Final Study Report

Stawell Flood Investigation (C14 2022/23)

Northern Grampians Shire Council

2 December 2024

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
V01	Draft	Ben Hughes	Ben Hughes	02/12/2024
V02	Final	Ben Hughes	Ben Hughes	14/01/2025

Project Details

Project Name	Stawell Flood Investigation (C14 2022/23)
Client	Northern Grampians Shire Council
Client Project Manager	Steven Cobden
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Document Number	23010370_R06V02.docx

Cover Image: Cato Park 2022 Flood Event

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Environment ISO 14001 SAI GLOBAL
OHS ISO 45001 SAI GLOBAL

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. In particular we acknowledge the Jardwadjali and Djab Wurrung Peoples as the Traditional Custodians of the waters and lands on which this this project is based.

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.

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*

2 December 2024

Steven Cobden
Senior Design Engineer
Northern Grampians Shire Council
PO Box 580 Stawell VIC 3380

Via email: steven.cobden@ngshire.vic.gov.au

Dear Steven

Stawell Flood Investigation (C14 2022/23)

Water Technology is pleased to present the Stawell Flood Investigation Final 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 – Model Development and Calibration Report.
- R03 – Design Modelling Report.
- R04 – Flood Intelligence and Warning Report, including Municipal Flood Emergency Plan (MFEP) Documentation.
- R05 – Flood Damages and Mitigation Report.
- **R06 – Final Study Report (this report).**

Water Technology would specifically like to thank the Northern Grampians Shire Council and the Stawell community members who gave their time to provide their personal observations of flooding and provide feedback on the flood modelling. A strong contribution 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

Ben Hughes
Senior Principal Engineer
Ben.Hughes@watertech.com.au
WATER TECHNOLOGY PTY LTD

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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 be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
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 and limb 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.

1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by Northern Grampians Shire Council (NGSC) to undertake the Stawell Flood Investigation. The investigation covered two study areas: the local Stawell township catchment (including Pleasant Creek) and the Stawell Golf Course catchment to the north of Stawell, as shown in Figure 1-1.

No previous flood studies have been undertaken for either of the study areas. The Mt William Creek Flood Investigation (2014) included the Pleasant Creek catchment which covers the southern areas of Stawell. The study utilised RORB hydrologic modelling and TUFLOW two-dimensional hydraulic modelling. Modelling was calibrated to streamflow gauge records, flood frequency analysis and historic flood level data. However, the flood mapping produced only coarsely covered a minor part of southeastern Stawell.

In 2021/2022, Water Technology undertook a hydraulic assessment of flooding in Stawell caused by runoff from Big Hill, located in the eastern portion of the town. The study covered most of central Stawell and utilised a direct rainfall on grid (RoG) modelling approach. The model was not calibrated and limited survey data of hydraulic and topographic features was available. The study addressed the uncertainty around flood risk within Stawell and developed an understanding flooding behaviour to inform future land use, prospective mitigation options and emergency management actions.

The study has produced reliable flood intelligence for use in emergency management situations, assess the current flood impact/exposure in terms of annual average damages caused by flooding in Stawell, investigated structural and non-structural mitigation options, and investigated and made recommendations for establishing a flood warning system for the town.

This report is one of a series documenting the outcomes of the Stawell Flood Investigation. Each reporting stage is shown below:

- R01 - Data Review Report – Draft completed 31 October 2023, final version issued 2 December 2024.
  - This report details the data collated and any data gaps, resulting in further survey of ground levels and the drainage network.
- R02 – Model Development and Calibration Report – Draft completed 22 December 2023, final version issued 2 December 2024.
  - This report documents development of the hydraulic models, and calibration and validation of the Stawell model using the 2011 flood event.
- R03 – Design Modelling Report – Draft completed 11 April 2024, final version issued 2 December 2024
  - This report should be read in conjunction with the Model Development and Calibration Report. Key design model parameters are outlined in the report along with design model results.
- R04 – Flood Intelligence and Warning Report (including Municipal Flood Emergency Plan (MFEP) Documentation) – Draft completed 1 November 2024, final version issued 2 December 2024
  - This report describes the flood intelligence products and warning improvement outputs developed as part of the study. The report was written to allow flood emergency personnel to understand the limitations in the intelligence data and make appropriate decisions. This report provided updated appendices to the MFEP.
- R05 – Flood Damages and Mitigation report - Draft completed 6 November 2024, final version issued 2 December 2024
  - This report documents the damage associated with flooding in the study area, as well as an assessment of mitigation options, costs and a cost/benefit ratio for the most preferable option.

- **R06 – Final Summary Report – this report**
  - This summary report does not include technical details, instead focuses on project outputs and deliverables produced by the study. Readers are directed to individual reports should additional information be required. The chapters and sections of this report broadly follow the previous reporting from R01 to R05 with a summary of the key points in each detailed report.

1.2 Study Area

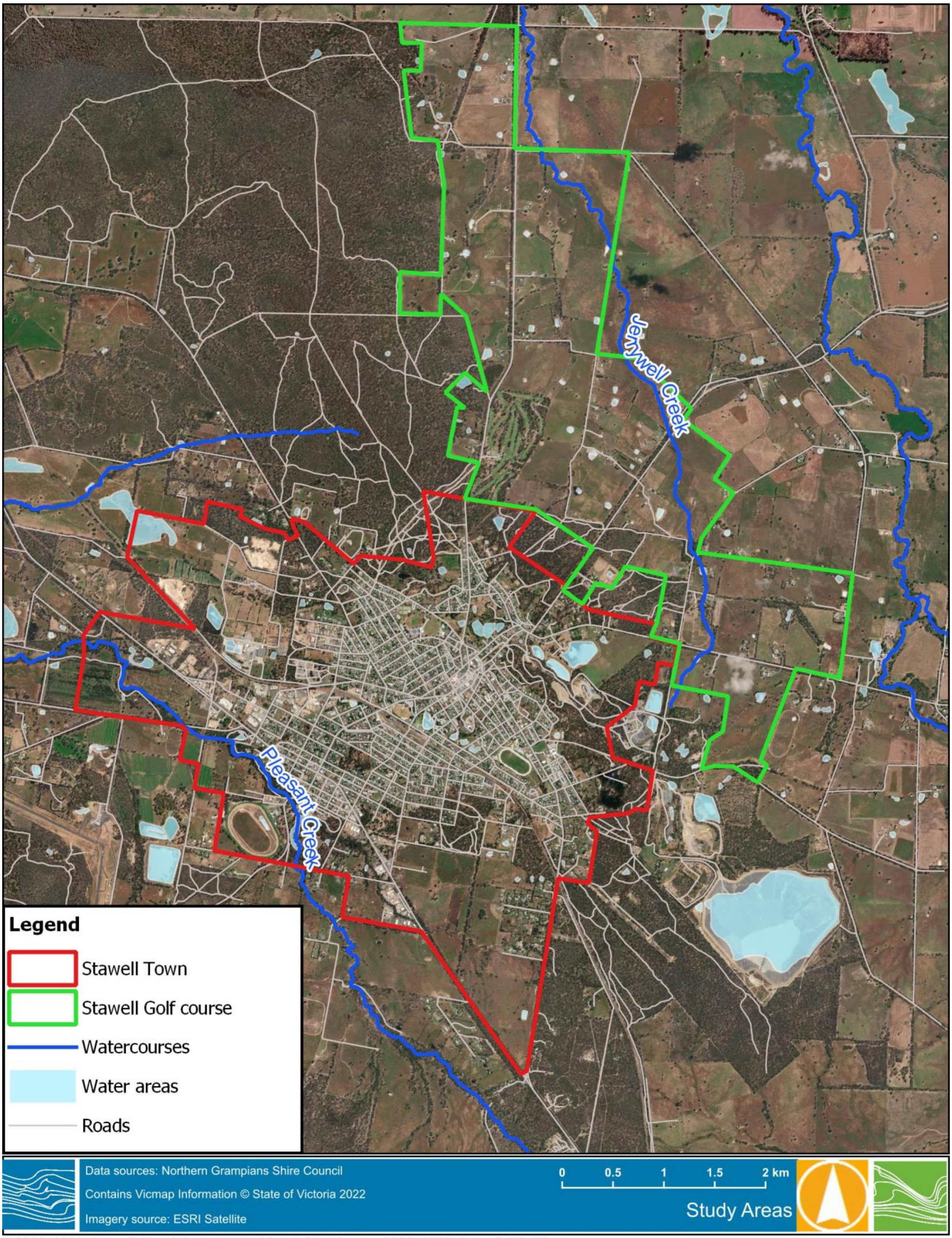
Stawell is in Victoria's Wimmera region on the Western Highway, located approximately 110 km northwest of Ballarat and 140 km southwest of Bendigo. There are no major watercourses running through the town, instead flood risk is mainly caused by local stormwater runoff from elevated areas east of the town including Big Hill. The southwestern parts of town are located within the Pleasant Creek catchment. Pleasant Creek originates approximately 8 km south of Stawell at the Black Range, flowing northwest along the Western Highway past southwestern Stawell, before eventually running into Lake Lonsdale, 9 km west of Stawell. The Pleasant Creek catchment upstream of Stawell is approximately 28 km^2 and consists of bushland in the upper reaches and cleared pasture in the lower reaches upstream of Stawell, see Figure 1-2.

Stawell can be separated into two distinct types of potential inundation: short duration stormwater flooding and longer duration riverine flooding from Pleasant Creek, to the southwest of town. While stormwater flooding is the primary driver of damage, Pleasant Creek has still historically caused issues but affects a smaller portion of the population.

The Stawell Golf Course study area is characterised by the Jerrywell Creek catchment. Jerrywell Creek originates on the eastern slope of Big Hill and flows north crossing the Stawell-Avoca Road. Multiple large overland flow paths from the Deep Lead Nature Conservation Reserve feed into the creek before it joins Concongella Creek, and finally the Wimmera River. The Jerrywell Creek catchment within the study area is largely cleared agricultural land with some vegetated areas in the upper reaches, see Figure 1-2.

The Stawell/Pleasant Creek and Stawell Golf Course study areas include the following key structures:

- Main waterway bridges at the following roads:
  - Western Highway.
  - Donald-Stawell Road.
  - Stawell-Avoca Road.
  - Black Range Road.
  - Grampians Road.
- Numerous major and minor culverts.
- The underground pit and pipe drainage network within Stawell.
- The Melbourne to Adelaide railway running southeast to northwest through Stawell and associated hydraulic structures.
- Several off-stream dams and ponds.



Data sources: Northern Grampians Shire Council
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Imagery source: ESRI Satellite

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Figure 1-1 Stawell study areas

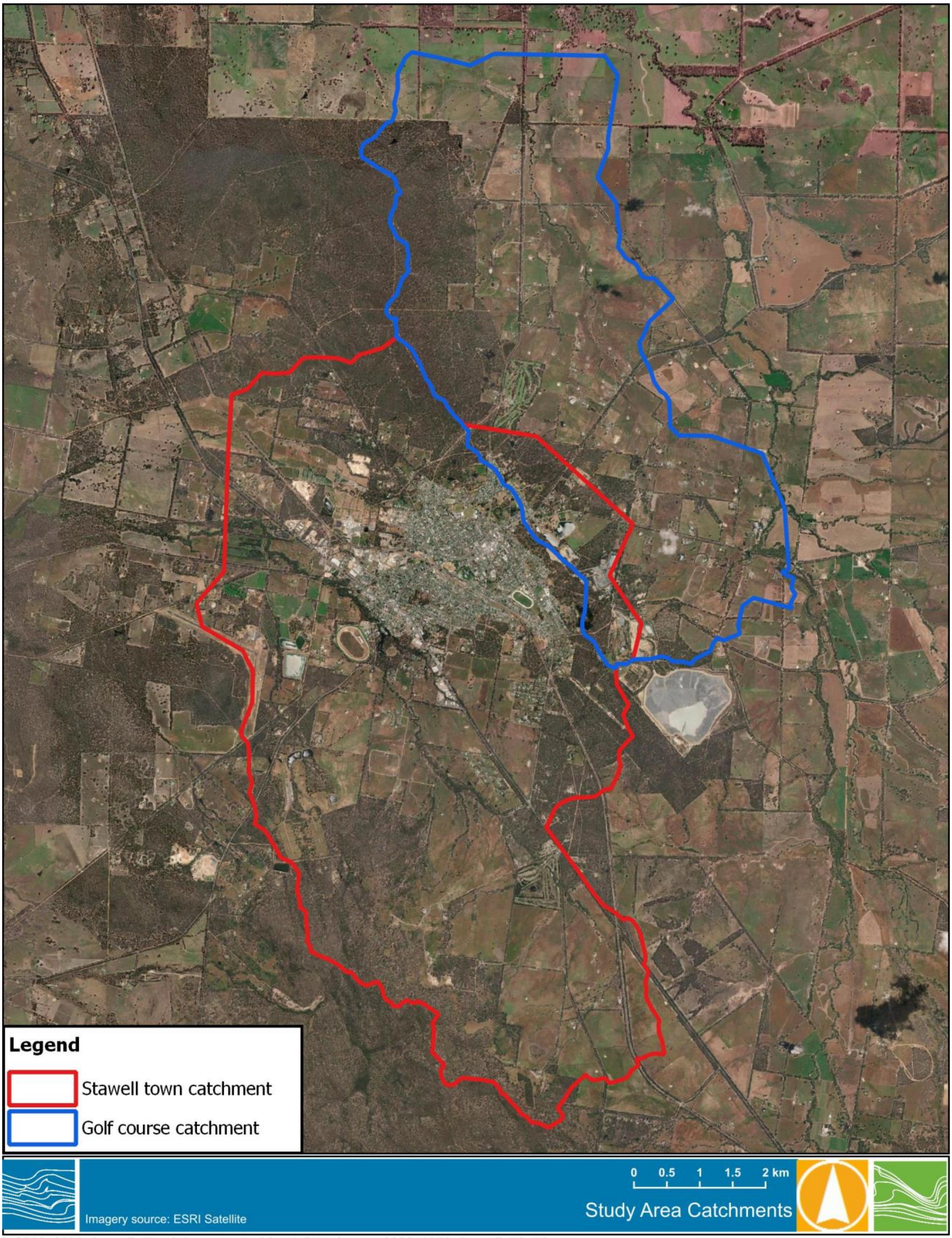

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Figure 1-2 Stawell catchments

2 DATA REVIEW AND VALIDATION

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

- Previous flood studies and reports.
  - Mt William Creek Flood Investigation[1].
  - Stawell Flood Investigation (Big Hill)[2].
- 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 and December 2011 event, which were selected for calibration/validation modelling based on the information available.
- Recorded streamflow.
  - The catchment has no active streamflow gauges.
- Recorded rainfall.
  - Including both daily and sub-daily rainfall.
- Storages.
  - Several dams within recreational areas and farm dams within the Pleasant Creek and Jerrywell Creek catchments were identified.
- Roads and drainage infrastructures.
  - Survey data collected for this study was supplied by council with gaps infilled for minor structures by site visits.
- Topographic data.
  - Multiple topographic data sets were available and were verified against survey captured for the project. Additional point cloud topographic survey was used to enhance representation of areas changed since the primary Light Detection and Ranging (LiDAR) data capture date.

The initial community consultation session formed part of the data collation aspect of the project, together with further contributions via phone and email. 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 project.

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[1] BMT WBM (2014). *Mt William Creek Flood Investigation* for WCMA.
[2] Water Technology (2022). *Stawell Flood Investigation* for Northern Grampians Shire Council.

3 MODEL DEVELOPMENT AND CALIBRATION MODELLING

3.1 Overview

The Model Development and Calibration Report (R02) described both hydraulic (TUFLOW) model builds and parameter selection adopted for the study. The report also detailed the calibration modelling of the historic events (January and December 2011). The calibration focused on how well the model was able to replicate the events as described by anecdotal evidence. The December 2011 event was modelled iteratively in TUFLOW, adjusting rainfall losses, refining the material layer, and adjusting the roughness values until the best overall match to the current historic dataset was achieved. The final parameters adopted for the December 2011 event were also adopted for the January 2011 event, which was modelled as a validation event.

3.2 TUFLOW summary

Modelling adopted a direct rain on grid (RoG) hydraulic modelling approach utilising 1D/2D TUFLOW software. Two hydraulic models were developed, covering the Pleasant Creek catchment including the Stawell township and the Stawell Golf Course catchment respectively. The hydraulic model developed during the Big Hill assessment[2] was used as a basis for the current Stawell model. It was expanded and upgraded with the data collected during the data review phase of the project.

The models were built using the TUFLOW HPC hydraulic modelling software. A gridded model was developed per catchment with a direct rainfall boundary applied to represent calibration and design rainfall events. The underground pit and pipe network within the town was incorporated as 1D structures, with the model topography developed and modelled in 2D.

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, for further detail on the model build see the full report.

The key TUFLOW model parameters, along with the design approach for key components of the model, are shown in Table 3-1. The TUFLOW model extent and boundary areas are shown in Figure 3-1 to Figure 3-3.

