WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Summary Report

St Arnaud Flood Investigation

Northern Grampians Shire Council

14 August 2022

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14 August 2022

Nic Murphy
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Via email nic.murphy@ngshire.vic.gov.au

Dear Nic,

St Arnaud Flood Investigation

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

- R01 – Data Collation and Review Report.
- R02 – Model Calibration Report.
- R03 – Design Modelling Report.
- R04 – Flood Mitigation Report.
- R05 – Flood Intelligence Report.
- R06 – Flood Warning Report.
- **R07 – Summary Report (this report).**

Water Technology would specifically like to thank the Northern Grampians Shire Council and the St Arnaud 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.

If you have any queries, please don't hesitate to contact me.

Yours sincerely

Ben Hughes
Principal Engineer

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1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Northern Grampians Shire Council to undertake the St Arnaud Flood Investigation. The project aimed to provide accurate flood mapping within the township of St Arnaud and consider how flood risk can be best managed through the development of mitigation options, improved flood intelligence and emergency response planning.

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 Collation and Review Report.
- R02 – Model Calibration Report.
- R03 – Design Modelling Report.
- R04 – Flood Mitigation Report.
- R05 – Flood Intelligence Report.
- R06 – Flood Warning Report.
- R07 – Summary Report, Mapping and Data Deliverables (this report).

1.2 Project Objectives

The objectives of this study are described below.

- Define flood related controls in the Northern Grampians Planning Scheme.
- Develop flood intelligence products and inform emergency response planning.
- Investigate opportunities for flood mitigation works and activities.
- Assist in the preparation of community flood awareness and education products.
- Assess feasibility for improved flood warning arrangements.
- Support the assessment of flood risk for insurance purposes.

1.3 Study Area

St Arnaud Creek, a tributary of Lexel Creek (shown in Figure 1-1), is the major waterway flowing through St Arnaud. The waterway is highly modified from its natural form, with sections of constructed open, lined and earthen channel. The waterway begins to the north west of St Arnaud, flowing underneath the railway line and the St Arnaud-Wycheproof Road adjacent to North Central Farm Trees. Much of the upstream catchment from this point is vegetated. The total modelled area including the St Arnaud and Lexel Creek catchments is 35 km^2.

Most recently the area was affected by flooding in January 2011, November 2018 and November 2021 when large number of homes and shops were impacted.

