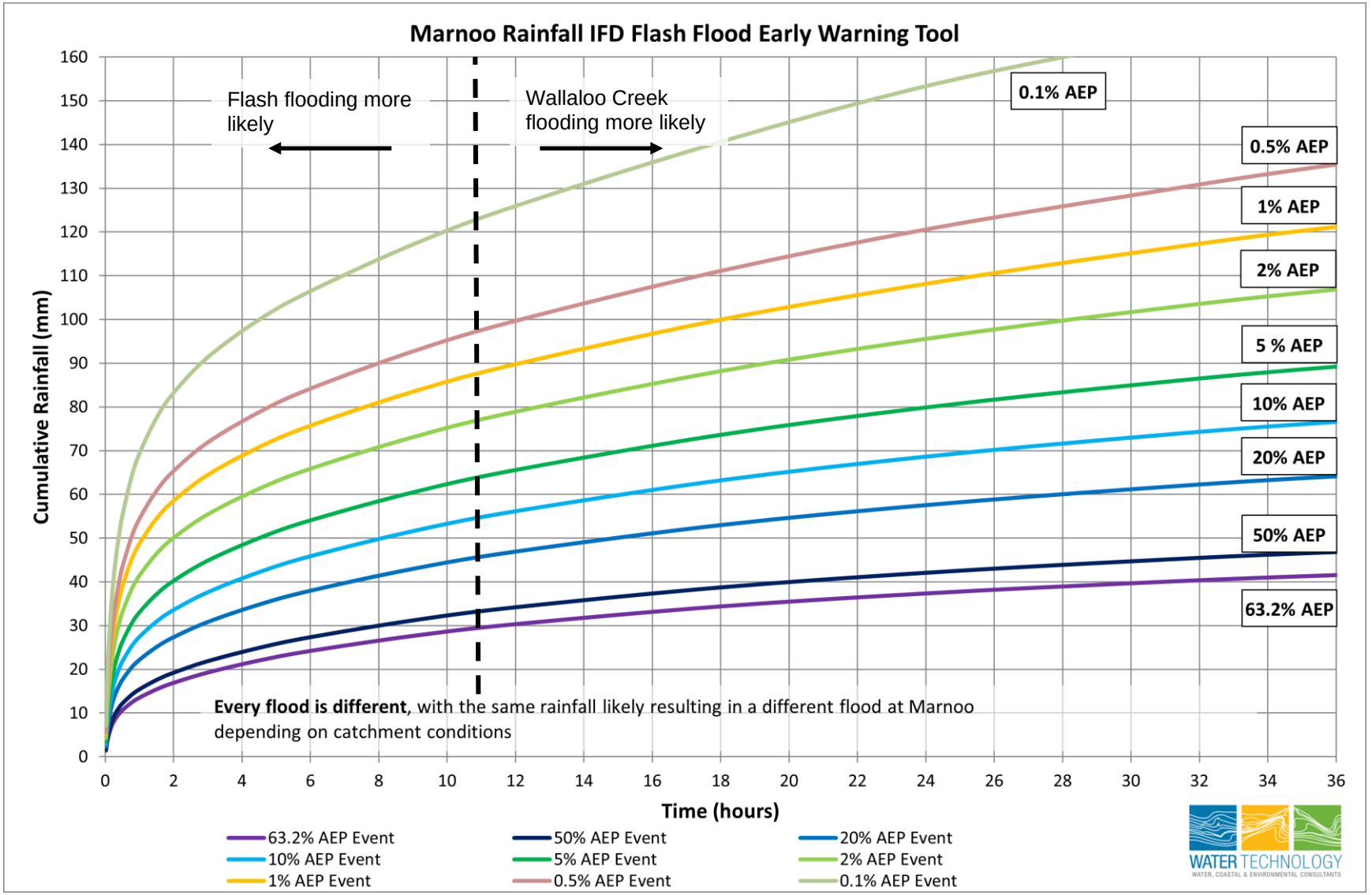

Figure 5-1 Marnoo Flood/No flood tool

6 FLOOD DAMAGES AND MITIGATION

6.1 Overview

Detail around the flood damage and mitigation potential in Marnoo is documented in the Flood Damages and Mitigation Options Assessment Report (R05). Flooding in Marnoo can occur as a result of both local rainfall (i.e. overland/stormwater inundation) and riverine flooding when Wallaloo Creek breaks its banks. Flooding within the township of Marnoo is predominantly caused by overland flow from a catchment east of the township. In a 20% AEP event overland flow can be observed crossing the Donald-Stawell Road and entering the central areas of the township, inundating several lots below floor level. With increasing rainfall, this flow path gets wider and deeper, eventually impacts dwellings above floor level in a 2% AEP event.

To classify the impact of flooding and risk to the Marnoo community, hydraulic flood model results were used to determine the properties and assets likely to be inundated during a range of design events (20% to 0.1% AEP).

6.2 Road inundation

During major flood events the road network can be 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 roads which are inundated by flooding in events ranging from 20% to 0.1% AEP events and listed by name in the Flood Damages and Mitigation Options Assessment Report (R05), these roads are shown in Figure 6-1 to Figure 6-3 for the township and downstream rural area.

6.3 Property inundation

Floor level survey was available for 35 residential and commercial buildings, including some outbuildings inside Marnoo. Although most properties are located outside of the Wallaloo Creek floodplain, the overland flow path from the east passes through the centre of the township causing inundation to several properties.

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

- Property flooded below floor
  - This indicates the flood level is below the surveyed floor level.
- Property flooded above floor
  - This indicates the flood level is above the surveyed floor level.