Table 3-1 Key TUFLOW model parameters

Parameter	Value
Model build	2023-03-AC-iSP-w64
Model precision	Single precision
Grid cell size	5 metres with Quadtree refinement down to 5/6 m in Stawell township
Sub grid sampling	1 m
Solution scheme	HPC
Inflows	Rainfall polygon with uniform pluviograph
Outflows	Height-flow slope of 1%
Hydraulic roughness	Manning’s ‘n’, varies with land use, see Table 3-2.
2D structures	12 bridges modelled as bridge flow constrictions
1D elements	Culverts and pipes linked to 2D domain

Parameter	Value
Model base topography	2005-2006 GWMWater Wimmera Mallee Pipeline project LiDAR (2 m x 2 m) – lowered based on LiDAR verification
Topography adjustment	Point cloud data and topographic survey of areas developed since LiDAR flown
Extent	Two model extents set at Stawell Township and Golf course
Roughness	Assigned based on land use and previous modelling, see Table 3-2
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 3-2 Land use types, Manning's 'n' values and rainfall losses

Land use	Roughness coefficient (Manning's 'n')	Initial loss (mm)	Continuing loss (mm/hr)
Open space, minimal vegetation	0.04	20	4
Open space, moderate vegetation	0.08	20	4
Built-up and residential areas – high density (buildings modelled separately)	0.10	20	3
Built-up and residential areas – low density (buildings modelled separately)	0.05	20	3
Building footprints	0.40	3	1
Commercial/industrial areas	0.30	2	0.5
Car park/pavement/roads	0.02	1	0.5
Railway	0.125	2	1
Open water	0.02	0	0

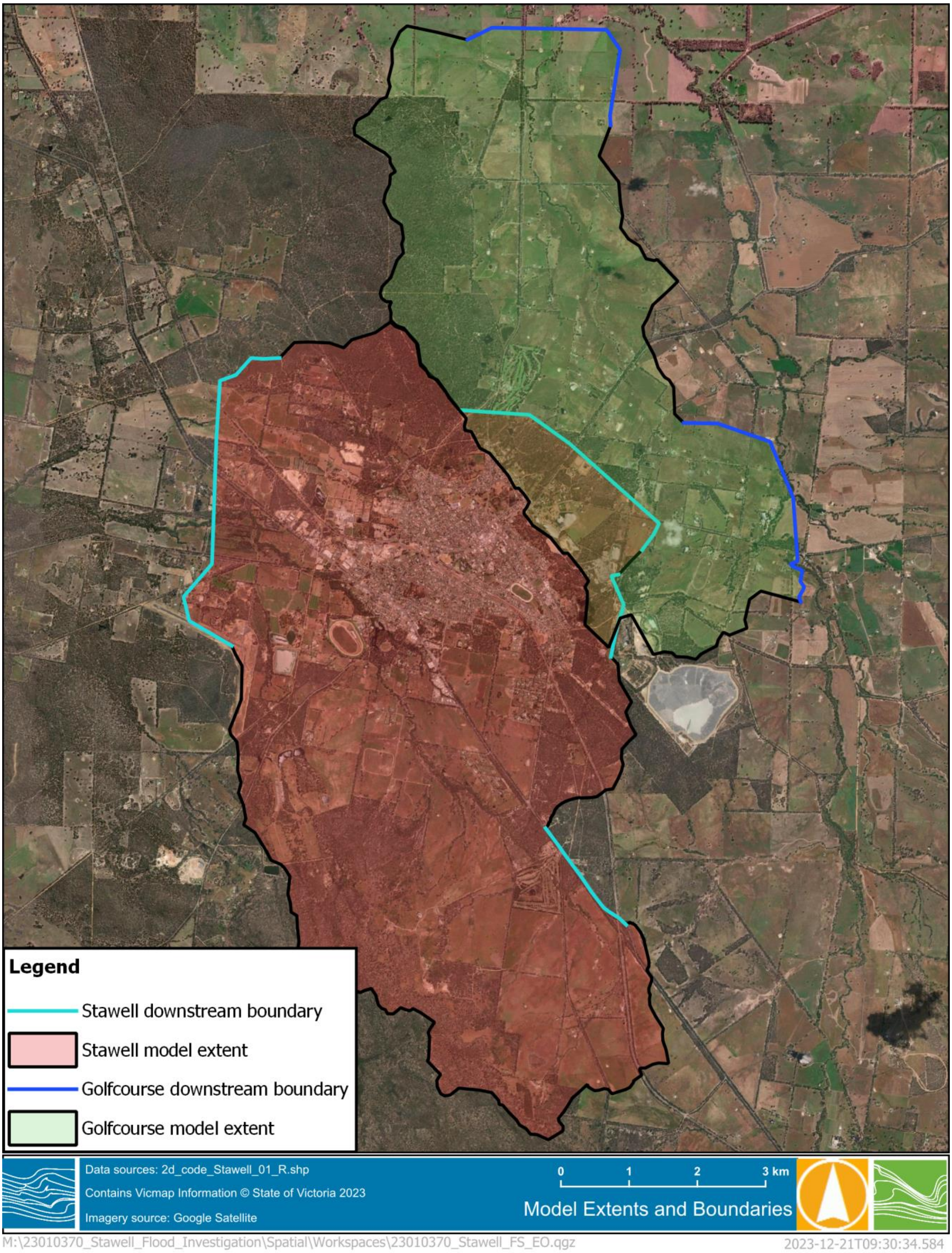

Figure 3-1 Hydraulic model extents and downstream boundaries

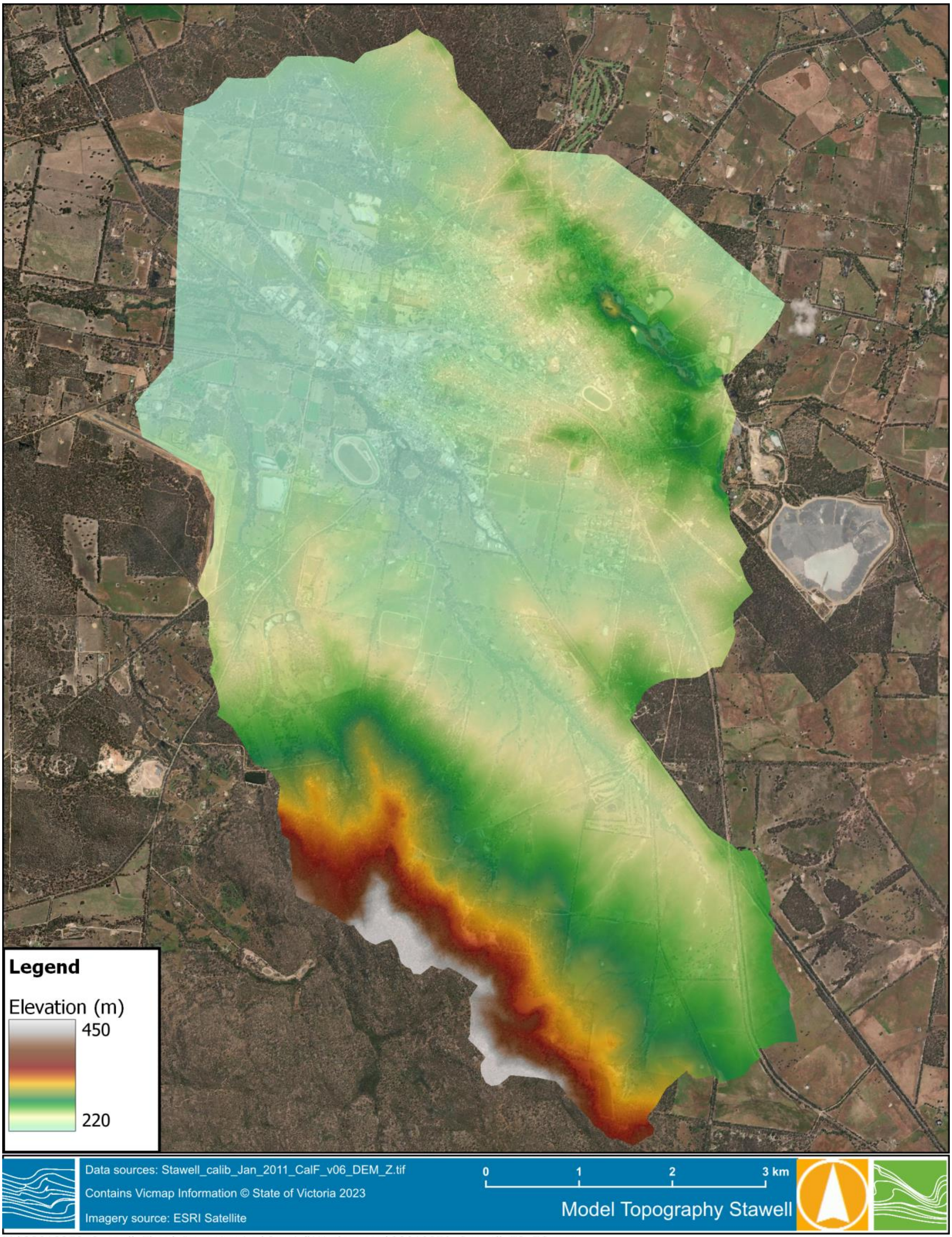

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Figure 3-2 Stawell model topography

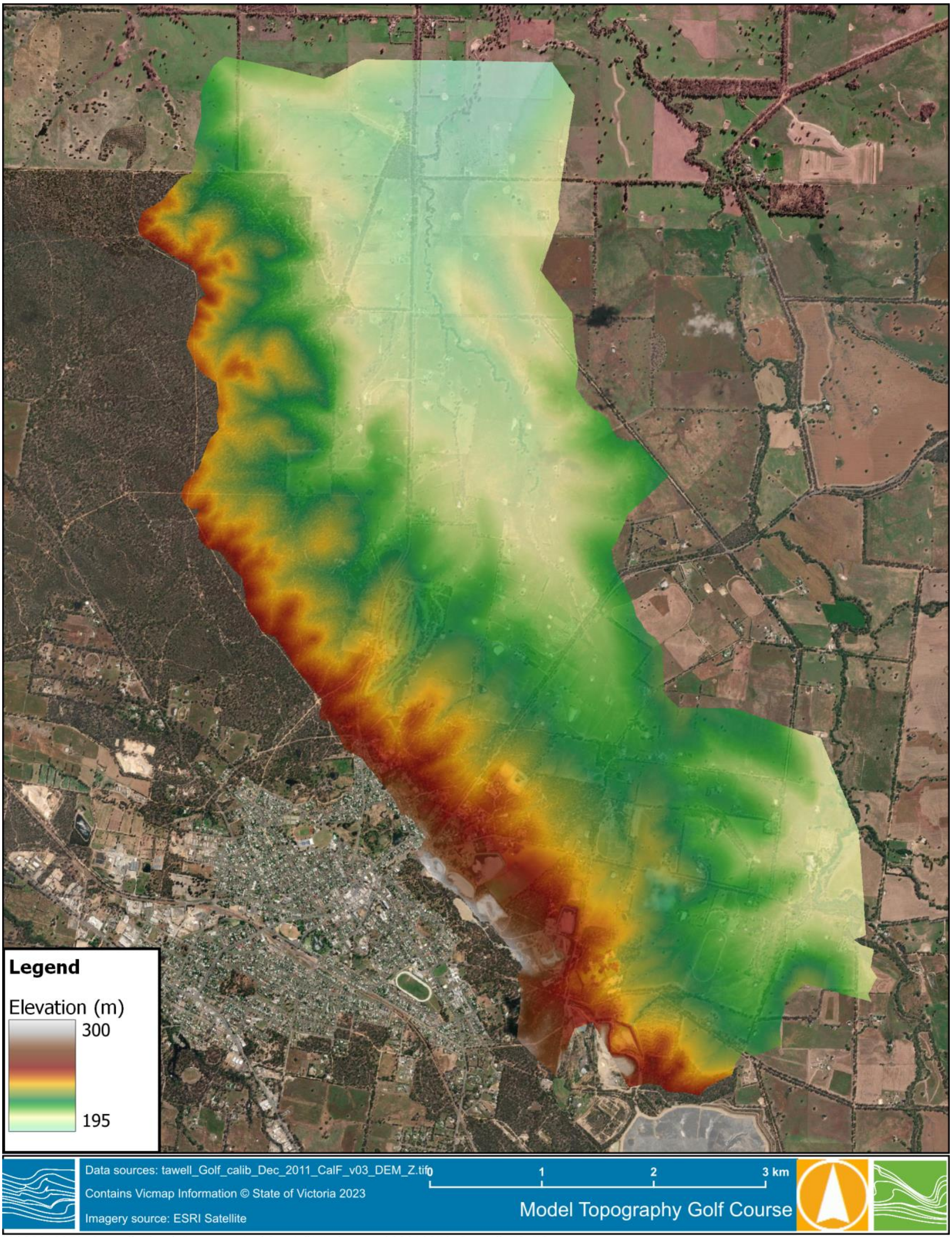

Figure 3-3 Stawell Golf Course model topography

3.3 Calibration modelling results

Calibration model results were used to ensure the models were performing as expected, reproducing depths and extent from the flooding experienced in January and December 2011. The model results were compared to anecdotal evidence obtained during the initial community consultation session in October 2023 and presented to community members at the second community consultation session held in June 2024.

The following calibration data sources were available for the December 2011 event:

- Photographs taken by Council staff showing inundation of bowling club grounds on Napier Street.
- Photographs taken by Council staff showing post-flood damage on Sloane Street.
- Anecdotal records relating to inundation at specific properties.

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

- Video footage taken by Council staff showing inundation at various locations in Stawell during the event.
- Photographs taken by Council staff showing post-flood damage at Federation Park.
- Photographs taken by a resident showing inundation at the intersection of Ligar Street and Franklin Street.
- Articles in the Stawell Times newspaper with photographs showing inundation at Pomonal Road, Stawell Racecourse, Sloane Street and Cooper Street.
- Anecdotal records relating to inundation at specific properties.

More detail around the calibration is presented in the Calibration Report (R02). Figure 3-6 and Figure 3-7 show the modelled flood depth for the January 2011 event, and Figure 3-6 and Figure 3-7 for December 2011 at Stawell township and Stawell Golf Course respectively. 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, considering the photos may have been taken after the peak flood level occurred.