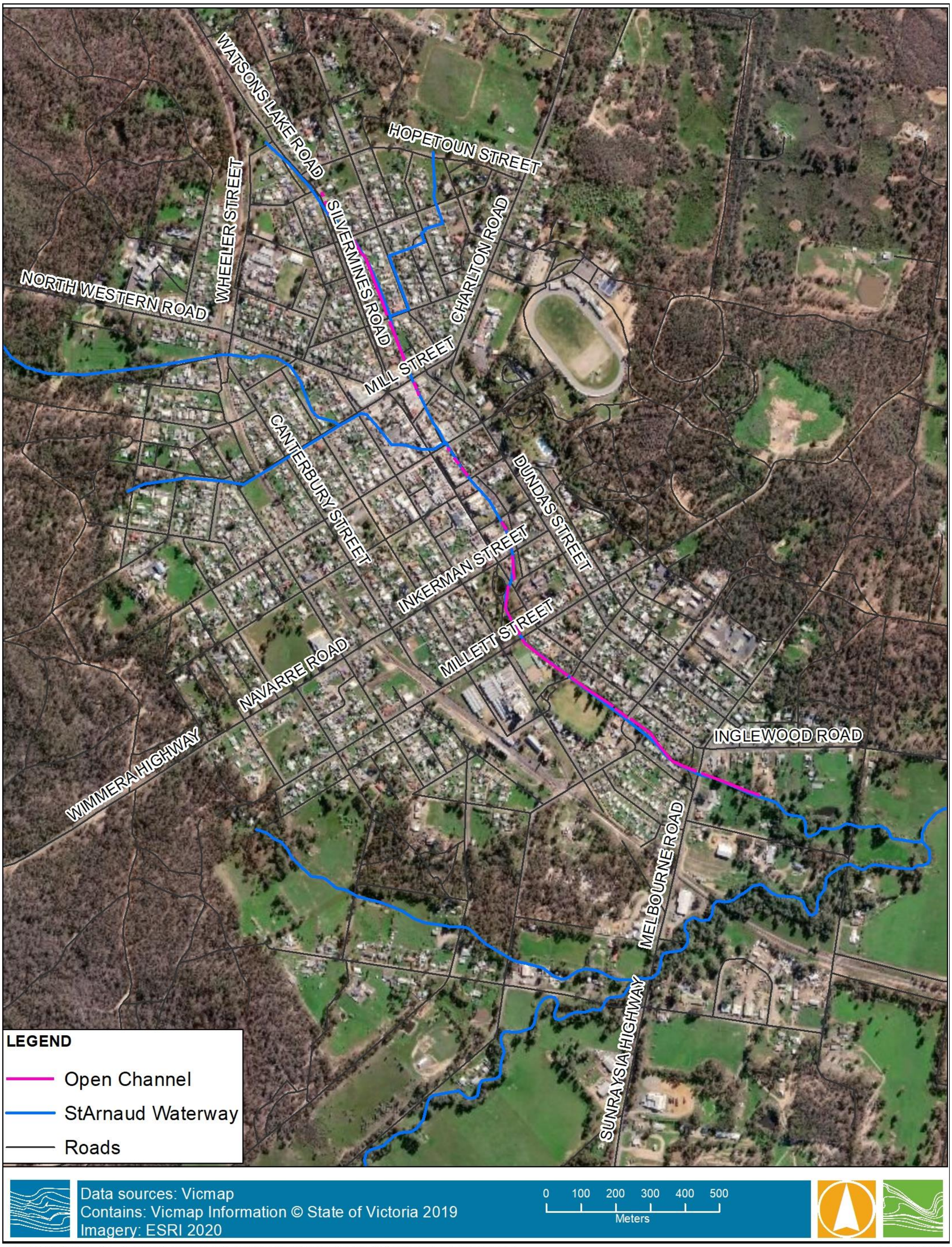

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FIGURE 1-1 ST ARNAUD WATERWAYS

2 DATA COLLATION, VERIFCATION AND METHODOLOGY

The Data Collation and Verification Report *(R01* - Data Collation and Verification) provided an overview of the available existing data and methodology which was used to complete the study. The data review identified and collated the following:

- Rainfall and streamflow data.
- Drainage infrastructure.
- Historic flood information.
- Topography data and verification of the data accuracy.
  - Floodplain 1m LiDAR
    - The floodplain LiDAR was shown to have a low spread of differences when compared to the survey data, ranging from 0 to 200m. On average the LiDAR was around 100mm higher than the feature survey. This is within the expected accuracy of the dataset.
  - GWMWater 2m LiDAR
    - The GWMWater LiDAR was shown to have a low spread of differences when compared to the surveyed data, ranging from -150mm to 50mm. On average the LiDAR was around 50mm lower than the feature survey. This is within the expected accuracy of the dataset.
  - NCCMA 5m LiDAR
    - The NCCMA 5m LiDAR had a larger spread of differences, ranging from 0.4m higher than the surveyed data to 3.8m lower than the surveyed data. On average the LiDAR was 0.6 to 0.8m lower than the surveyed levels. DELWP 10m DTM
  - The DELWP 10m DTM had the largest spread of differences comparing the topography to the feature survey, ranging from -700mm to 500mm. On average the LiDAR was around 0.1m higher than that surveyed.

A review of the 1m Floodplains and 2m GWMWater data showed the 1m data gave a better representation of the defined channel infrastructure, not only due to an increased resolution but better represented the location of channels.

2.1 Summary

The report detailed the thorough data review process undertaken and identified several gaps in the available data with appropriate methods to overcome these issues. The major data gaps included detail of the main St Arnaud Creek channel.

Feature survey was collected across the study area to fill some of these data gaps, as well as to validate the LiDAR used in the study. The LiDAR dataset was compared against transect survey of Edwards Street, Raglan Street, Dundas Street. Review of the 1m Floodplains and 2m GWMWater data showed the 1m data gave a better representation of the defined channel infrastructure, not only due to an increased resolution but better represented the location of channels.

3 MODEL DEVELOPMENT

3.1 Overview

The Calibration Report *(R02 – Hydrology/Hydraulic Calibration Report)* discussed the modelling methodology. A joint hydrology/hydraulic calibration approach was adopted for the following reasons:

- There was no available streamflow information for the St Arnaud Creek catchment.
- There were no available flow estimates of historical flood events.
- The joint calibration approach allowed for the uncertainties in both flow estimation and hydraulic model behaviour to be combined, with both models evaluated against the known flood observations (i.e. flood heights, extents, photos, etc).