The existing conditions 1% AEP flood extent and the properties flooded above floor during the range of modelled design events are shown Figure 6-4. All highlighted properties north of Park Road are commercial properties.

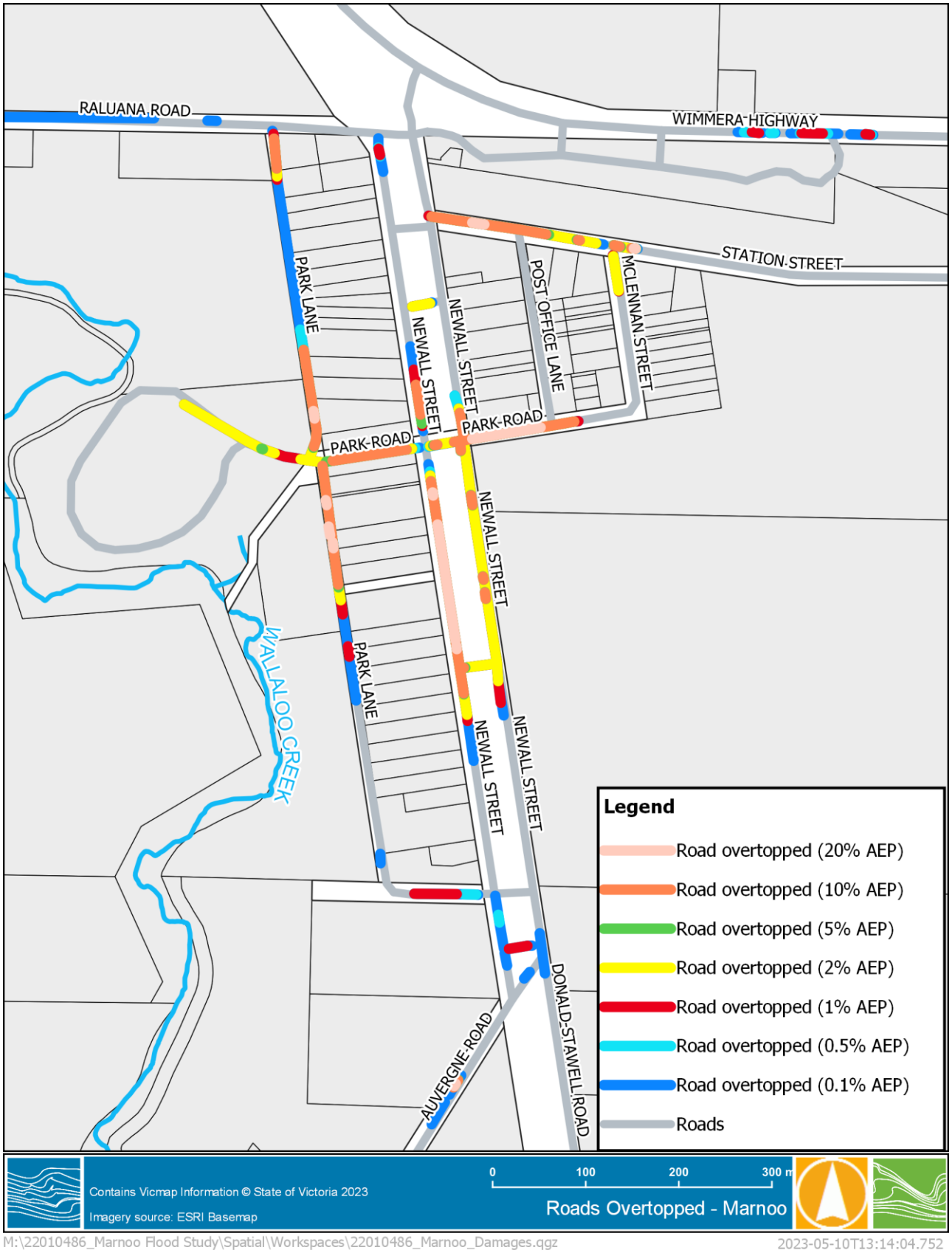

Figure 6-1 Roads overtopping within Marnoo

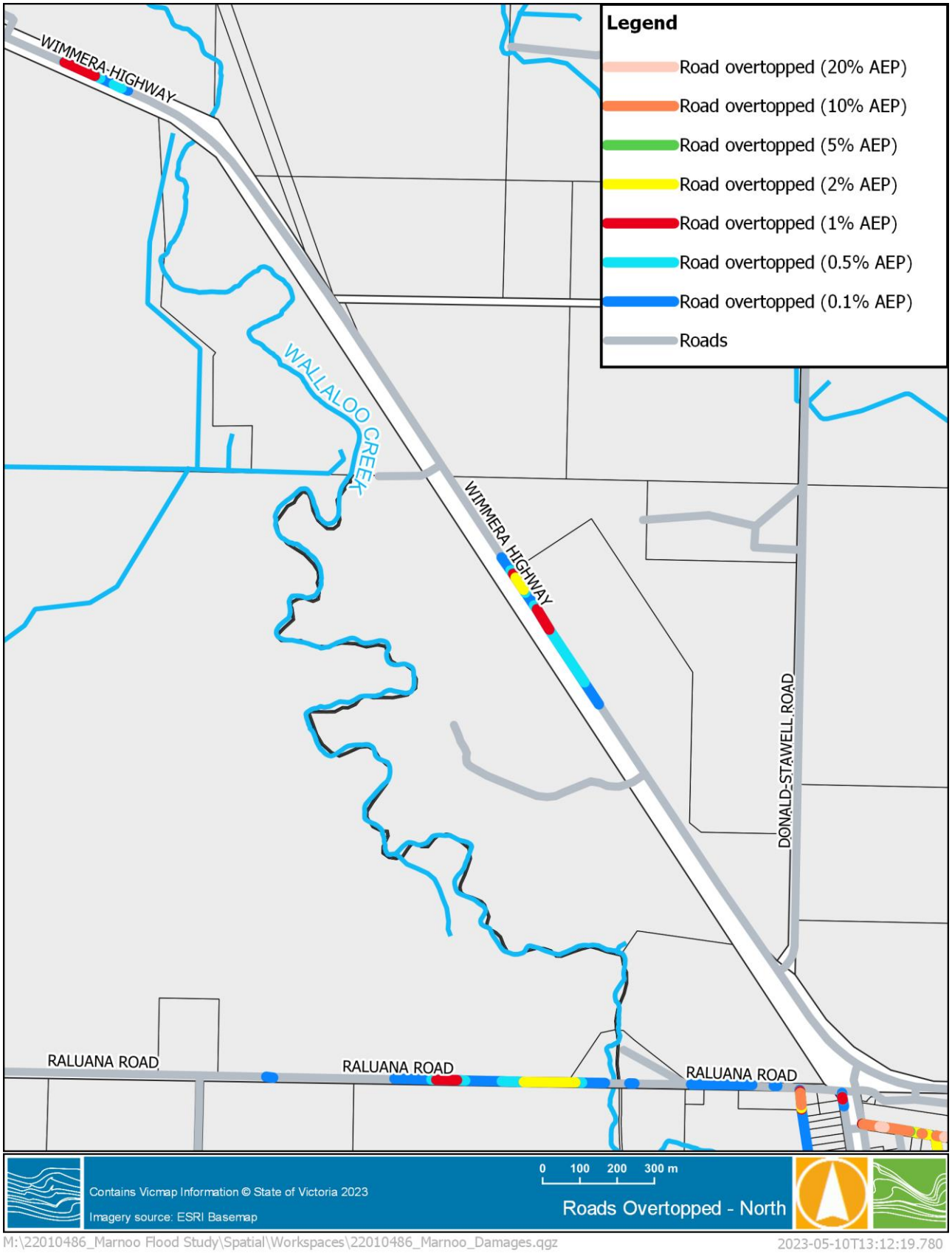