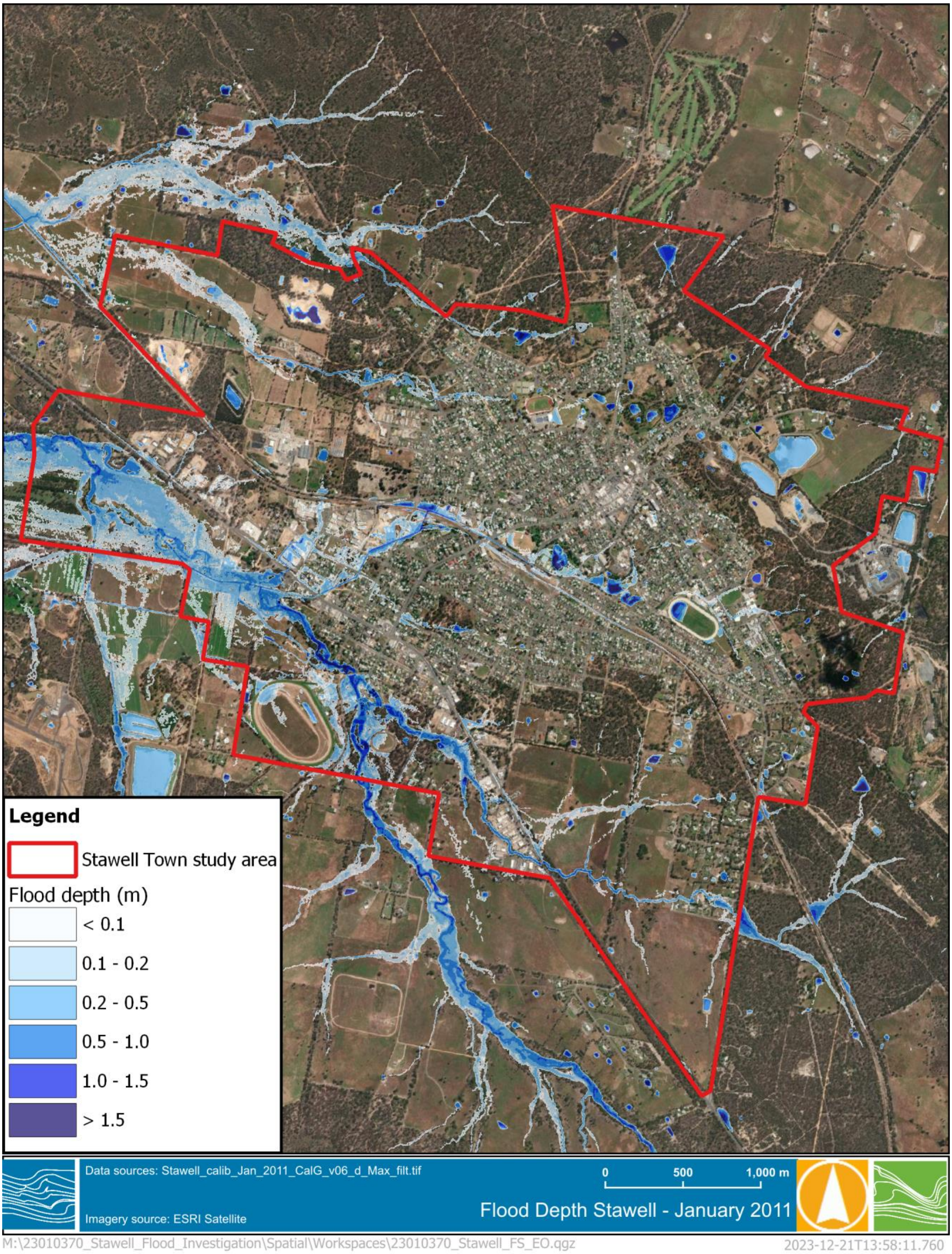

Figure 3-4 Calibration modelling flood depth Stawell – January 2011

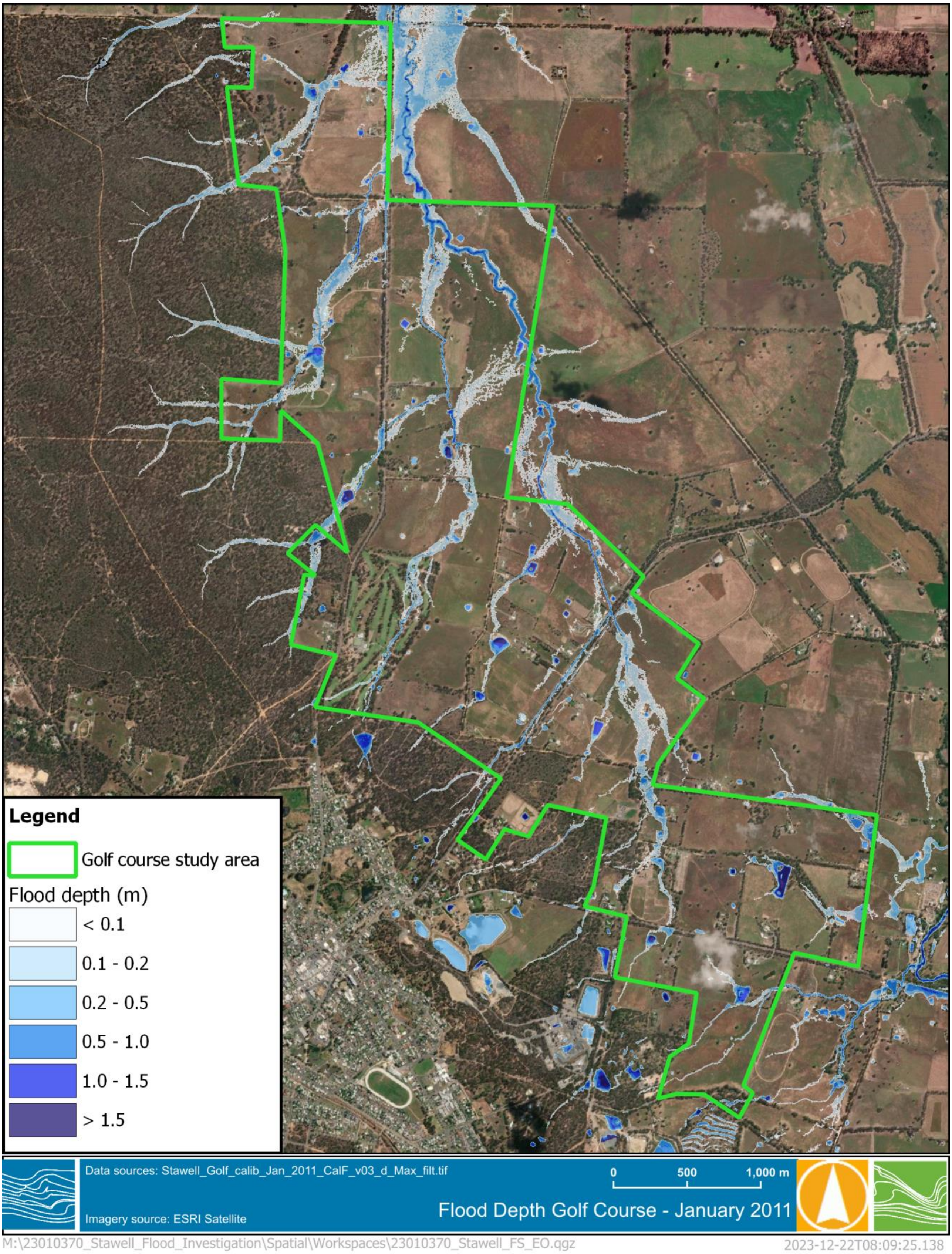

Figure 3-5 Calibration modelling flood depth Stawell Golf Course catchment – January 2011

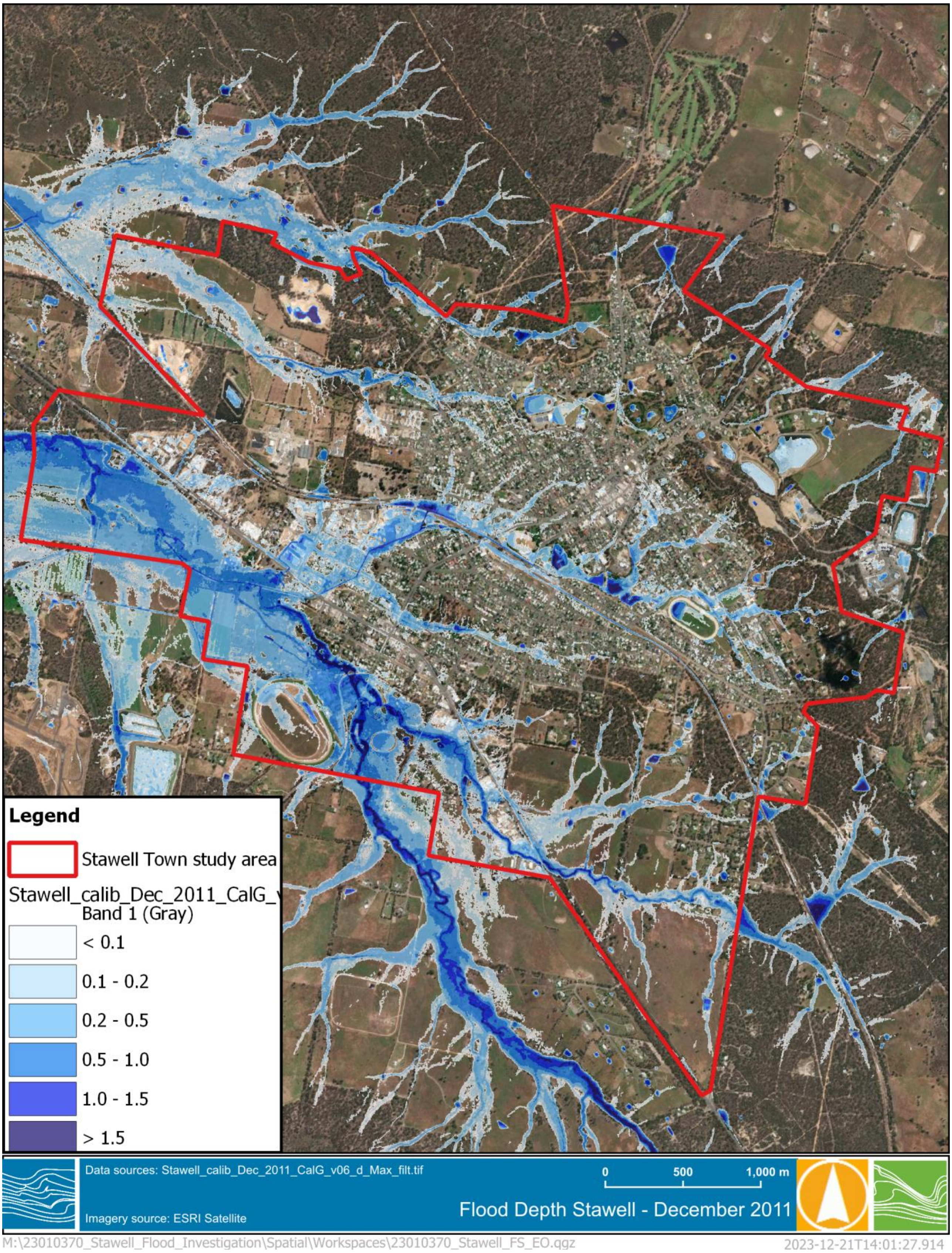

Figure 3-6 Calibration modelling flood depth Stawell – December 2011

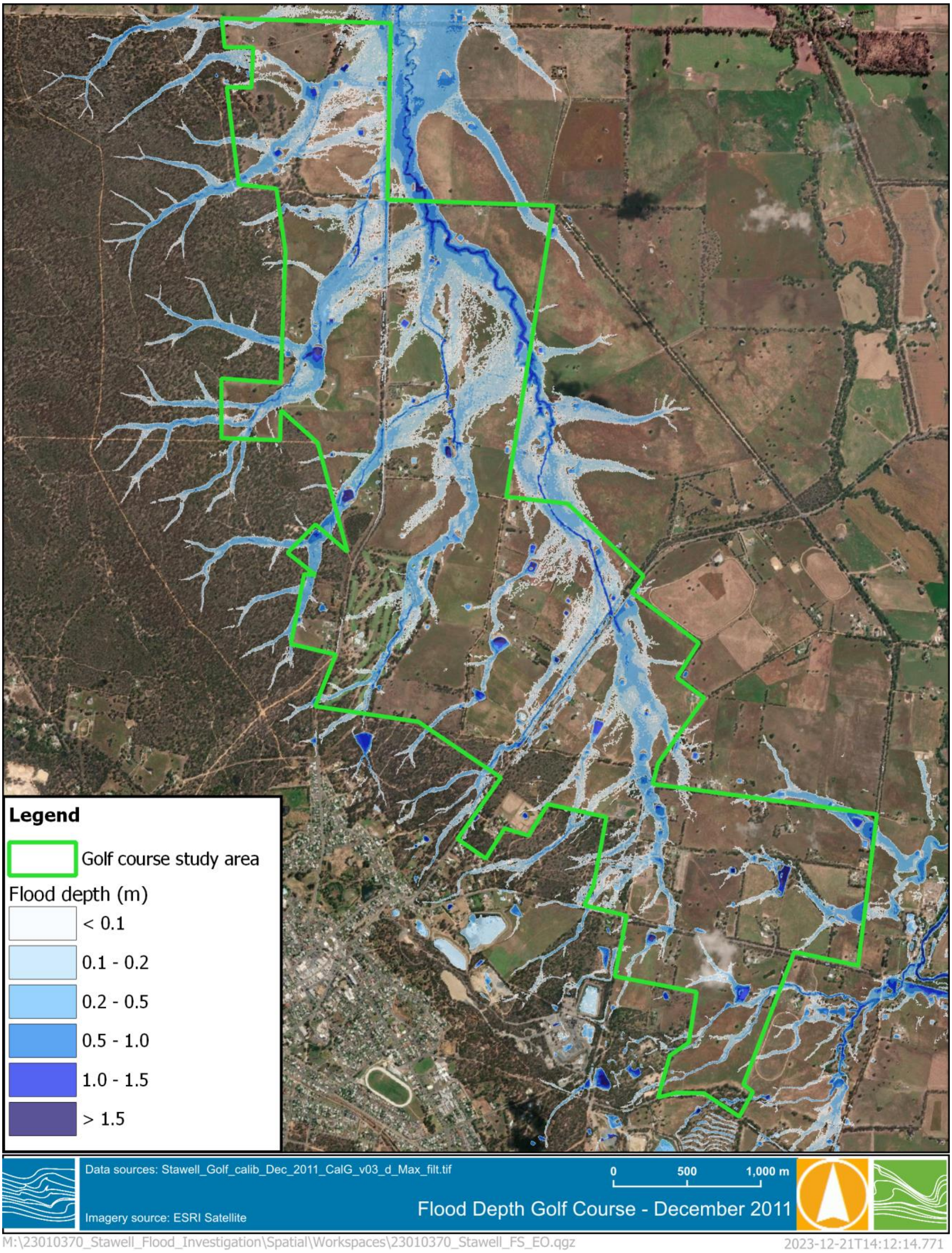

Figure 3-7 Calibration modelling flood depth Stawell Golf Course – December 2011

4 DESIGN MODELLING

4.1 Overview

The calibrated models developed for the Pleasant Creek/Stawell township catchment and Jerrywell Creek/Stawell Golf Course catchment respectively were adopted for the design modelling. The design modelling adopted an ensemble approach to determine design peak flows and the corresponding critical duration and temporal patterns to produce the median peak flow at model key locations, as outlined in Australian Rainfall and Runoff 2019 (ARR2019)[3]. Spatial variations, event duration and temporal patterns were also analysed by comparing maximum depth results.

4.2 Design inputs

The design rainfall depths were downloaded via Bureau of Meteorology (BoM) website using the centroid of each sub-catchment. The spatially varying design rainfall depths across each catchment were applied in conjunction with subarea weighting to produce an Intensity Frequency Duration (IFD) table with one design rainfall depth for each Annual Exceedance Probability (AEP) and duration for the entire catchment.

Temporal patterns were obtained via the ARR Data Hub using the catchment centroid. Temporal patterns were selected from the “Murray Basin region”. Given the limited size of each catchment, and in line with the recommendations of ARR2019, point temporal patterns were adopted. To reduce computational time, the ensemble of temporal patterns modelled for each duration consisted of three patterns: a front loaded, median and back loaded. The front loaded pattern had most of the rainfall occurring within the first third of the storm, the median had most in the middle third and the back loaded in the last third.

4.3 Critical duration

A range of durations were modelled to determine the critical event durations across each model extent. Using peak flows and maximum depth from the three temporal patterns selected for each duration, a representative temporal pattern was selected based on the median peak flow at key locations throughout each model. The critical duration varied each modelled catchment and the results were created by modelling each required duration and enveloping the model results.

Comparison of the modelled flow hydrographs in Pleasant Creek downstream of Grampians Road is shown in Figure 4-1. Solid lines represent the temporal pattern resulting in the median peak flow for each modelled duration, indicating the critical duration in Pleasant Creek location is 6 hours, with temporal pattern 03 (TP03) the median. Figure 4-2 shows 1 hour is the critical duration in central Stawell with TP08 the median temporal pattern.

Figure 4-3 and Figure 4-4 show the peak flood depths for the 1% AEP event. Complete results including velocity and hazard mapping and pipe capacity utilisation are available in the Design Modelling Report (R03).

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

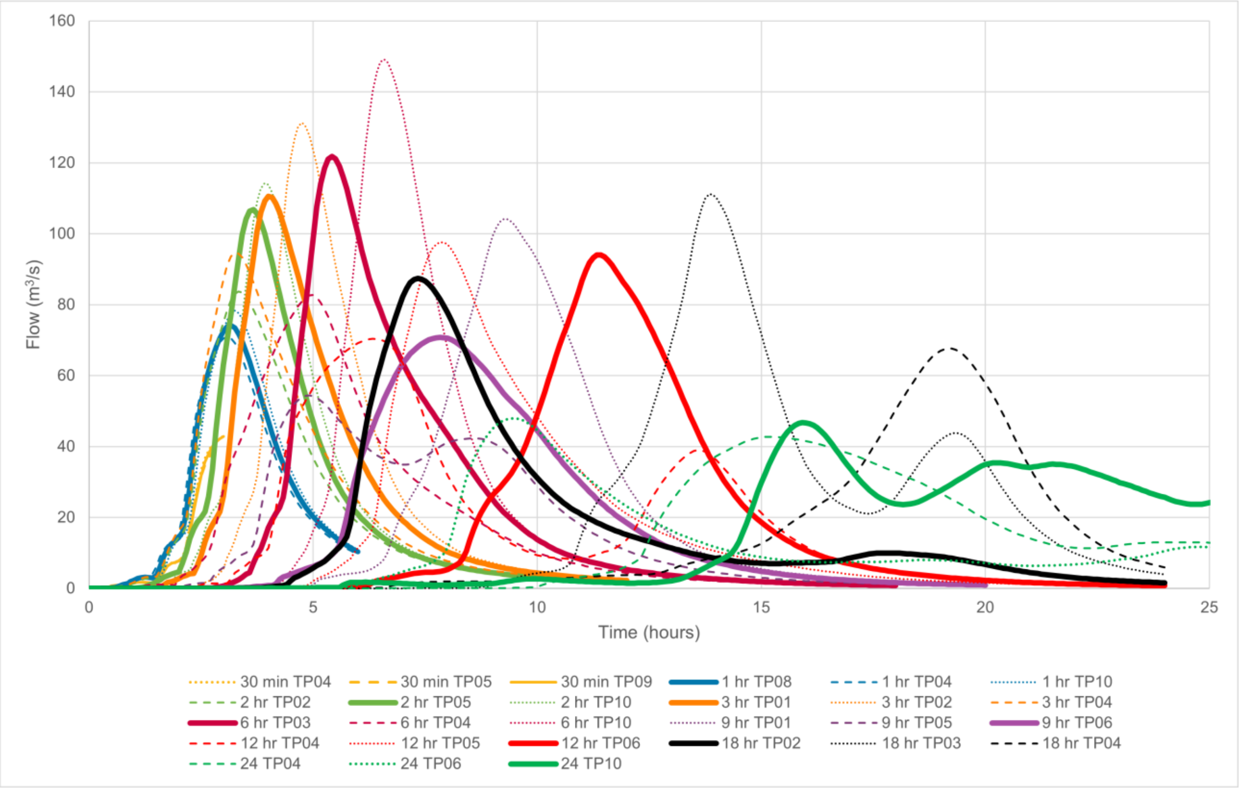

Figure 4-1 Modelled 1% AEP flows in Pleasant Creek DS Grampians Road (m^3/s)