3.2 Hydrology

The hydrologic assessment used a rainfall-runoff approach using the RORB software package. The RORB model produced hydrographs which were then used as inflow boundaries to the hydraulic TUFLOW model. The RORB model schematisation is shown in Figure 3-1, representing the broader catchment, smaller sub-catchments and reaches.

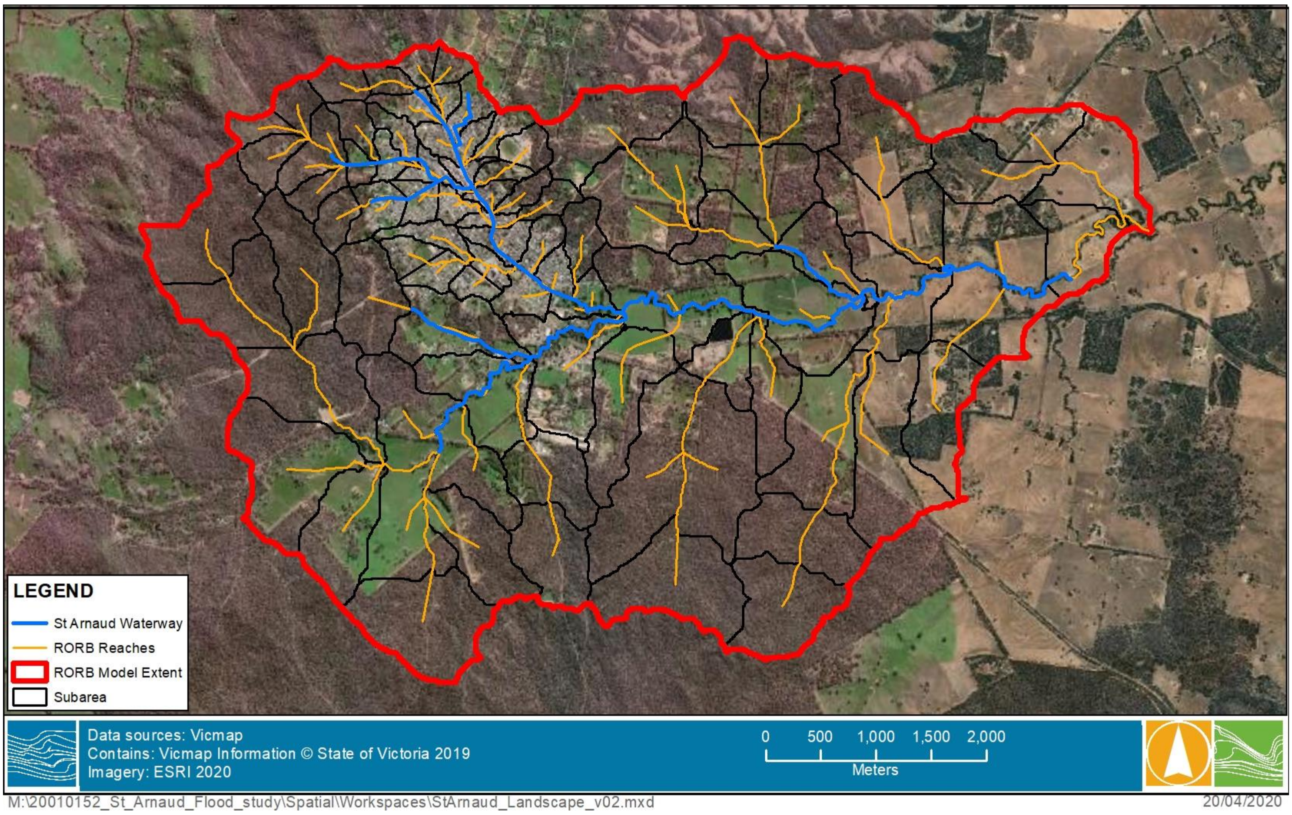

FIGURE 3-1 RORB MODEL SCHEMATISATION

3.3 Hydraulics

A hydraulic model of the St Arnaud township and Lexel Creek was built using the TUFLOW HPC software modelling package. A model with a 3 metre grid resolution was developed with multiple inflow boundaries applied to represent runoff from local catchments into several waterways, with the key feature being the St Arnaud Creek open channel running through the township. Hydraulic structures including culverts and open

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drains were incorporated into the model and modelled as 1D structures. The model topography was developed using a combination of validated LiDAR collected from 2006 (2 m resolution) and 2011 (1 m resolution).

The model structure and extent is shown in Figure 3-2.