Figure 6-2 Roads overtopping north of Marnoo

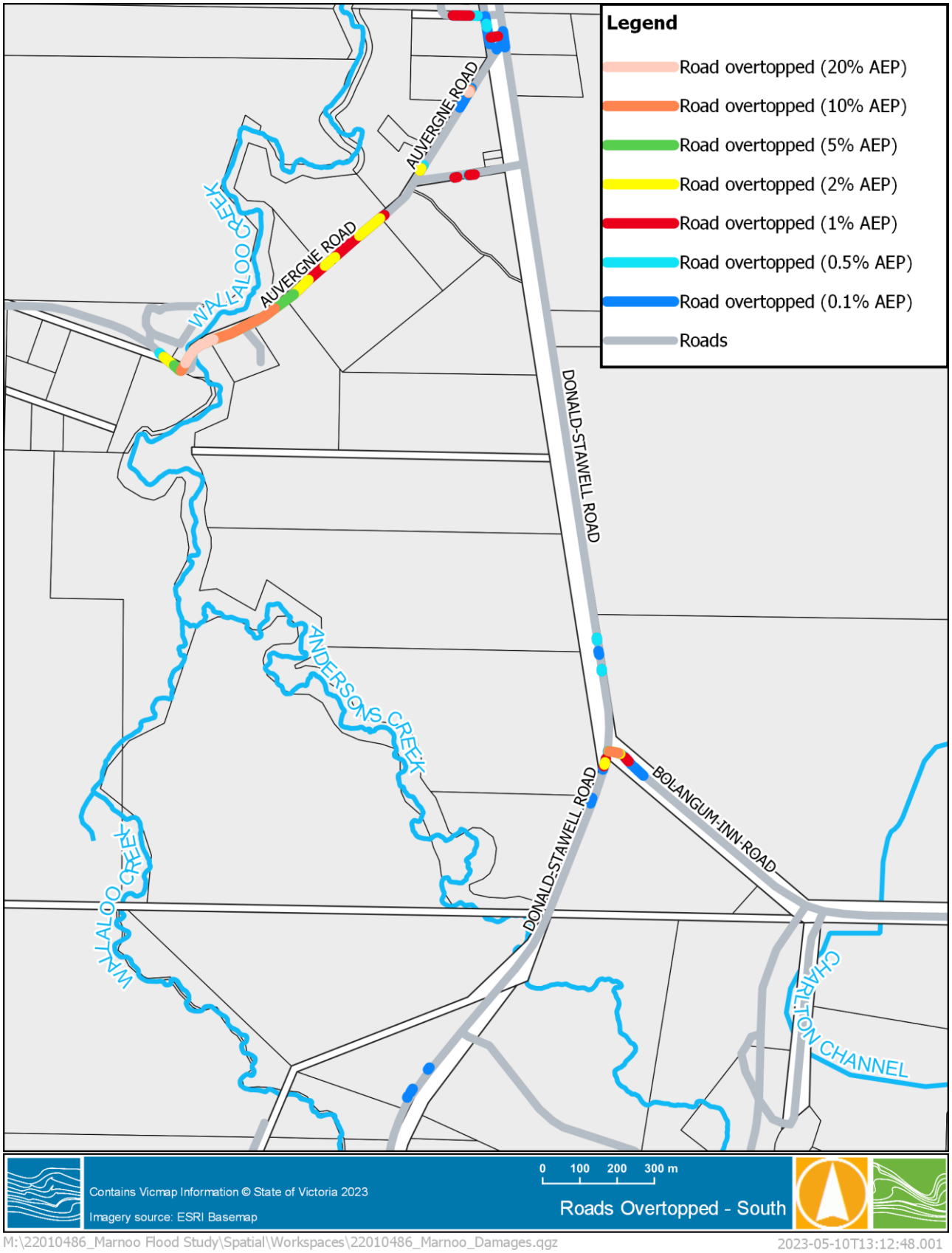

Figure 6-3 Roads overtopping south of Marnoo

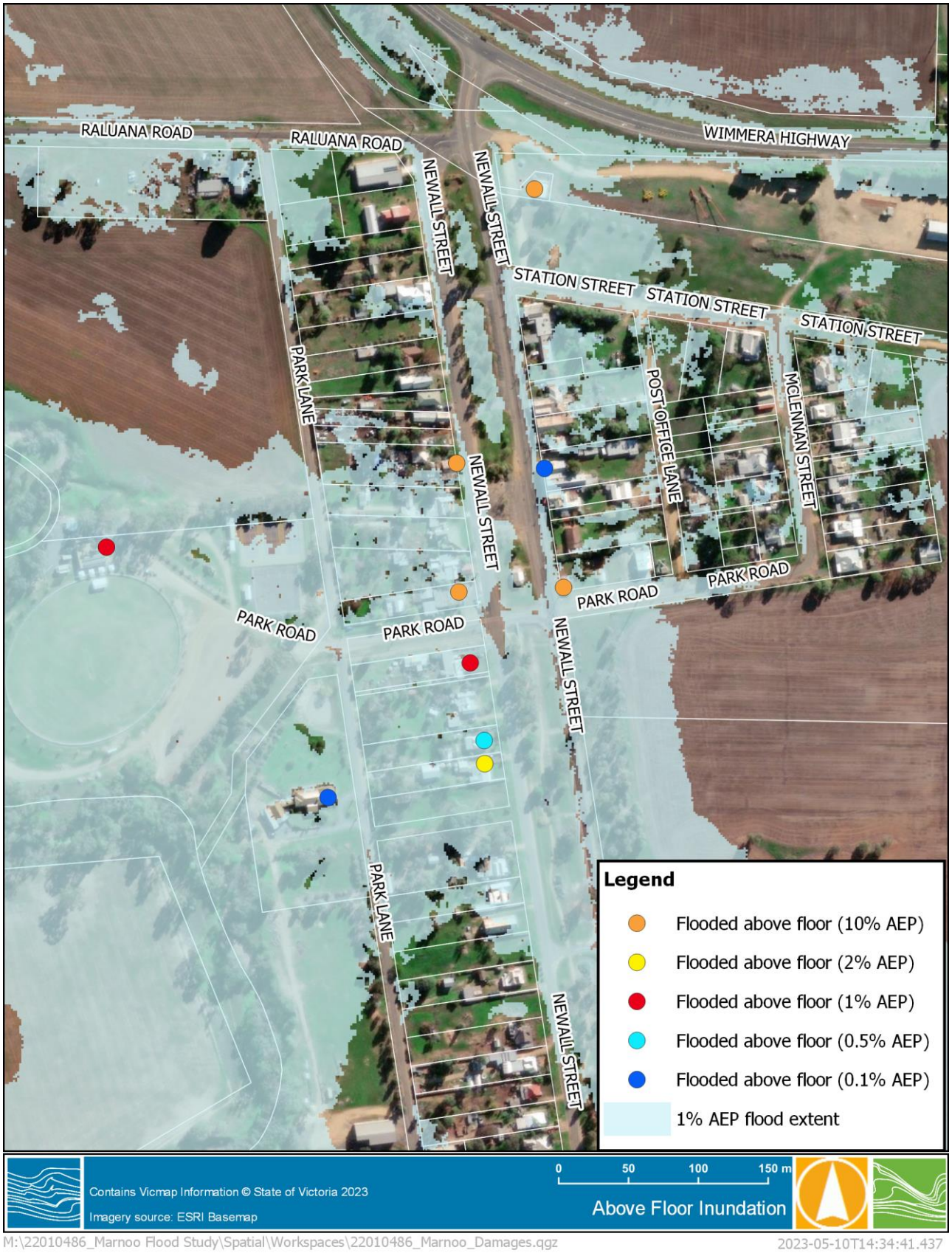

Figure 6-4 Properties inundated above floor

6.4 Damage assessment

Floor level survey was available for 35 residential and commercial buildings, including some outbuildings inside Marnoo. Flood model results for the range of existing conditions events were processed to calculate the Average Annual Damages (AAD) for Marnoo, which totals $64,597. The damages figure takes into account flooding of roads, properties and buildings. The damages assessment table is shown in Figure 6-5.