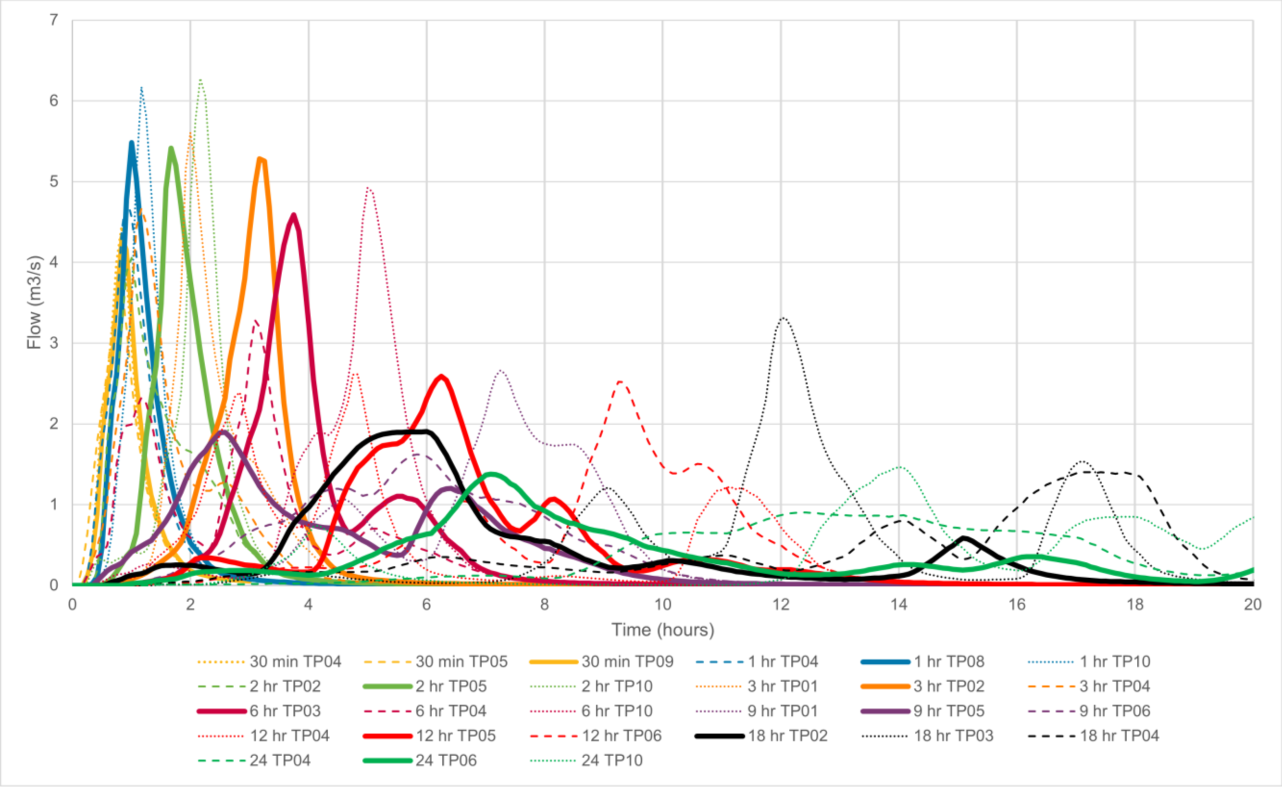

Figure 4-2 Modelled 1% AEP flows in overland flow path east of hospital towards Maud Street Dams (m^3/s)

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Imagery source: Google ESRI
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Figure 4-3 1% AEP depth – Stawell

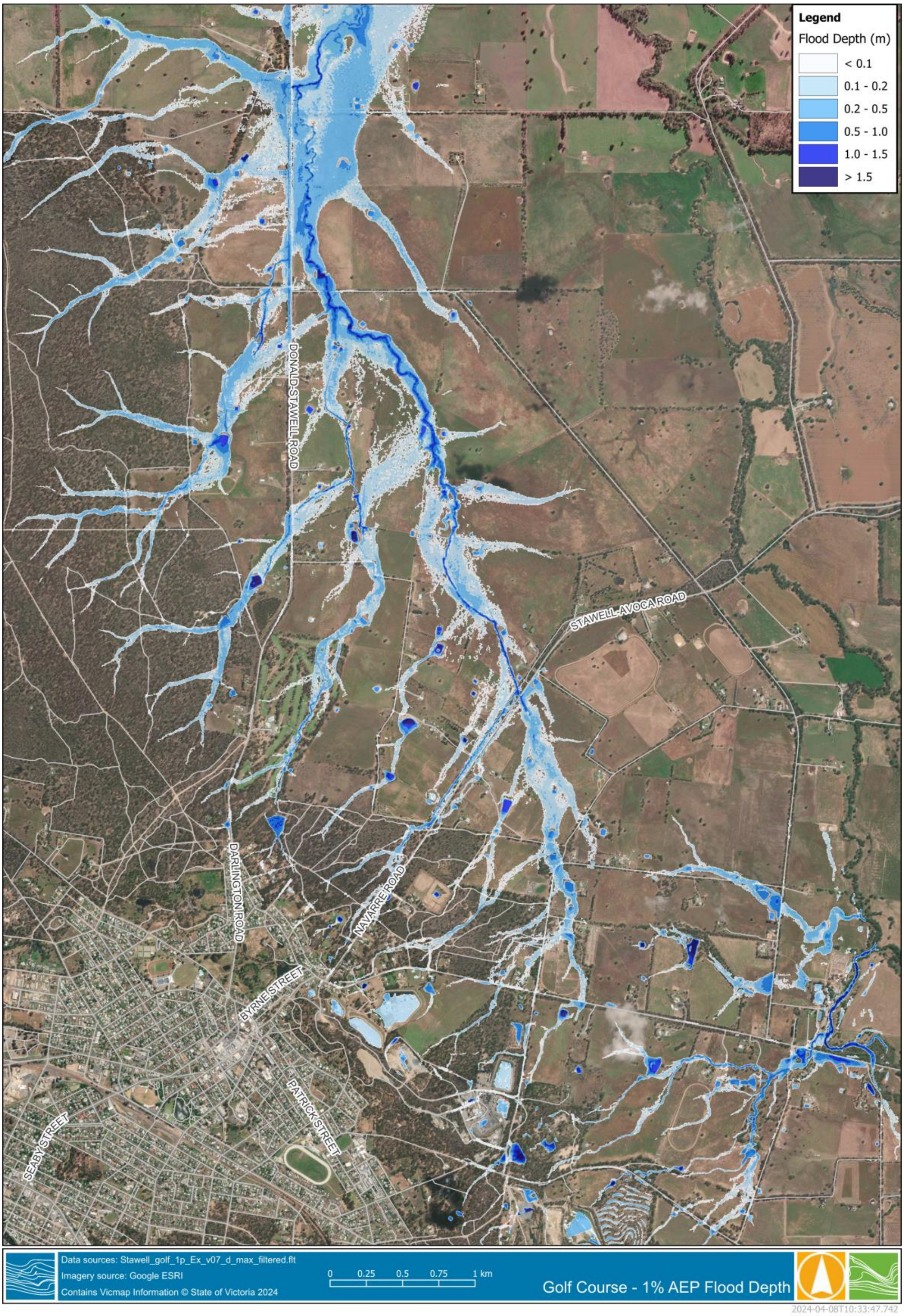


Figure 4-4 1% AEP depth – Stawell Golf Course

4.4 Climate change modelling

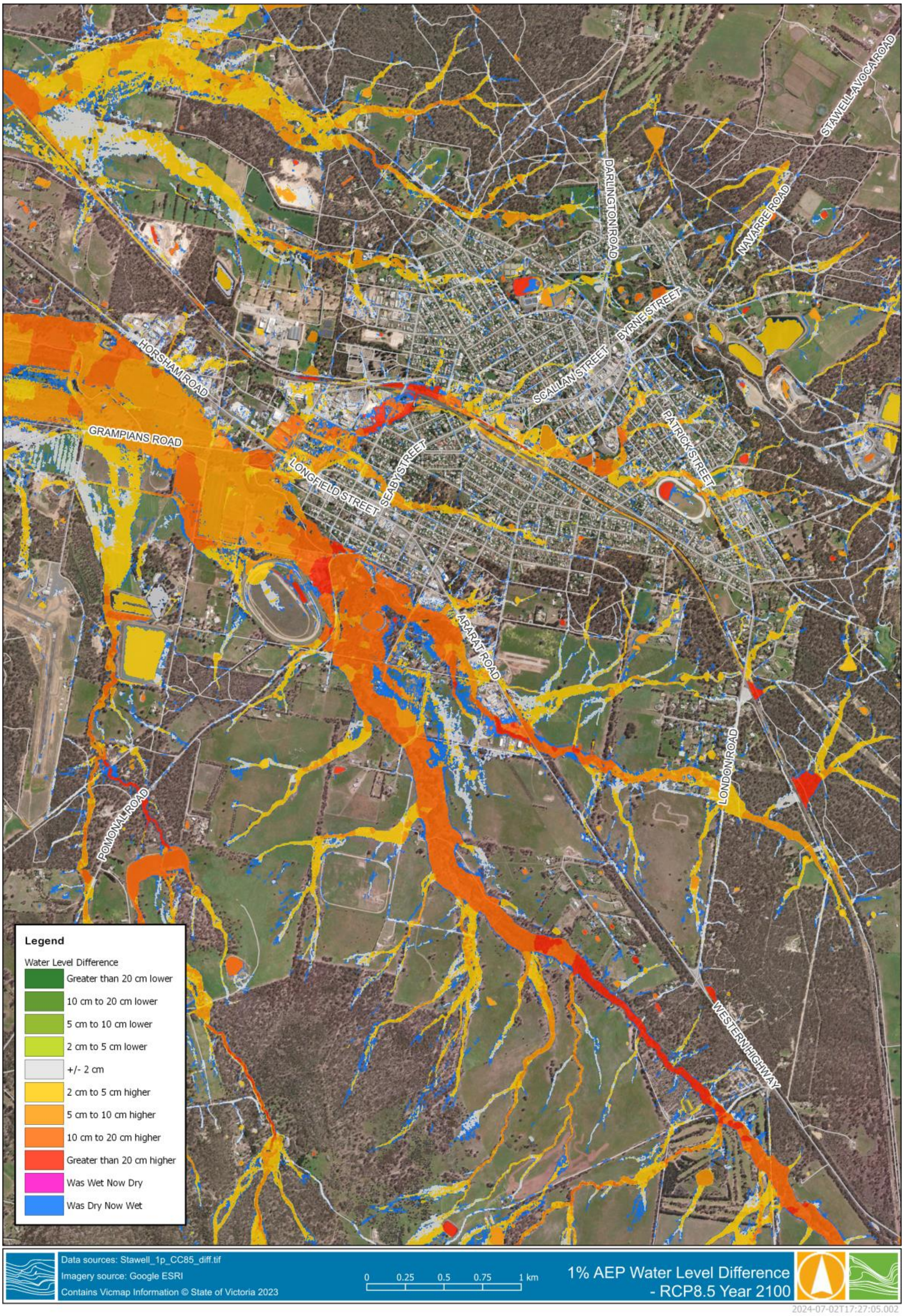
The impact of increased rainfall intensity associated with climate change was investigated for the 20%, 10% and 1% AEP events. Modelling considered Representative Concentration Pathways (RCP) 4.5 and 8.5 under projections to the year 2100 in line with the ARR guidelines with rainfall scaling factors obtained from the ARR Datahub. The resultant rainfall depths and hydraulic model peak flows downstream of Stawell are shown in Table 4-1. The 6 hr and 12 hr duration rainfall depths were provided for comparison, but increases were applied to all modelled durations.

The model results indicate climate change will cause an increase in peak flow for both models. The 1% AEP flows under an RCP8.5, 2100 scenario are increased by 51%,. The 10% AEP flows for the same climate scenario increased 41%. The difference in water level for the RCP8.5, 2100 1% AEP event is shown in Figure 4-5.

As expected, the increased rainfall intensity RCP8.5, 2100 scenario produces an increase in flood levels across the study areas. In the township, levels increase up to 0.3 m with larger increases in and around Pleasant Creek.

Table 4-1 Climate change assessment summary

1% AEP (6 hr duration)	RCP4.5 (Year 2100)	RCP8.5 (Year 2100)
Current IFD rainfall (mm)	76.2	76.2
% increase	9.60	23.33
Projected rainfall depth (mm)	83.5	94.0
Peak flow Pleasant Creek DS Grampians Road (m/s)	149	176
% flow increase	19	41
10% AEP (6 hr duration)	**RCP4.5 (Year 2100)**	**RCP8.5 (Year 2100)**
Current IFD rainfall (mm)	47.5	47.5
% increase	9.60	23.33
Projected rainfall depth (mm)	52.1	58.6
Peak flow Pleasant Creek DS Grampians Road (m/s)	54	70
% flow increase	32	71
20% AEP (12 hr duration)	**RCP4.5 (Year 2100)**	**RCP8.5 (Year 2100)**
Current IFD rainfall (mm)	50.6	50.6
% increase	9.60	23.33
Projected rainfall depth (mm)	55.5	62.4
Peak flow Pleasant Creek DS Grampians Road (m/s)	30	40
% flow increase	36	82



Data sources: Stawell_1p_CC85_diff.tif
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Figure 4-5 1% AEP water level difference - Climate change RCP8.5 2100

4.5 Sensitivity testing

Model sensitivity testing was conducted on the Stawell hydraulic model for the following parameters:

- Catchment storage.
- Hydraulic roughness.
- Structure blockage.
- Boundary conditions (slope).

Modelling showed limited sensitivity to hydraulic roughness and catchment storage conditions. For the 1% AEP event, structure blockage and boundary conditions were not shown to be influential on results in the township aside from localised increases upstream of blocked culverts.

4.6 Developed conditions modelling

A developed conditions scenario of the Stawell model was prepared by incorporating future changes in land use according to the Stawell Structure Plan[4]. Future growth areas include both high- and low density residential zones and industrial zones. For areas with changed land use, the Manning's 'n' roughness and rainfall losses were modified to suit the proposed land use. Most of the areas were previously defined as open space.

Increased roughness in development areas resulted in increased flood extents and depths within and directly upstream of these areas. Consequently, flood levels downstream of these areas decrease as a result of the changed timing of flows through the rougher developed areas. Further details can be found in the Design Modelling Report (R03).

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[4] Hansen Partnership, Tim Nott & Martyn Group, 2021, Stawell Structure Plan

5 FLOOD INTELLIGENCE AND WARNING

5.1 Overview

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

- Flood/No flood tool – rainfall intensity and flooding indicator.
- Flood peak travel time calculator/warning time available.
- Draft documentation for inclusion in the NGSC MFEP including flood intelligence cards and inundation tables, see the MFEP Documentation in R04.
- Assessment of existing flood warning arrangements and flood warning service needs.
- Develop the structure and investigate feasibility of a Total Flood Warning System (TFWS).

These products were 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 peak travel time estimates and Flood/No Flood tool have been reproduced herein for reference.

5.2 Flood/No Flood tool

See Figure 5-1.

5.3 Flood peak travel time

Table 5-1 Flood peak travel timing

Location from	Location to	Typical travel time	Comments	Duration
Pleasant Creek catchment				
Start of rainfall (catchment)	Stawell	3 – 10 hours	To peak – may be longer depending on rainfall pattern and catchment antecedent conditions (dryness)	Generally 10 – 15 hours
Stawell township catchment				
Start of rainfall (catchment)	Stawell	1 – 12 hours	Subject to flash flooding depending on rainfall intensity and duration	Generally 15 to 30 minute

5.4 Municipal Flood Emergency Plan tables

A set of summary tables were developed for Stawell, 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 MFEP Documentation (R04).

5.5 Flood warning assessment and feasibility

The monitoring capability and infrastructure availability to enable flood warning for Stawell was reviewed in the Flood Intelligence and Warning Report (R04).