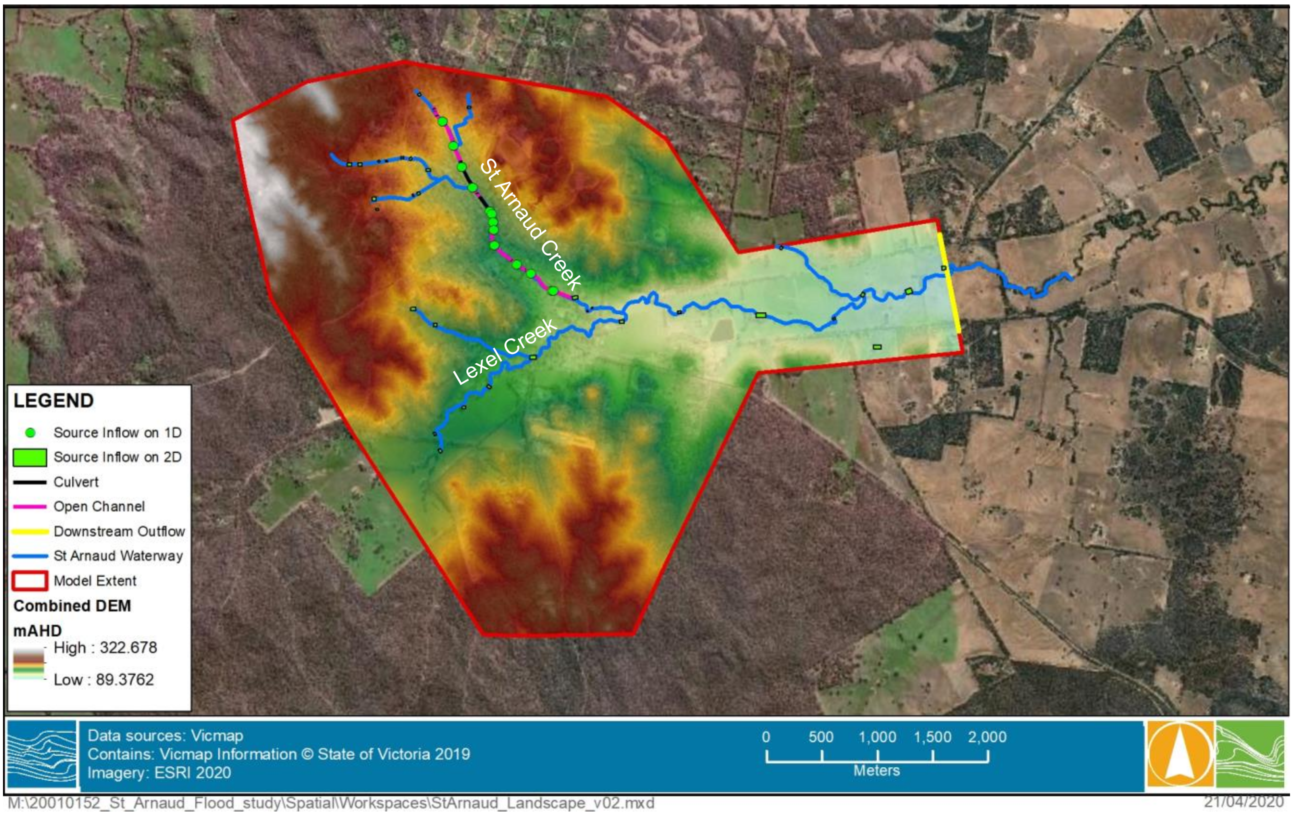

FIGURE 3-2 HYDRAULIC MODEL EXTENT, TOPOGRAPHY AND BOUNDARIES

4 MODEL CALIBRATION

Through the calibration phase drainage infrastructure throughout the township was incorporated into the model to better estimate hydraulic controls and flood behaviour (hydraulic modelling) for the range of modelled flood events. The extensive calibration provided confidence that the models were producing realistic results and ensured the design modelling results were fit for purpose.

The calibration process was able to replicate the observed 2018 flooding with the modelled flood depths shown in Figure 4-1. Due to the business disruption caused by COVID-19 and implementing social distancing practice, community consultation moved to an online mapping portal. The calibrated results for flood depth were made available online through ArcGIS online platform for the St Arnaud community and adjustments were made based on the feedback received.