EXISTING CONDITIONS

ARI (years)	PMF	1000yr	200yr	100yr	50yr	20yr	10yr	5yr
AEP	0.000001	0.001	0.005	0.01	0.02	0.05	0.1	0.2
Residential Buildings Flooded Above Floor	12	4	3	2	1	0	0	0
Commercial Buildings Flooded Above Floor	14	6	5	5	4	4	4	0
Properties Flooded Below Floor	62	31	29	30	27	20	20	13
Total Properties Flooded	**88**	**41**	**37**	**37**	**32**	**24**	**24**	**13**
Direct Potential External Damage Cost	$559,608	$57,456	$46,742	$44,953	$42,773	$27,000	$25,598	$9,603
								$0
Direct Potential Residential Damage Cost	$1,186,943	$268,819	$143,871	$86,908	$34,824	$0	$0	$0
Direct Potential Commercial Damage Cost	$1,198,509	$165,644	$136,546	$121,592	$94,486	$63,595	$46,905	$0
Total Direct Potential Damage Cost	**$2,945,060**	**$491,919**	**$327,159**	**$253,453**	**$172,083**	**$90,595**	**$72,503**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$2,356,048**	**$393,535**	**$261,727**	**$202,762**	**$137,666**	**$72,476**	**$58,002**	**$0**
Infrastructure Damage Cost	**$1,150,388**	**$452,465**	**$325,526**	**$244,640**	**$193,794**	**$134,162**	**$125,800**	**$46,771**
Dryland Broadacre	$554,531	$300,699	$232,593	$204,143	$169,350	$125,331	$113,039	$64,607
Total Rural Cost	**$554,531**	**$300,699**	**$232,593**	**$204,143**	**$169,350**	**$125,331**	**$113,039**	**$64,607**
Total Cost	**$4,060,967**	**$1,146,699**	**$819,845**	**$651,546**	**$500,810**	**$331,970**	**$296,841**	**$111,378**

Average Annual Damage (AAD)	$64,597

Figure 6-5 Existing conditions Average Annual Damage (AAD)

6.5 Flood mitigation

6.5.1 Overview

Several structural mitigation options were assessed during this study, focusing on the areas of Marnoo impacted by inundation in the 1% AEP flood event, predominantly the properties located at 34 to 42 Newall Street. The mitigation options were hydraulically assessed using the 1% AEP design flood event.

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

- Increasing the height of the existing levee along Newall Street as well as extending it both north and south.
- Increasing the capacity of the channel and culverts running west along the southern side of Park Road draining to Wallaloo Creek, as well as adding a culvert connecting to the eastern side of Donald-Stawell Road.

- Adding a channel from the eastern side of the Donald-Stawell Road (eastern Newall Street) directly to Wallaloo Creek via the non-residential lot south of 44 Newall Street.

The options were investigated separately and are discussed below.

6.5.2 Option 1: Levee upgrade

The levee height was increased to above the 1% AEP flood level. Figure 4-2 shows a difference plot comparing the existing and proposed mitigation scenario water levels. Decreased flood levels are shown behind the levee. However, flood levels and extents are increased upstream of the levee. Inundation is also pushed further north and causes more widespread inundation in the northern parts of Marnoo and across the Donald-Stawell Road.

6.5.3 Option 2: Northern channel upgrade

The channel was made 10 m wide and 1.5-2 m deep to match the depth of Wallaloo Creek at the outlet. The culvert capacity under Park Lane was doubled and the capacity under the western part of Newall Street was tripled. A single culvert matching the upgraded culvert under Newall Street was added under Donald-Stawell Road (eastern Newall Street). Figure 4-3 shows a difference plot comparing the existing and proposed mitigation water levels. Increasing the capacity of the Park Road channel and culverts decreases the flood levels at 34 to 42 Newall Street but only by up to 5 cm. Only a minor reduction in flood extent is observed.

6.5.4 Option 3: Central channel

The channel was modelled as 10 m wide and 2-3 m deep to match the depth of Wallaloo Creek at the outlet. The depth and width were exaggerated to assess the maximum potential impact of a channel at this location. Figure 4-4 shows a difference plot comparing the existing and proposed mitigation water levels. Directing the eastern overland flow to Wallaloo Creek decreases flood depths and extents across a large area around the channel, including 34 to 42 Newall Street. No increase to flood depth or extent is observed in Marnoo.

Based on the preliminary mitigation modelling, and observations at the proposed location made during a site visit, a new channel alignment was modelled, while implementing a more feasible channel width of 4 m and depth of 1.5 to 2 m. Figure 4-5 shows a difference plot comparing the existing and proposed mitigation water levels. The reduced channel capacity was not enough to convey a significant proportion of the overland flow directly to the channel, and inundation extents and depths in Marnoo are largely unchanged.