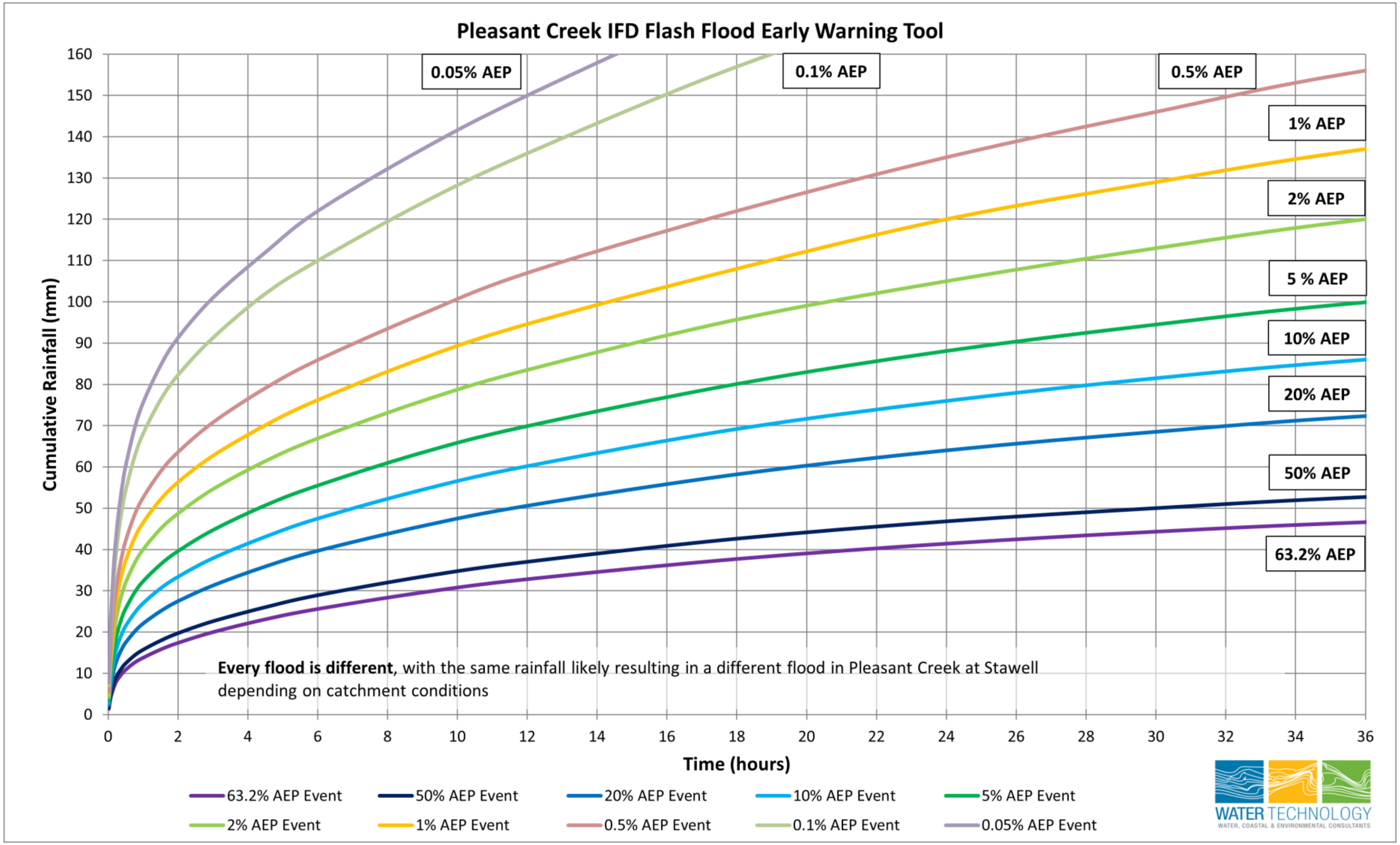
The total flood warning system concept includes many elements; flood prediction, interpretation of the flood impact, messaging and communication of the flood risk, generating a timely response from the community and timely reviews of the system.

Given most of Stawell has a small urban upstream catchment, the major flood risk is flash flooding. There are no streamflow gauges in the catchment, so the flood prediction element of the total flood warning system relies on rainfall forecasts and observations.

The BoM will provide Severe Weather Warnings and Flood Watches, forecasting likely conditions. In predicting the likely magnitude of flooding on Pleasant Creek near Stawell, as well as direct catchment inundation within Stawell itself, real time rainfall forecasts, radar and the rainfall gauge network and are more useful than an upstream streamflow gauge network.

A streamflow gauge on Pleasant Creek was identified as a possible but not necessarily beneficial option. While it would improve the monitoring and data gathering capability for creek flooding, given the short flood travel time it would not enable significant flood response and is unlikely to provide a positive cost benefit ratio.

A flood prediction procedure utilising BoM warnings, the Flood/No Flood tool and an automatic flood alert system based on radar rainfall was proposed for Stawell.



Every flood is different, with the same rainfall likely resulting in a different flood in Pleasant Creek at Stawell depending on catchment conditions

Figure 5-1 Stawell Flood/No flood tool

6 FLOOD DAMAGES AND MITIGATION

6.1 Overview

Detail around the flood damage and mitigation potential in Stawell is documented in the Flood Damages and Mitigation Report (R05). In the 20% AEP event, overland flooding within Stawell is patchy and shallow, concentrated to local depressions, dams and the Main Drain. As rainfall intensity increases flow paths become more well defined with increased depth and velocity. In the 2% AEP event, overland flow is occurring along and across several streets, with all previously described flow paths continuous along their respective reaches.

When Pleasant Creek floods, the upper reaches of the creek are relatively well contained within a floodplain less than 50 m wide even in rare events (0.05% AEP). More widespread flooding is observed downstream and in a 20% AEP event, the inundated floodplain between Grampians Road and the Western Highway is over 500 m wide and overtops Grampians Road.

Black Range Road overtops in a 5% AEP event and the Western Highway overtops in a 2% AEP event.

To classify the impact of flooding and risk to the Stawell 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 0.05% 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 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). Table 2-1 shows a list of major roads impacted by flooding and the lowest magnitude (i.e. most frequent) event at which the road is impacted within the study area. The extent of road inundation for all modelled events is detailed in the Flood Intelligence and Warning Report (R04).

Table 6-1 Major roads overtopped in the study area

Design event overtopped (AEP)				
20%	**10%**	**5%**	**2%**	**1%**
Albion Road	Bulgana Road	Black Range Road	Horsham Road	Alfred Street
Ararat Road	Concongella School Road	Longfield Street	Byrne Street	Duke Street
Barnes Street	Darlington Road	Pomonal Road	Church Street	
Clifton Avenue	Seaby Street	Stawell - Avoca Road	Layzell Street	
Crowlands Road			Scallan Street	
Deep Lead Road			Western Highway	
Donald - Stawell Road				
Grampians Road				

Design event overtopped (AEP)				
Landsborough Road				
London Road				
Main Street				
Navarre Road				
Newington Road				
Patrick Street				
Sloane Street				

6.3 Property inundation

Floor level survey of 522 buildings was captured within the study area, including 163 commercial and 359 residential buildings. These buildings were selected for survey based on the preliminary flood modelling undertaken during this study. It should be noted that there were minor limitations within the floor level survey data captured, in that only the main residential dwelling or commercial building was captured for each property, outbuildings were not surveyed. It should be noted the number of properties flooded below floor indicates a property with a building on it. This does not include parcels of land which are flooded and do not have an associated building i.e. vacant lots, farm paddocks etc.

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

- Property flooded below floor.
    - This indicates the 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 in Figure 6-1 to Figure 6-10.

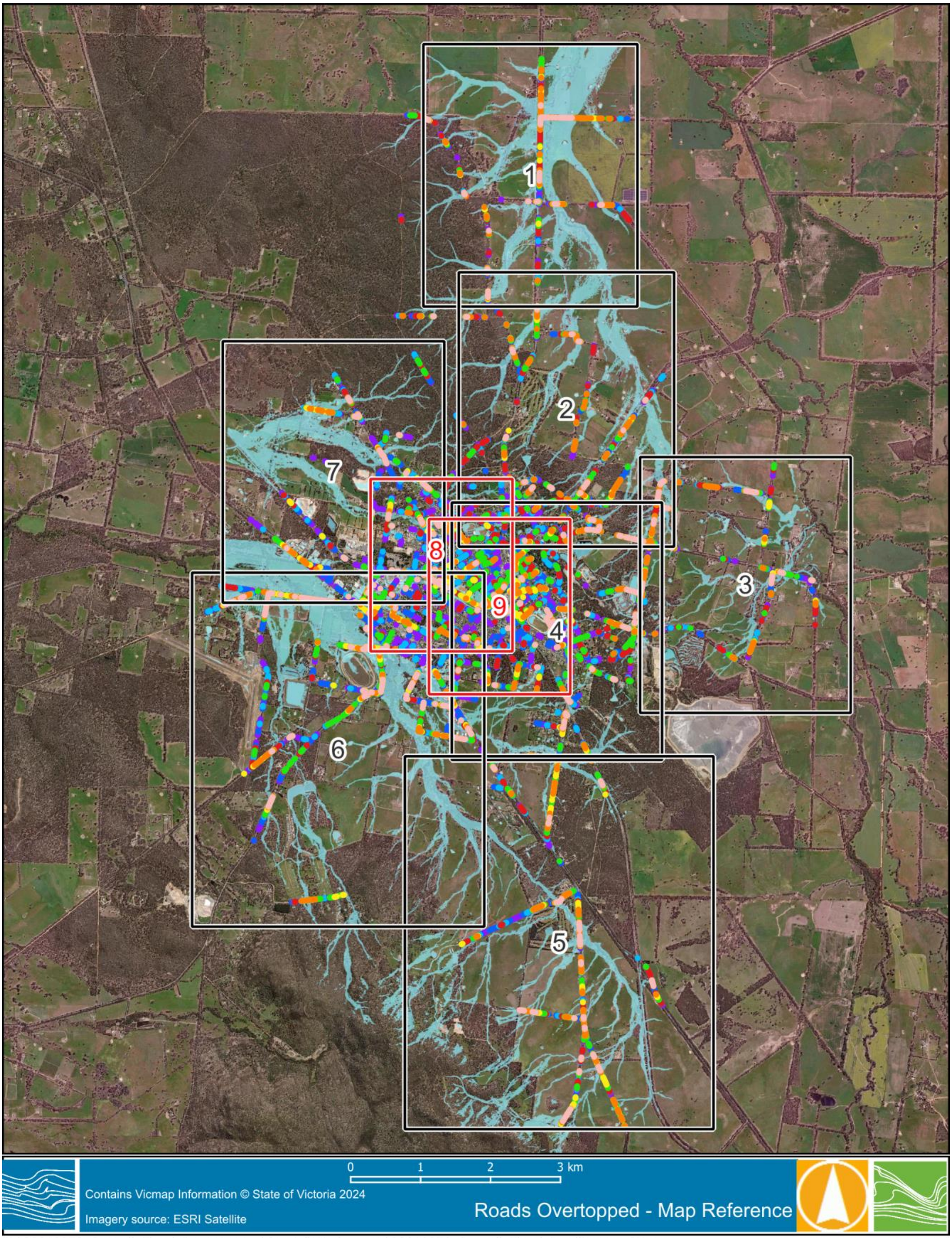


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Figure 6-1 Roads overtopped reference map

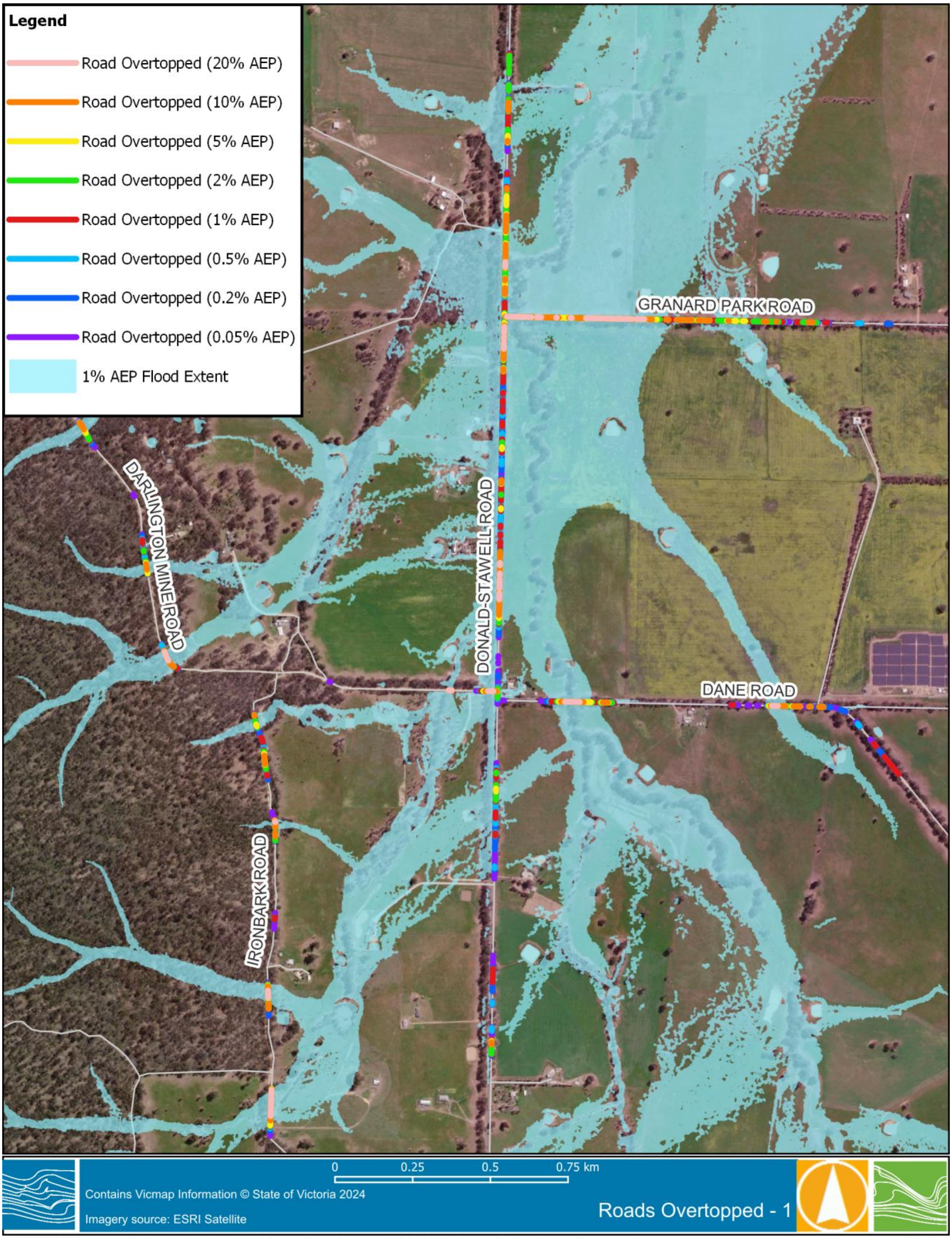

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Figure 6-2 Roads overtopped - 1

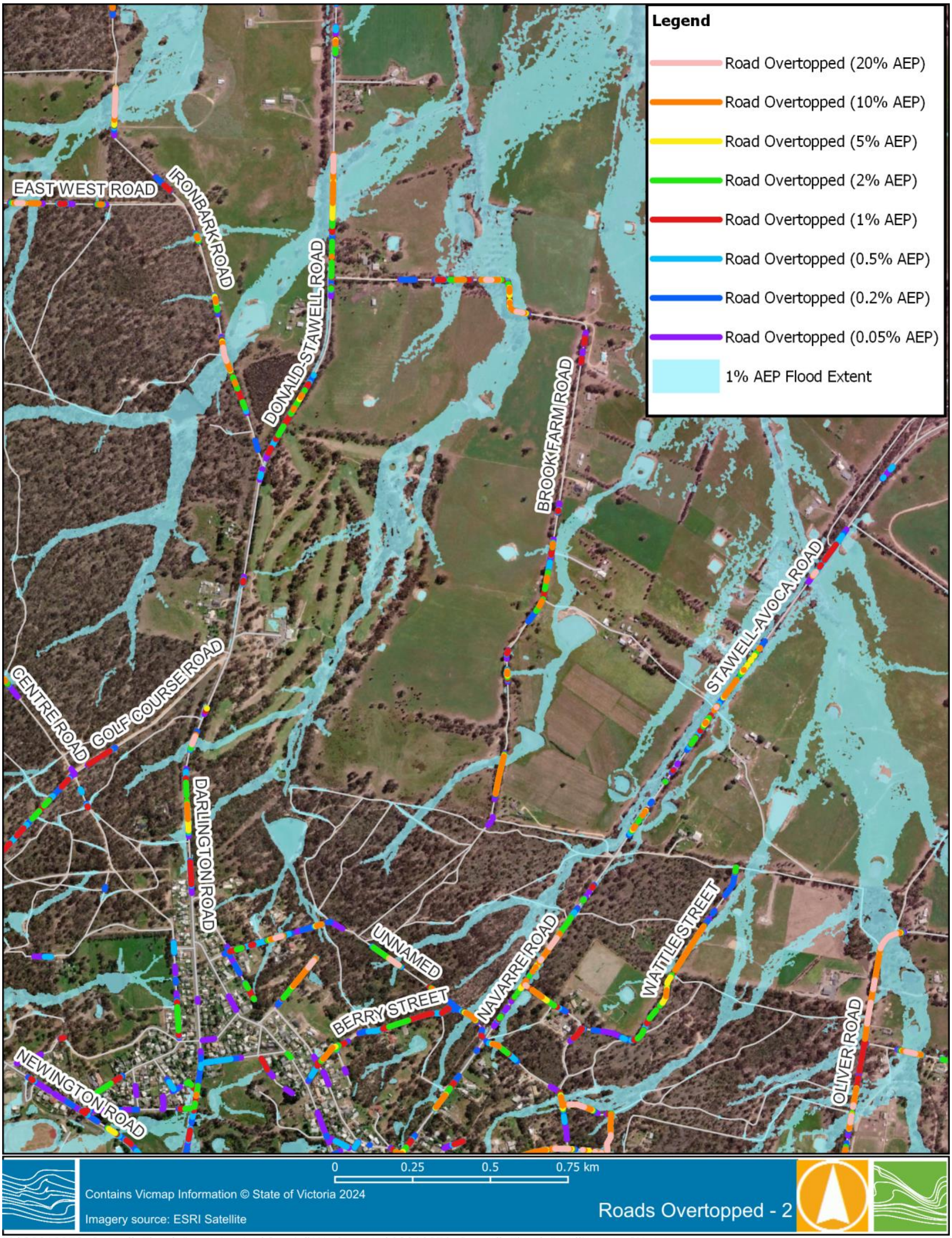

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Figure 6-3 Roads overtopped - 2