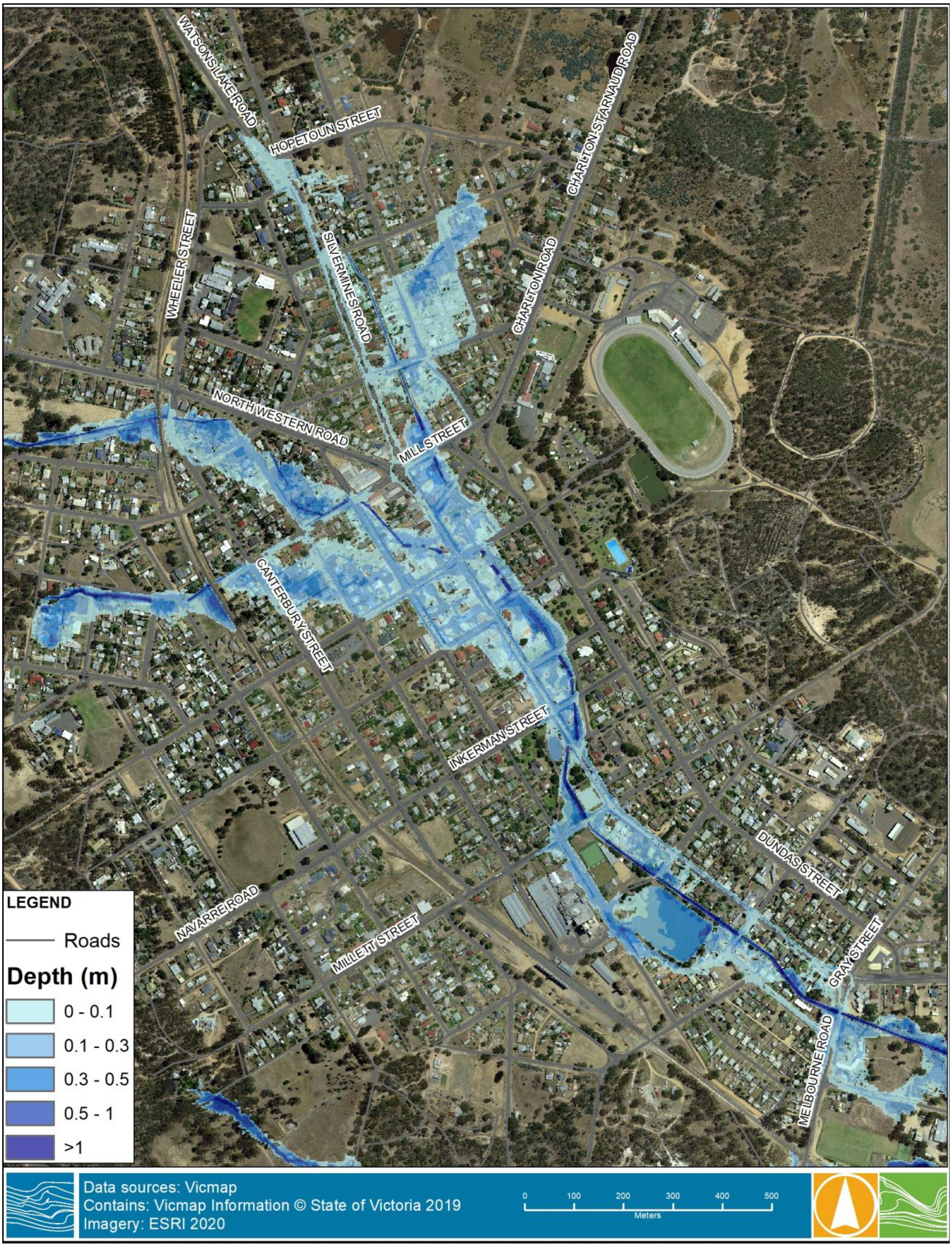

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FIGURE 4-1 ST ARNAUD TOWNSHIP DEPTH PLOT FOR NOVEMBER 2018 EVENT

4.1 Summary

The joint calibration process showed the combination of hydraulic and hydrologic modelling was suitable to replicate major flood events. The calibration process relied heavily on recorded flood marks, ground-based photography and anecdotal observations. The hydrology model parameters adopted (initial loss, continuing loss and kc) were within reasonable ranges based on the regional parameters documented in Australian Rainfall and Runoff (ARR2019) and the RORB regional approximation equations. The results of the joint calibration validate the parameters adopted in both the RORB and TUFLOW models.

5 DESIGN MODELLING

5.1 Hydrology

In line with the methodology outlined in Australian Rainfall and Runoff 2019 (AR&R 2019), a Monte Carlo simulation was first used to determine the design peak flows and the corresponding critical durations at selected key locations. RORB was then run using the Ensemble simulation approach for the critical durations identified by Monte Carlo simulation (i.e. modelling ten temporal patterns per AEP event). The temporal pattern which produces the median peak flow was chosen for design modelling for each AEP event, as suggested by AR&R 2019. The process flow chart of this approach is shown in Figure 5-1.