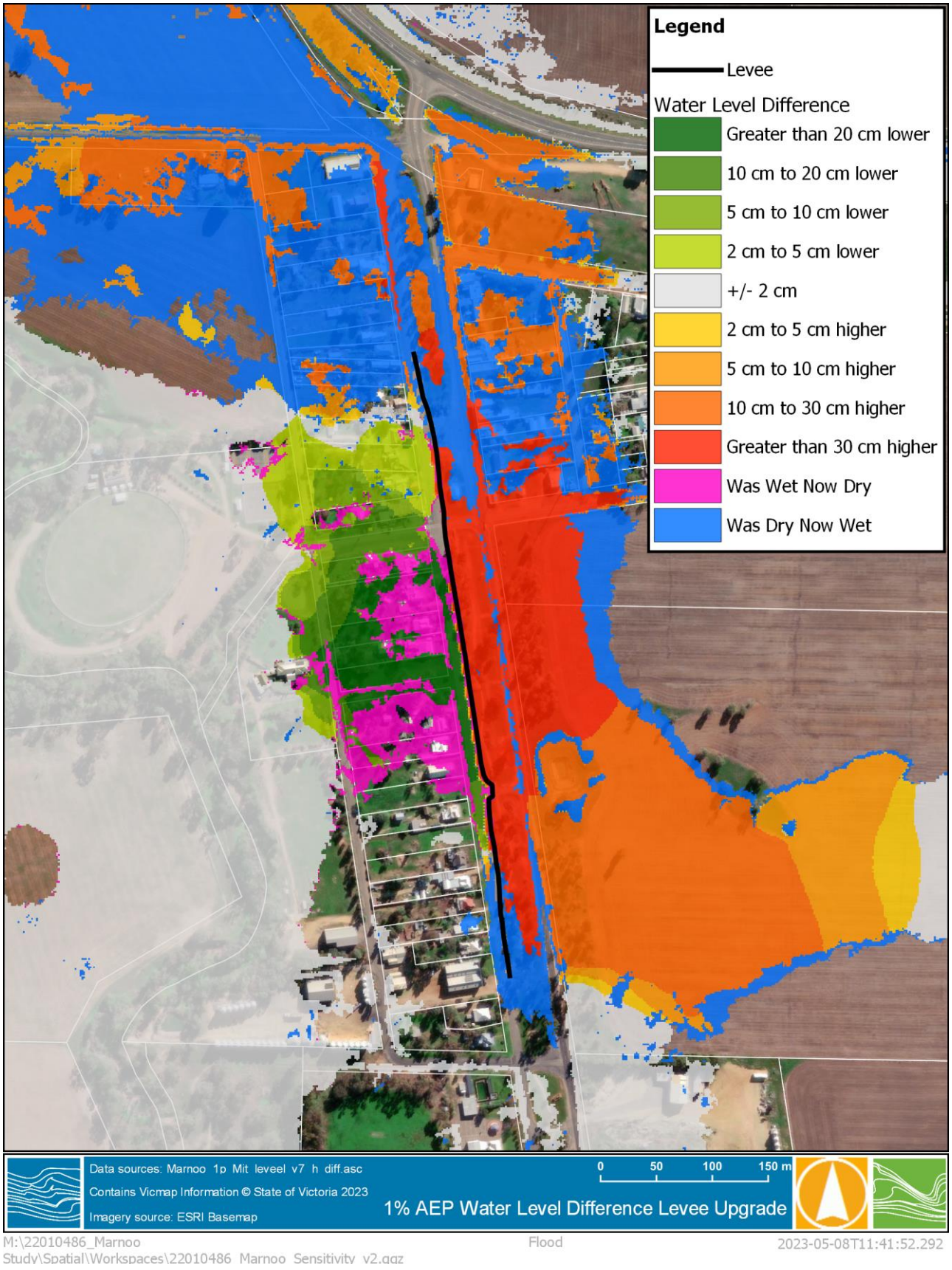

Figure 6-6 1% AEP flood level difference – Levee upgrade

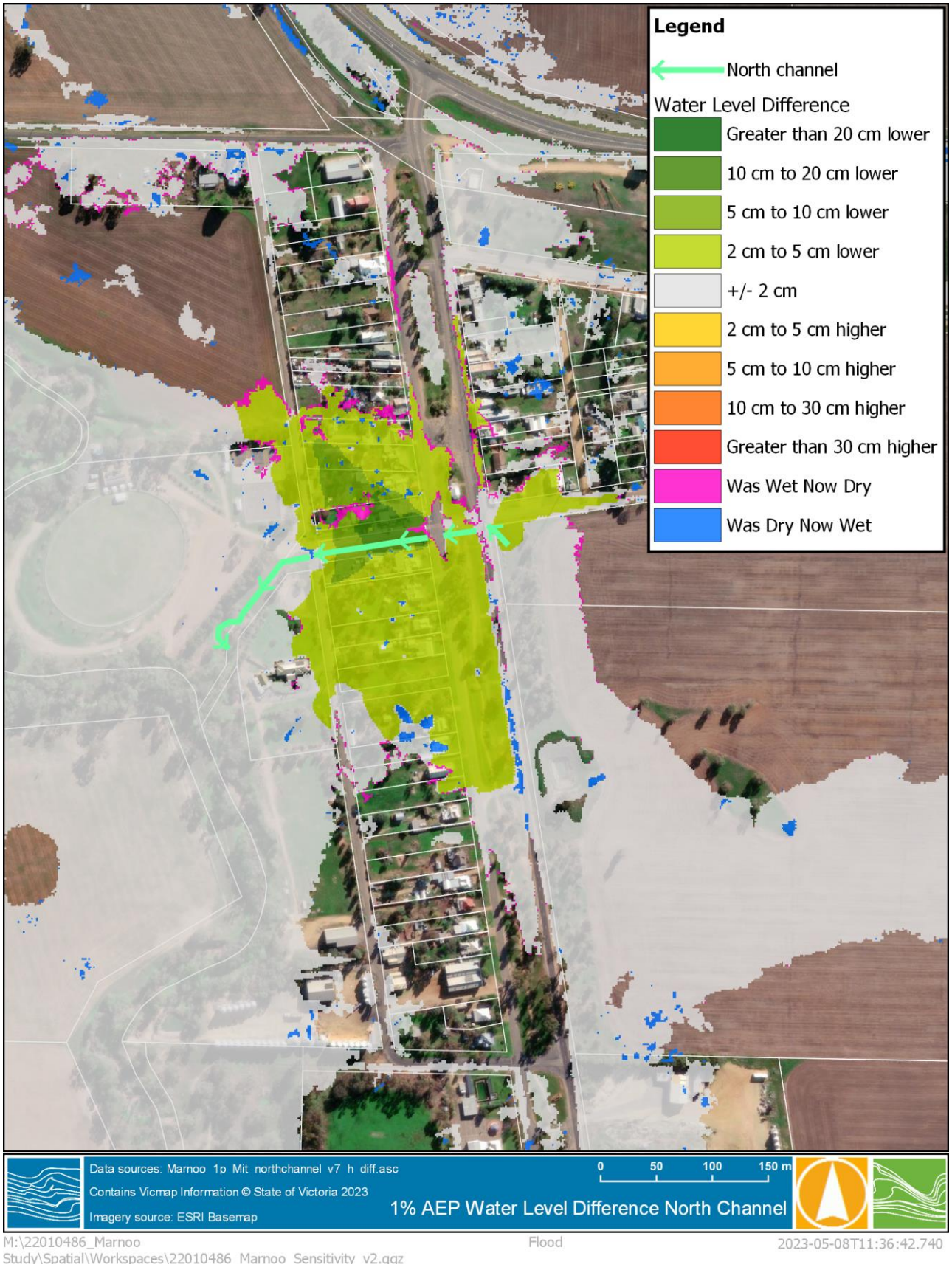

Figure 6-7 1% AEP flood level difference – North channel

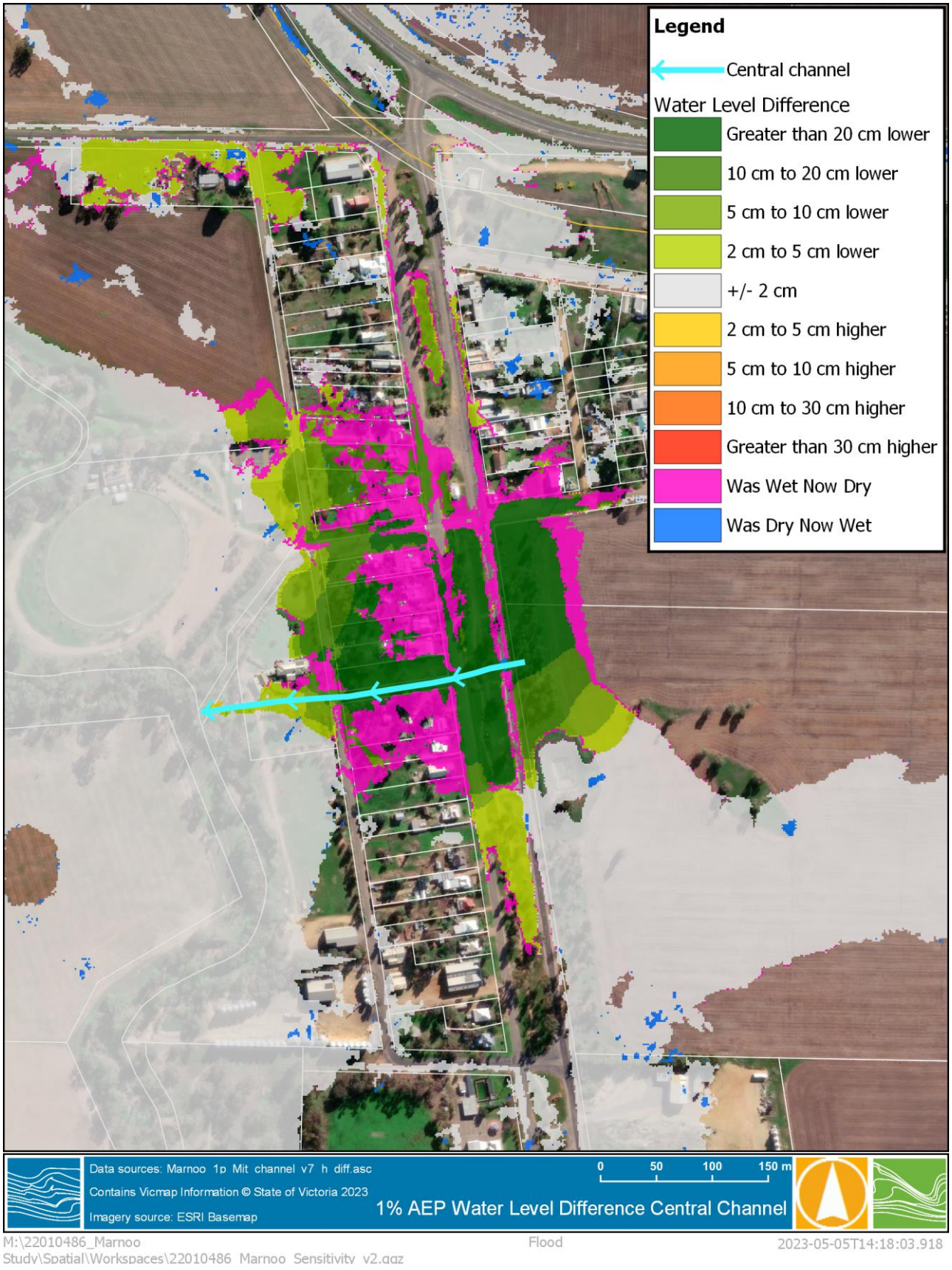

Figure 6-8 1% AEP flood level difference – Central channel

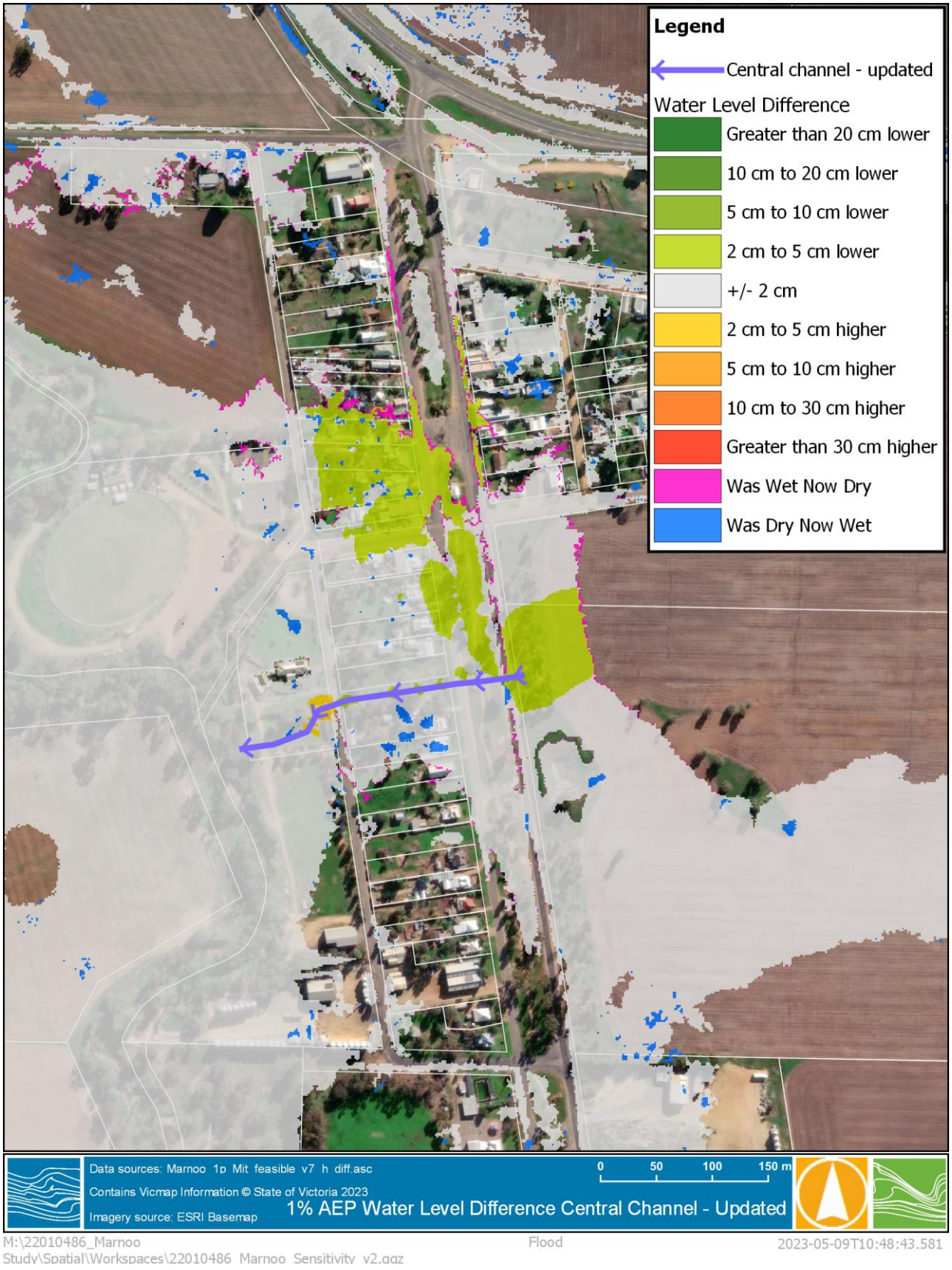

Figure 6-9 1% AEP flood level difference – Updated central channel

6.5.5 Summary

Several mitigation options were tested in the Marnoo hydraulic model, focusing on reducing the flood risk in central Marnoo. However, modelling more feasible channel dimensions showed limited reductions in depth and flood extent. An updated AAD was calculated for this mitigation option. A construction cost estimate was assessed against the option's reduction in AAD from the existing case to inform net present value analysis. The assessed mitigation option was shown to be financially unviable. As such no structural mitigation option was recommended.

The option of constructing a retention dam within the private property east of Stawell-Donald Road was also discussed and found not feasible due to the size required, cost to construct and maintain, reduction in valuable farmland and reduced amenity within the township.

A further option is to adopt localised structural mitigation at properties shown as most at risk, e.g raising floor levels to above the 1% AEP flood levels.