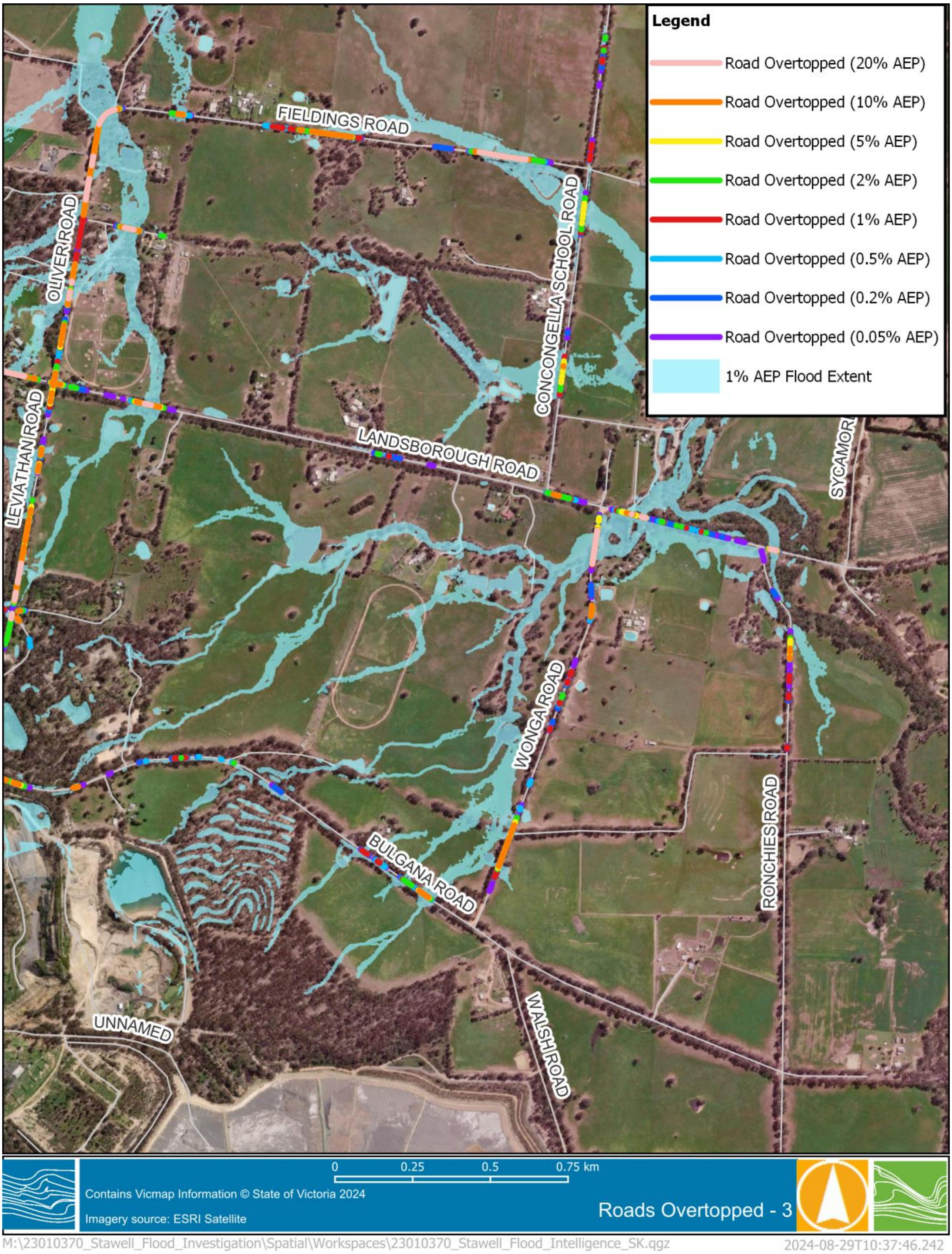

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Figure 6-4 Roads overtopped - 3

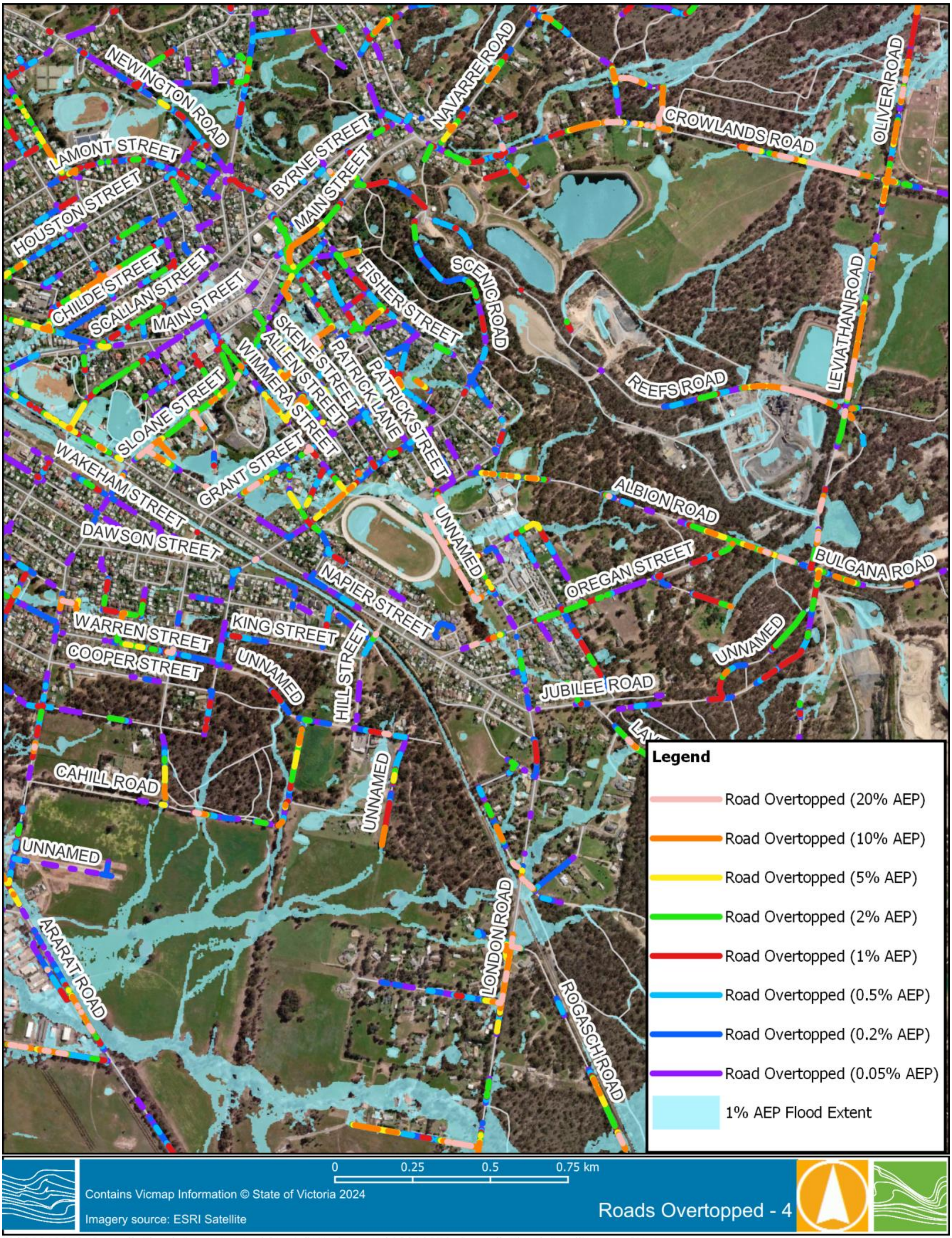

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Figure 6-5 Roads overtopped - 4

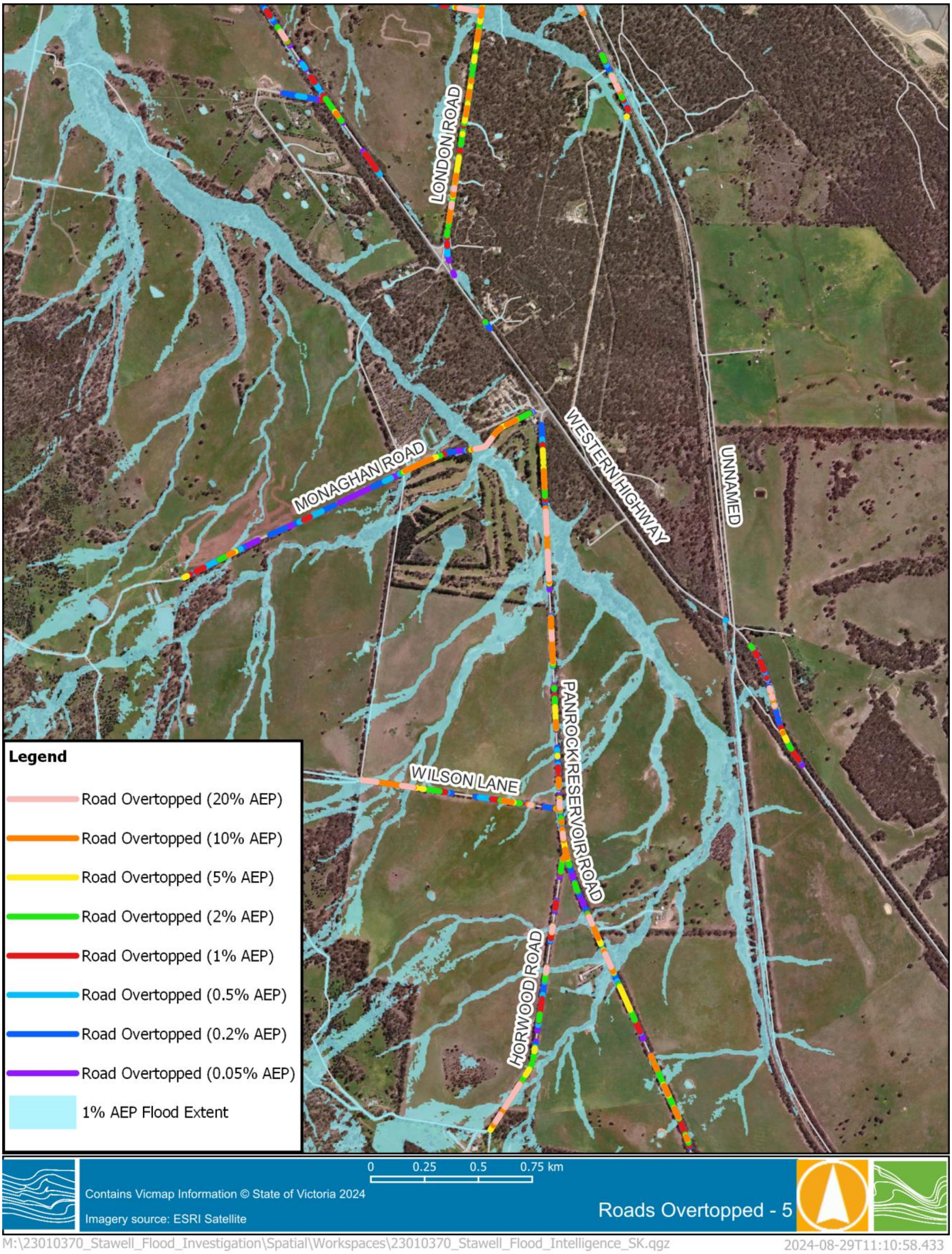

Figure 6-6 Roads overtopped - 5

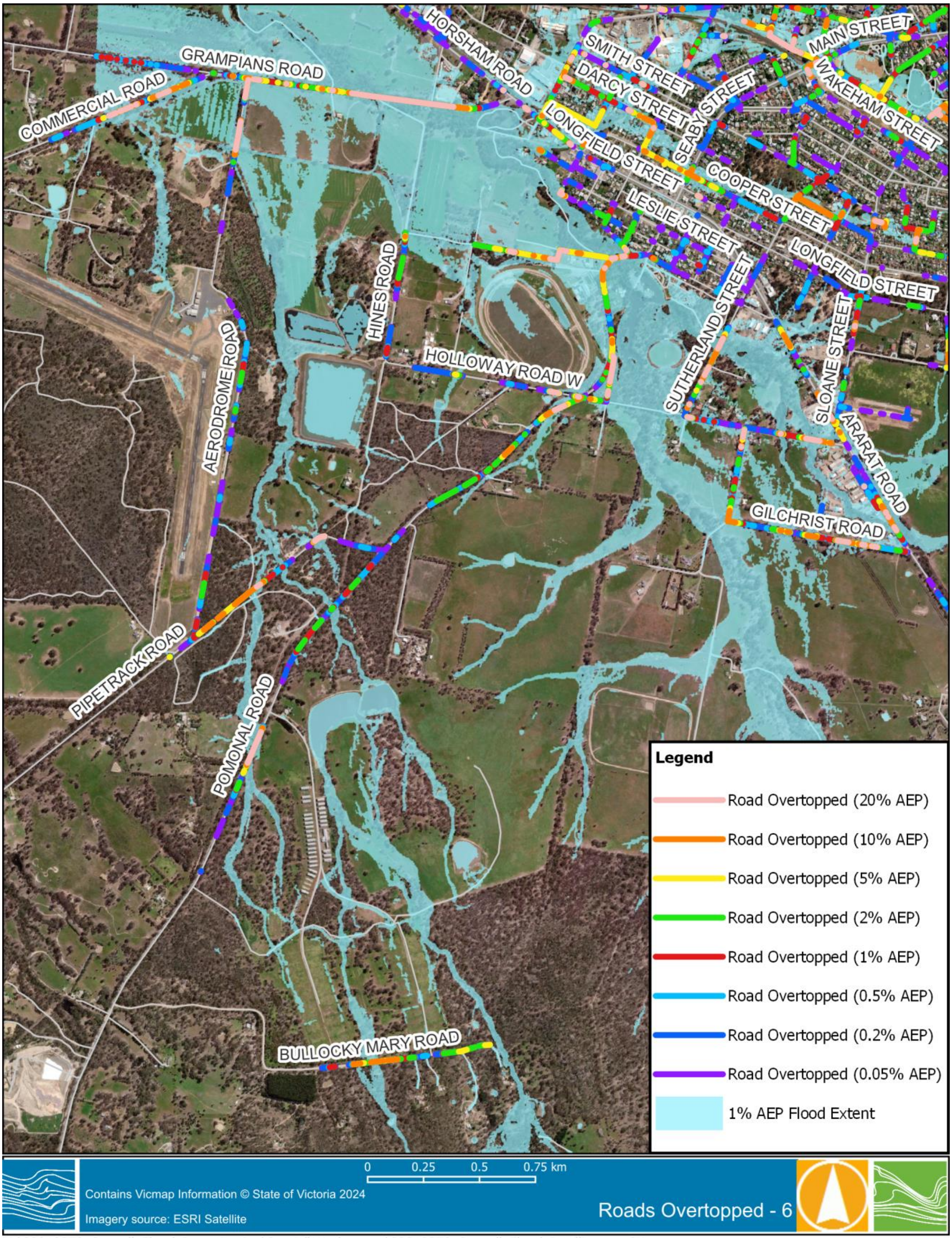

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Figure 6-7 Roads overtopped - 6