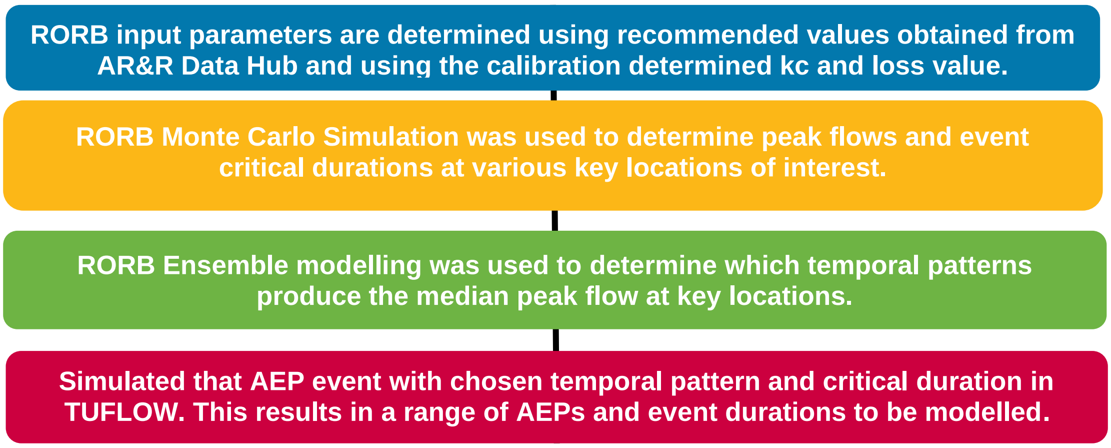

FIGURE 5-1 DESIGN MODELLING PROCESS DIAGRAM

The RORB design modelling inputs were obtained via the AR&R Data Hub[1] using the coordinates of the St Arnaud and Lexel Creek catchment centroid. An initial/continuing loss model was applied for the RORB modelling. Losses were determined based on flood modelling results for a large number for catchments across Australia using the ARR online datahub. The suggested losses were 29 mm initial loss and 4 mm/hr continuing loss. However, findings in previous studies near the site[2] and the hydraulic model calibration determined lower losses and a continuing loss of 2.5 mm/hr was adopted along with the recommended initial loss of 29 mm.

The RORB Monte Carlo analysis was undertaken for St Arnaud catchment. During a Monte Carlo Simulation run, the RORB model is run many times, sampling for an extensive range of temporal patterns and rainfall initial losses. This is completed in combination with the other set of model parameters of spatial pattern, continuing loss, aerial reduction factors, k_c and m. The model then utilised the hydrographs from all modelled runs and produces a statistical design peak flow and the corresponding critical duration at each RORB output location.

The RORB model was also run using Ensemble simulation, using the determined k_c value and the same predefined losses applied in Monte Carlo analysis. The Ensemble simulation allows the RORB model to run for all 10 AR&R 2019 recommended temporal patterns for each event duration. Based on the peak flows and critical durations determined in the Monte Carlo analysis, a temporal pattern from the Ensemble analysis was chosen which produces the median peak flow. This comparison of peak flows between the Monte Carlo and Ensemble analysis was completed at each location of interest to ensure they are within an acceptable range

[1] http://data.arr-software.org/
[2] BMT (2014) – Charlton Flood Investigation (Prepared for North Central CMA)

5.2 Hydraulics

Design flood modelling for the 50%, 20%, 10%, 5%, 1%, 0.5% and 0.2% AEP events and the Probable Maximum Flood (PMF) event was completed using the calibrated hydraulic model. Flood modelling outputs will inform flood emergency response improvement and planning, and will be used to guide future land use development.

The maximum flood extents for the full range modelled AEP events across the St Arnaud township and broader area are shown in Figure 5-2 and Figure 5-3 respectively.