6.6 Planning scheme mapping

Inclusion of flood mapping in the planning scheme is a key non-structural mitigation measure to prevent flood risk from increasing into the future. The project has produced flood mapping suitable for inclusion in the planning scheme, with Land Subject to Inundation (LSIO) and Floodway (FO) layers developed in line with the North Central CMA delineation criteria.

Currently there is no LSIO or FO available for Marnoo or the Wallaloo Creek catchment. Updating the planning scheme mapping allows development applications within the floodplain to be assessed in line with current national, state, regional and local policies and guidelines.

7 SUMMARY

The Marnoo Flood Study has produced detailed flood modelling of Wallaloo Creek through Marnoo as well as overland flooding from the local catchments. The mapping produced 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 and included in a draft update to the Northern Grampians Municipal Emergency Management Plan.

Recommendations from the Marnoo Flood Study have been separated into the agencies responsible for their fulfilment, these are as follows:

- Northern Grampians Shire Council
  - Endorse the flood study with the aim of adopting the flood study recommendations.
  - Undertake a planning scheme amendment to update the flood related planning overlays to introduce new LSIO and FO mapping.
  - Consider the designation of flood prone land as provisioned under the Building Act
  - Continue to include Climate Change as a consideration in understanding and assessing flood risk.
  - Discuss with the Bureau of Meteorology and NCCMA for the consideration of potential flash flood monitoring.
  - Review the information within the Flood Intelligence and Flood Warning Report to undertake an update of the MFEP.
  - Undertake a review of the current response, maintenance and operations documentation with Council staff.
  - Develop maintenance schedule for large pipes and pipes with low design grade.
- 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.
- Victoria State Emergency Service with assistance from North Central CMA and the Northern Grampians Shire Council:
  - Continue to engage the community through regular flood awareness programs such as the VICSES FloodSafe program.
  - Update Local Flood Guide once new template is developed.
  - Assist the Northern Grampians Shire Council in updating the MFEP.
  - Review the updated MFEP (when available) and discuss with the Northern Grampians Shire Council the changes proposed by Water Technology prior to adopting the revised document.

Future flood events in Marnoo 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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