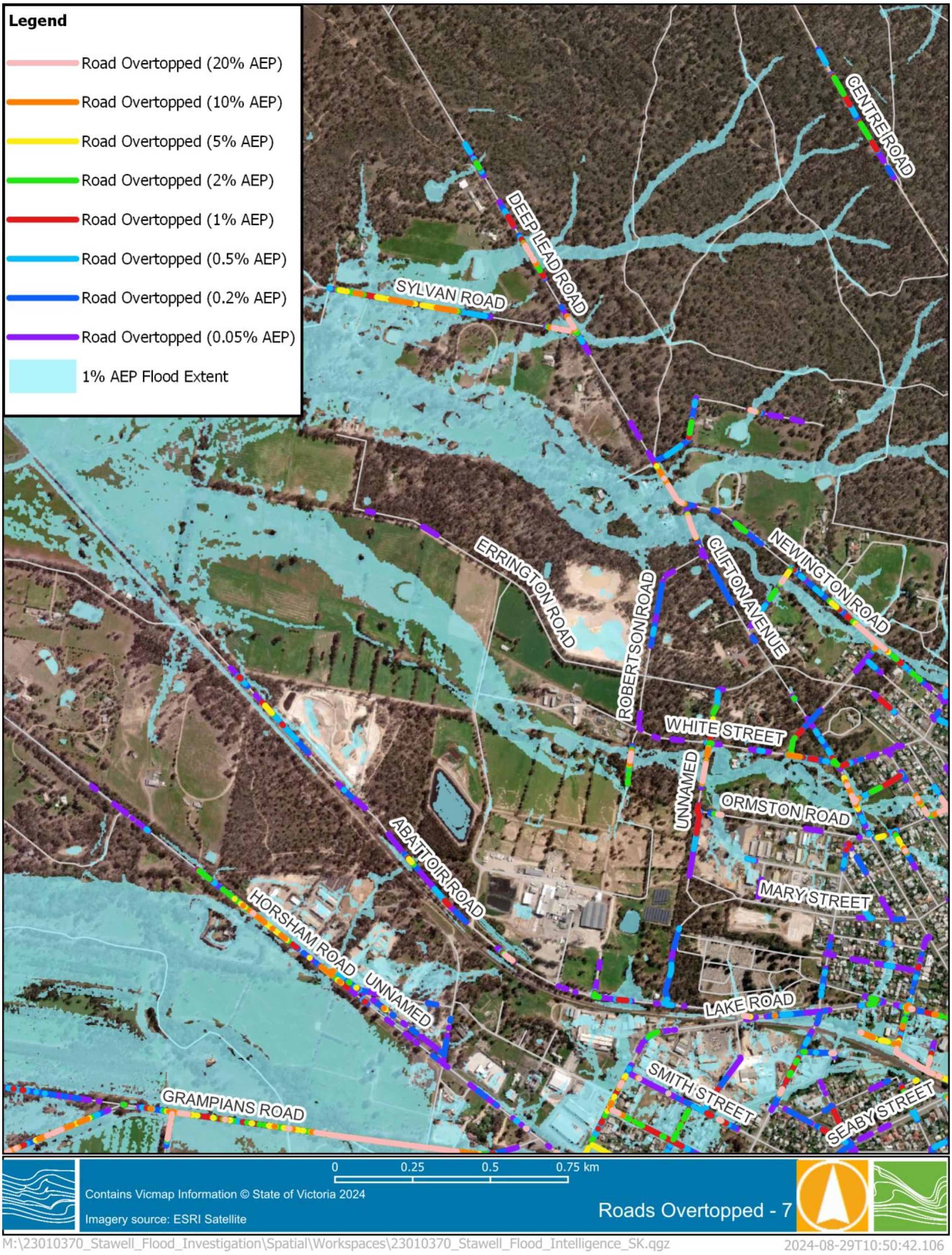


Figure 6-8 Roads overtopped - 7

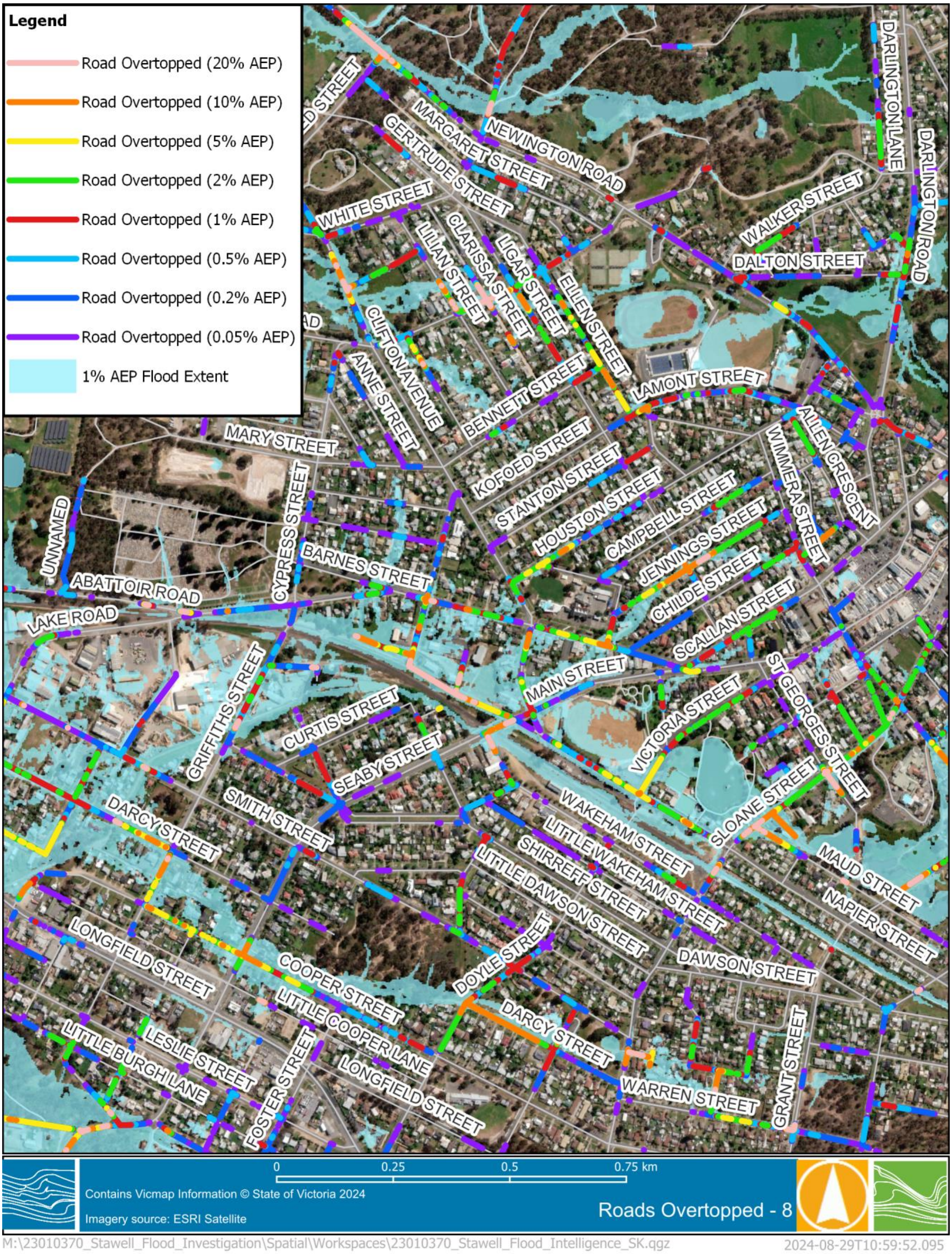
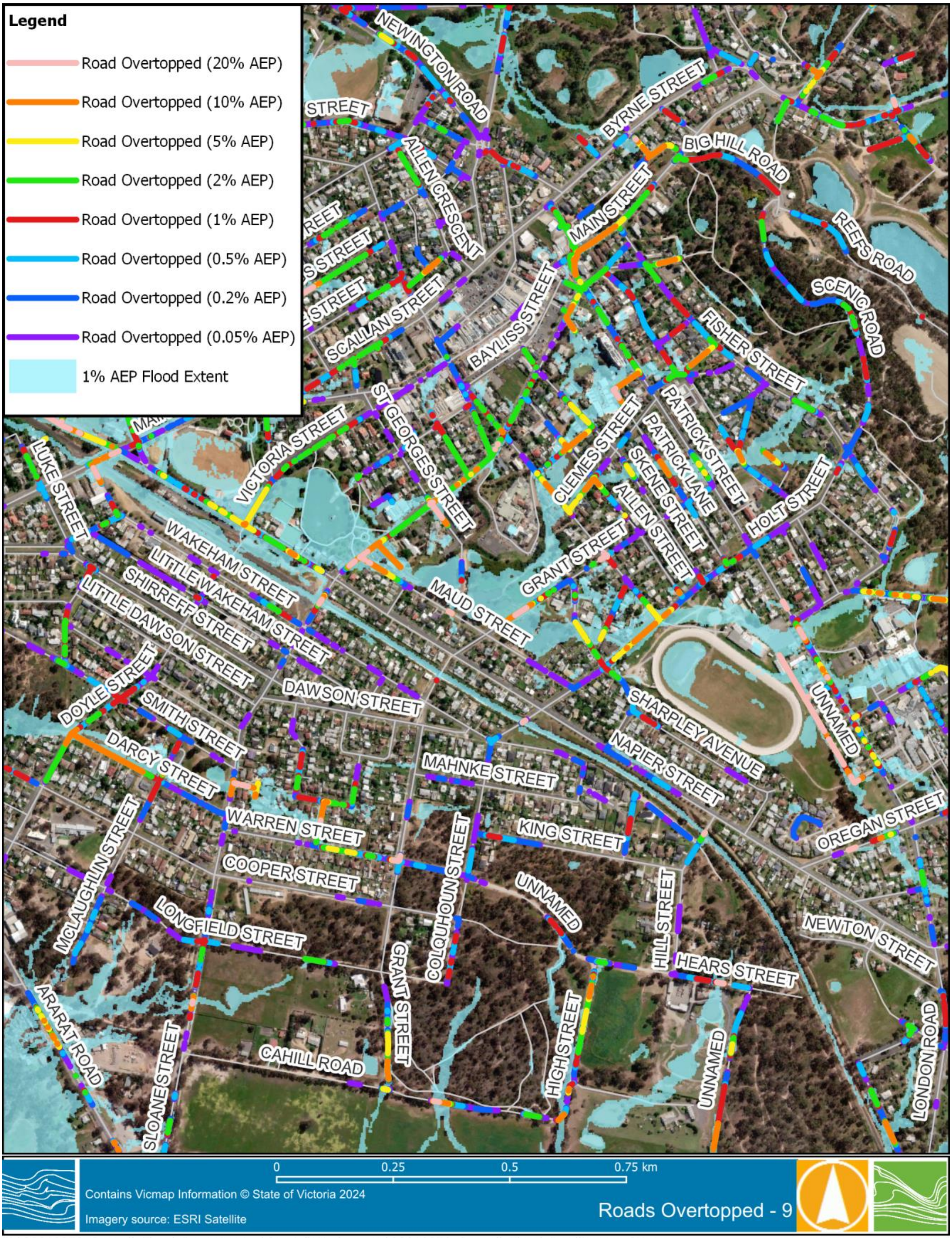


Figure 6-9 Roads overtopped - 8



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Imagery source: ESRI Satellite

Roads Overtopped - 9

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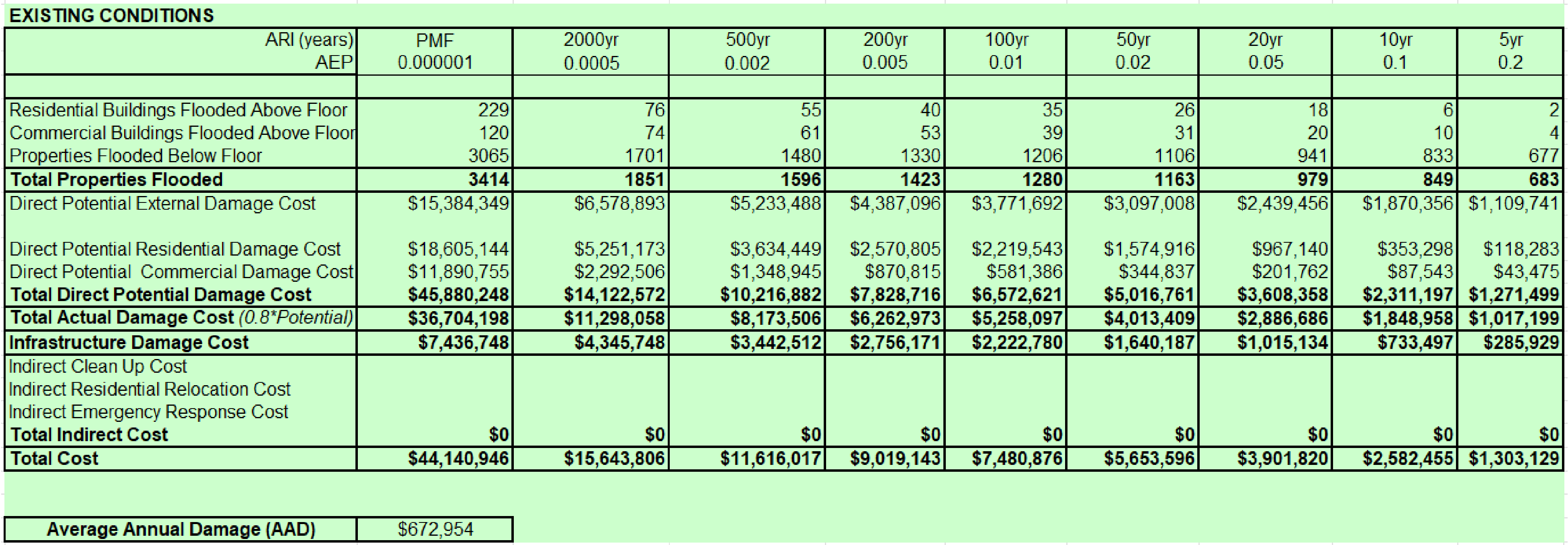
Figure 6-10 Roads overtopped – 9

6.4 Damage assessment

Flood model results for the range of existing conditions events were processed to calculate the Average Annual Damage (AAD) for Stawell, which totals $672,954. The damages figure takes into account properties inundated above floor, properties inundated below floor, properties which were not impacted but the grounds of the property were, and the lengths of flood affected roads. It should be noted that only sealed roads were assessed due to the availability of associated costs for flood damages. The damages assessment table is shown in Figure 6-11.



EXISTING CONDITIONS

ARI (years) AEP	PMF 0.000001	2000yr 0.0005	500yr 0.002	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Residential Buildings Flooded Above Floor	229	76	55	40	35	26	18	6	2
Commercial Buildings Flooded Above Floor	120	74	61	53	39	31	20	10	4
Properties Flooded Below Floor	3065	1701	1480	1330	1206	1106	941	833	677
Total Properties Flooded	**3414**	**1851**	**1596**	**1423**	**1280**	**1163**	**979**	**849**	**683**
Direct Potential External Damage Cost	$15,384,349	$6,578,893	$5,233,488	$4,387,096	$3,771,692	$3,097,008	$2,439,456	$1,870,356	$1,109,741
Direct Potential Residential Damage Cost	$18,605,144	$5,251,173	$3,634,449	$2,570,805	$2,219,543	$1,574,916	$967,140	$353,298	$118,283
Direct Potential Commercial Damage Cost	$11,890,755	$2,292,506	$1,348,945	$870,815	$581,386	$344,837	$201,762	$87,543	$43,475
Total Direct Potential Damage Cost	**$45,880,248**	**$14,122,572**	**$10,216,882**	**$7,828,716**	**$6,572,621**	**$5,016,761**	**$3,608,358**	**$2,311,197**	**$1,271,499**
Total Actual Damage Cost *(0.8*Potential)*	**$36,704,198**	**$11,298,058**	**$8,173,506**	**$6,262,973**	**$5,258,097**	**$4,013,409**	**$2,886,686**	**$1,848,958**	**$1,017,199**
Infrastructure Damage Cost	**$7,436,748**	**$4,345,748**	**$3,442,512**	**$2,756,171**	**$2,222,780**	**$1,640,187**	**$1,015,134**	**$733,497**	**$285,929**
Indirect Clean Up Cost									
Indirect Residential Relocation Cost									
Indirect Emergency Response Cost									
Total Indirect Cost	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Cost	**$44,140,946**	**$15,643,806**	**$11,616,017**	**$9,019,143**	**$7,480,876**	**$5,653,596**	**$3,901,820**	**$2,582,455**	**$1,303,129**

Average Annual Damage (AAD)	$672,954

Figure 6-11 Existing conditions Average Annual Damage (AAD)

]

6.5 Structural Flood Mitigation

6.5.1 Overview

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

- Increasing the storage capacity and improving capture for seven detention basins within Stawell including:
  - Grant Street dam.
  - Taylors Gully Park dam.
  - Cooper Street dam.
  - Lake Cato.
  - Maude Street dams 3 and 4.
  - Duke Street dam.
- Lowering the Stawell Main Drain 500 mm across the entire width from the Curtis Street dams to the exit into Pleasant Creek
- Doubling the culvert crossing capacity at 11 locations in the Pleasant Creek and Jerrywell Creek catchments

The options were investigated separately and are discussed below.

6.5.2 Option 1: Increased dam storage capacity

Seven existing detention basins and dams were lowered and/or expanded. In some instances, levees and drains diverting water towards the storage were adjusted to improve capture of overland flow. Figure 6-12 shows a difference plot comparing the existing and proposed mitigation scenario water levels. For Lake Cato, only the bed level was lowered to accommodate more volume. The results show generally reduced flood levels in the flow paths through the upgraded dams. Flood extents are slightly reduced but not enough to reduce the number of roads overtopped in the 1% AEP scenario.

6.5.3 Option 2: Increased Main Drain channel capacity

The bed level of the Stawell Main Drain was lowered 500 mm across its entire width from the Curtis Street dams to the confluence with Pleasant Creek. Figure 6-13 shows a difference plot comparing the existing and proposed mitigation scenario water levels. The results show reduced flood levels in the lowered drain, as well as in the industrial and residential area bound by the Main Drain to the east and Smith Street to the north.

6.5.4 Option 3: Increased culvert capacity

11 culvert locations with insufficient capacity were identified. Culvert capacity was doubled, and in locations where no culvert was present, a culvert was added with dimensions based on similar crossing sizes. Figure 6-14 and Figure 6-15 shows a difference plot comparing the existing and proposed mitigation scenario water levels for both the Stawell township and golf course catchments respectively. Capacity increases showed very limited positive flood level impacts, with localised increases and decreases in flood levels immediately upstream and downstream of the culvert locations. Only one additional road crossing is flood free in the 1% AEP scenario.

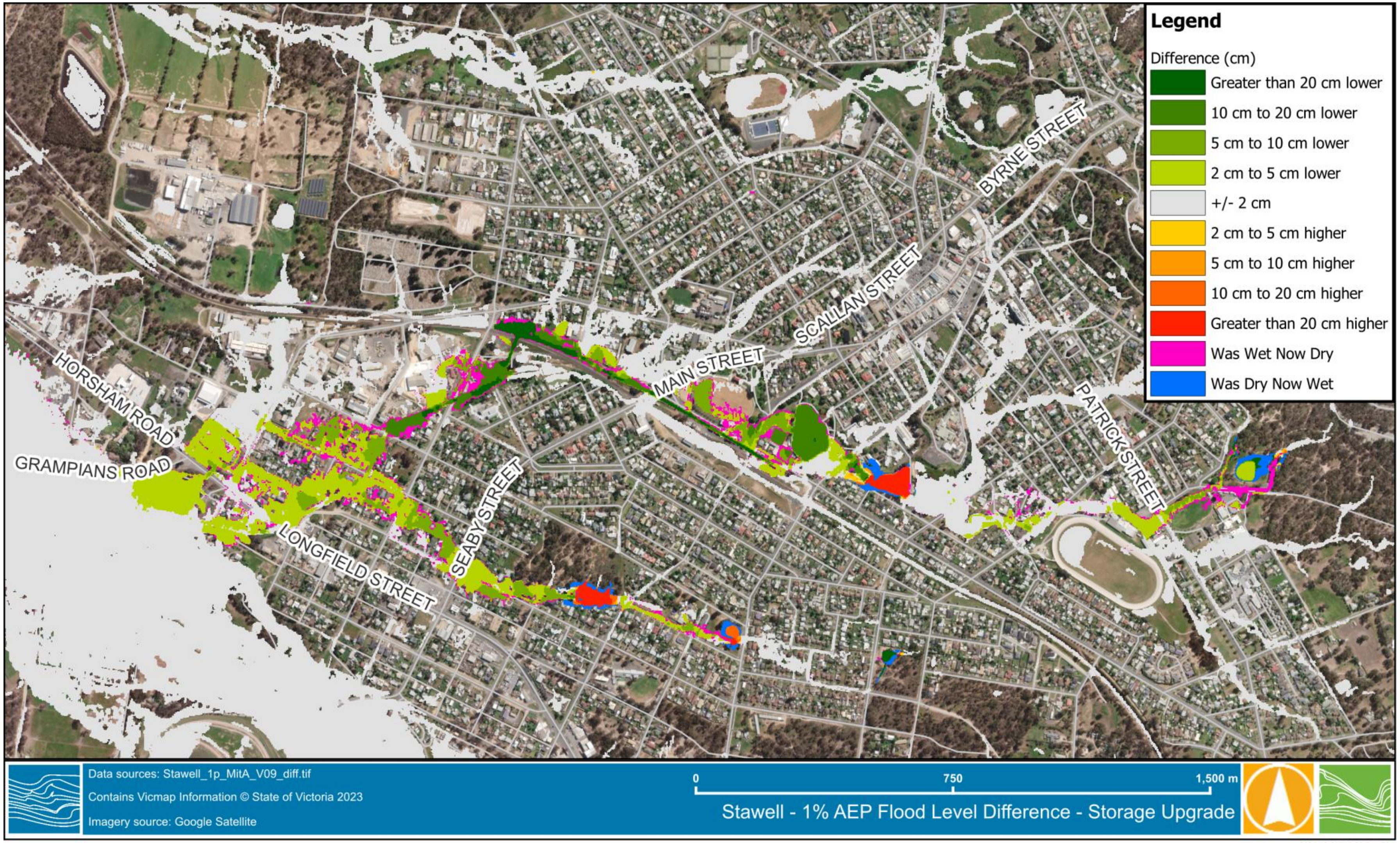


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Figure 6-12 1% AEP flood level difference – Storage upgrade

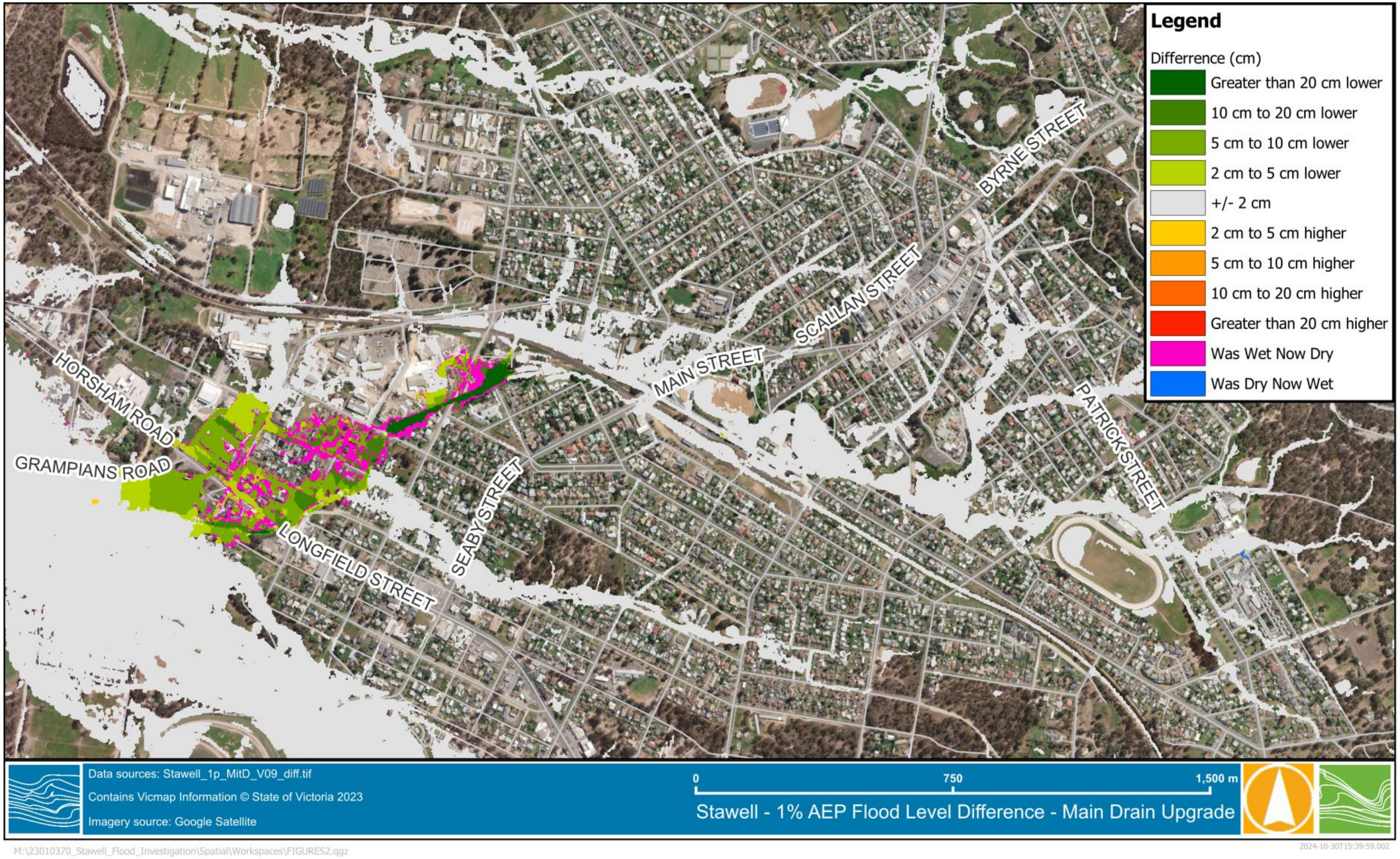
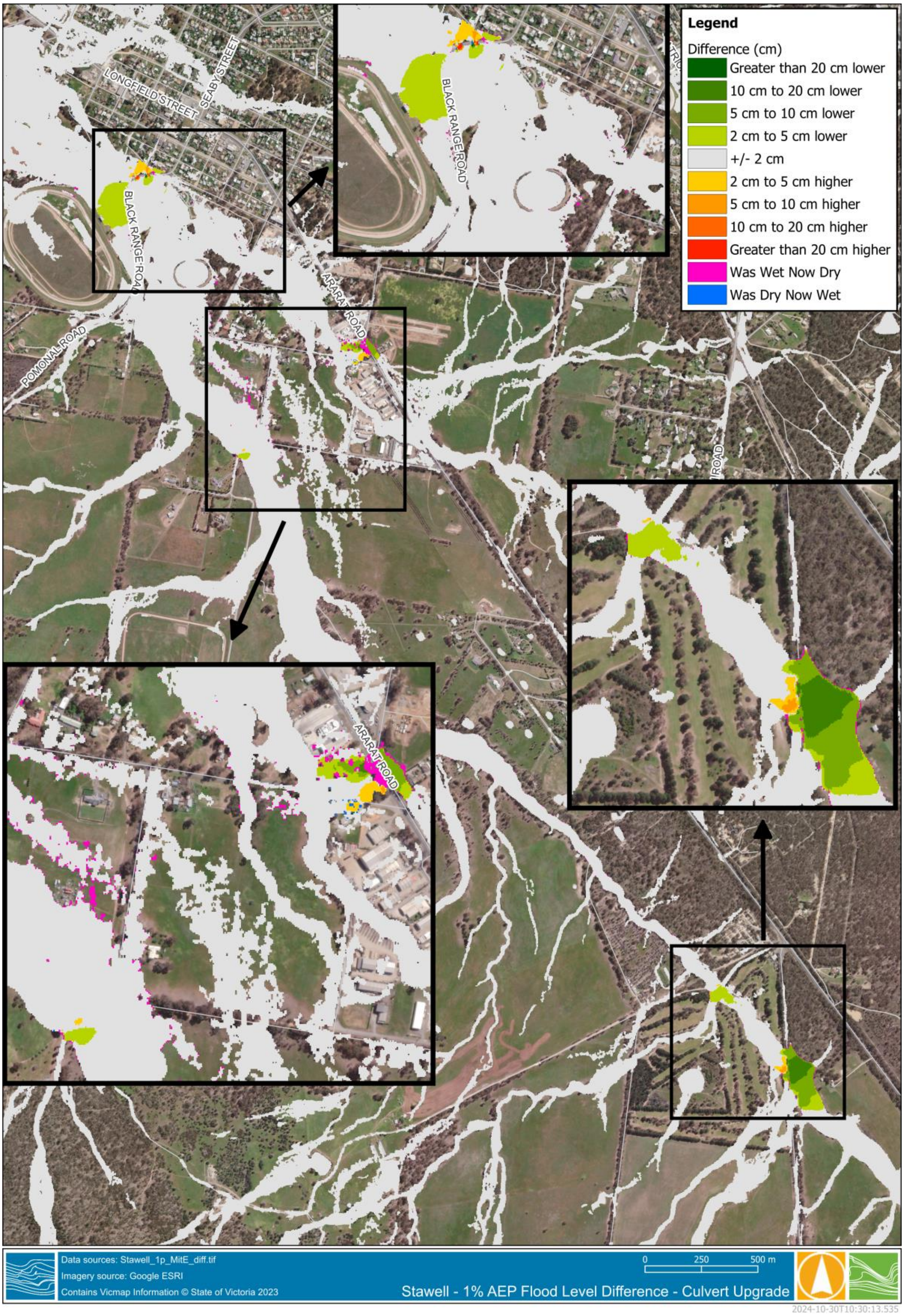


Figure 6-13 1% AEP flood level difference – Main Drain upgrade



Data sources: Stawell_1p_MitE_diff.tif
Imagery source: Google ESRI
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Figure 6-14 1% AEP flood level difference – Culvert upgrade – Pleasant Creek

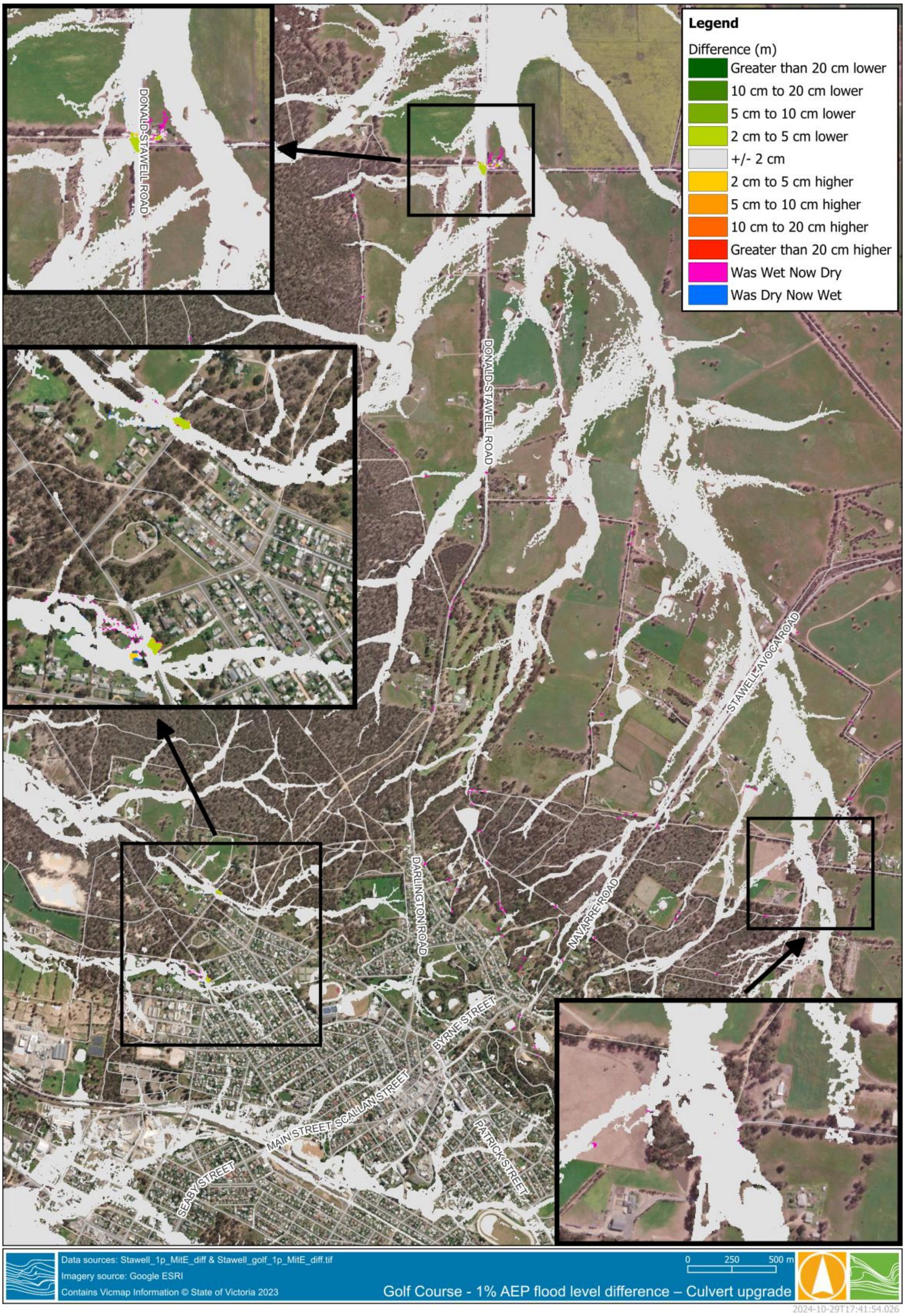

Figure 6-15 1% AEP flood level difference – Culvert upgrade – Stawell and golf course catchment

6.5.5 Cost-benefit analysis

Based on the initial feasibility screening and discussions with NGSC, it was determined to assess a combination of the increased dam storages and the increased Main Drain capacity for the full range of design events. The model results were processed to assess the new AAD for Stawell under the mitigated scenario, providing an annual reduction of $103,363.

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. More detailed investigation could be undertaken to assess components of the mitigation option individually to target flood mitigation works.

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. Currently there is only LSIO and FO developed for Stawell along Pleasant Creek based on the Mt William Creek Flood Investigation (2014) and along Jerrywell Creek based on the Concongella Creek Regional Flood Mapping project (2014). There is no SBO for the study area. Planning overlays will be developed as direct outcomes from this study. Updating the planning scheme mapping allows development applications within the floodplain to be assessed in line with current national, state, regional and local policies and guidelines. The ultimate effect of this will be to discourage inappropriate development within the floodplain, reducing the number of future buildings and occupants exposed to flood risk.

7 SUMMARY

The Stawell Flood Investigation has produced detailed flood modelling of Pleasant Creek, the Stawell township and Jerrywell Creek. 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 AAD and the potential for structural mitigation to reduce those damages. Flood intelligence products were produced and included in a draft update to the Northern Grampians Municipal Emergency Management Plan, these are detailed in the Flood Intelligence and Warning Report (R04).

Recommendations from the Stawell Flood Investigation 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 reflect the flood risk mapping produced by this project.
  - 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. Consider extending climate change modelling to include the updated ARR 4.2 guidelines.
  - Discuss with the BoM and Wimmera CMA 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.
  - Consider targeted structural flood mitigation works.
  - Consider the application of rainfall based radar products to improve the spatial understanding of rainfall and rainfall depths across Stawell and contributing catchments.
- Wimmera CMA:
  - 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 Wimmera 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 Stawell 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 should be considered.

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