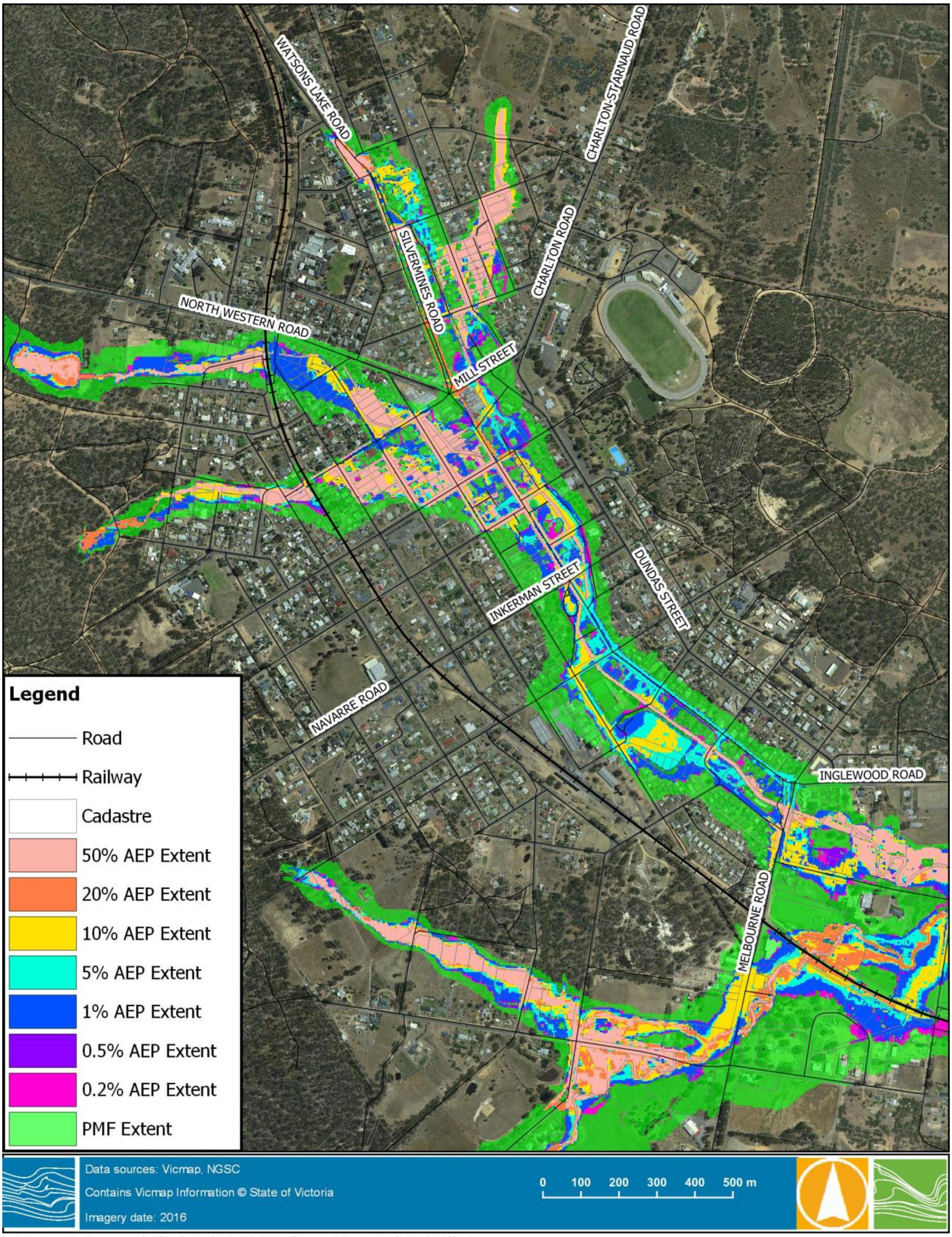

FIGURE 5-2 DESIGN MODELLING EXTENT – ST ARNAUD TOWNSHIP

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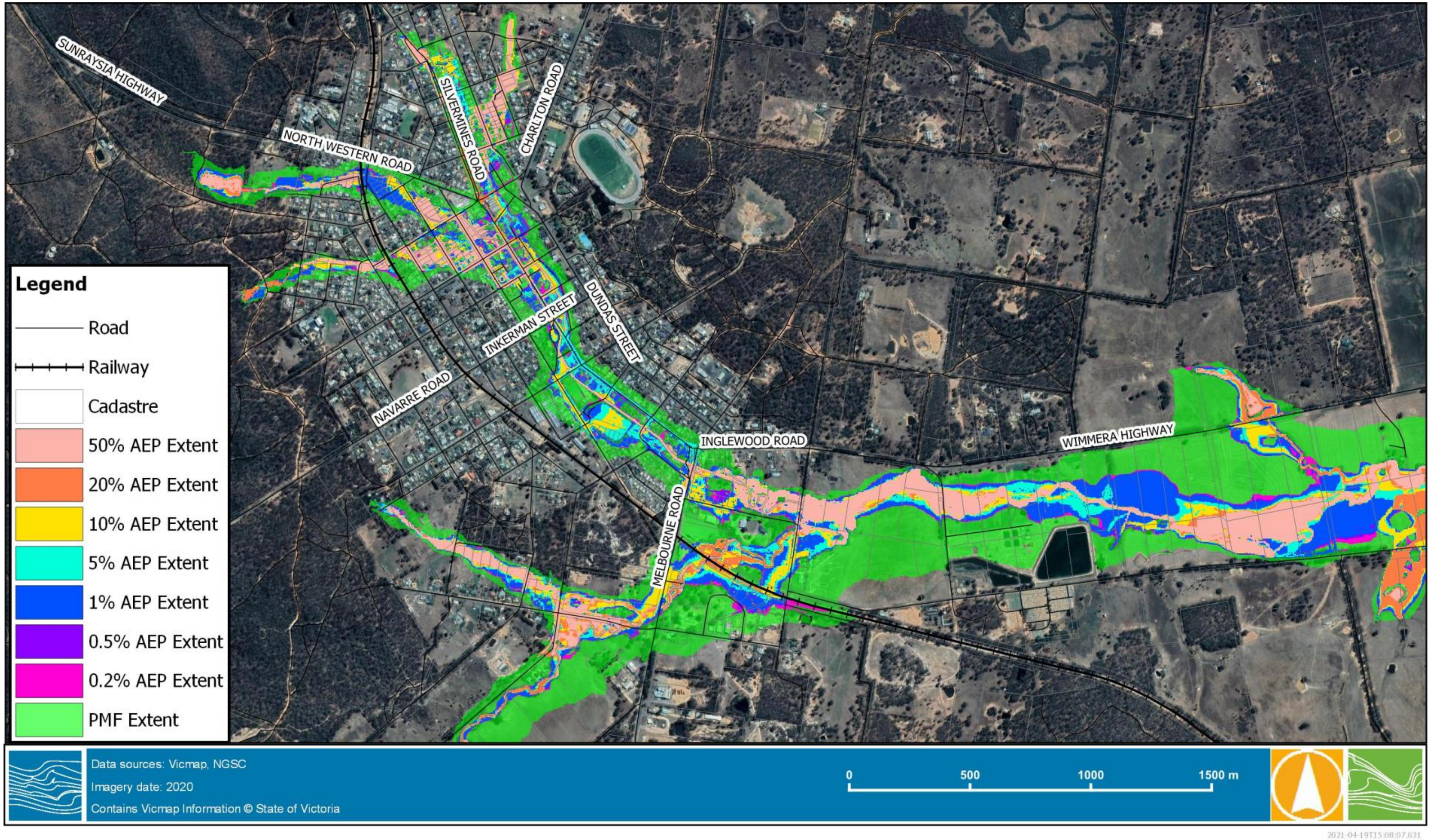

FIGURE 5-3 DESIGN MODELLING EXTENT

5.3 Design Flood Behaviour

A summary of flood behaviour across the St Arnaud study area is provided in this section for each modelled design AEP event. Detailed road inundation and flood damage assessment will be undertaken in the Flood Intelligence Report.

- 50% AEP
  - No overbank flow from the main channel within St Arnaud Township.
  - Shallow water found across the residential area between Edwards Street to Powell Street.
  - Water flows along Mill Street from the west then breaks out from the roadside drain at Canterbury Street and McMahons Street. After that, the overland flow goes along the Napier Street and joins the main channel after Inkerman Street.
  - Water generally confines within the Lexel Creek.
- 20% AEP
  - Water flows in the roadside drain along Silvermines Road, joining the main channel at Alma Street.
  - A minor ponding at intersection of Lexel Creek and railway.
- 10% AEP
  - Shallow breakout flow observed near Brisbane Street impacting several houses.
  - Minor breakout from the main channel at Millett Street.
  - Minor breakout from the Lexel Creek overtopping the Melbourne Road.
- 5% AEP
  - Minor breakout at the start of the main channel.
  - Overland flow occurs at Jennings Street from the main channel, flowing along the Kings Avenue.
  - King Georges Park is filled with water coming off McMahon Street.
- 1% AEP
  - Greater extent of overland flow near Brisbane Street is observed.
  - Overtopping at Walker Street exceeds 0.3 m.
  - Kings Avenue is overtopped, impacting several houses by backwater.
  - Flow velocity along the road exceeds 0.5 m/s and 1 m/s within the side drain.
  - Flood hazard is generally low within residential area, with a few pockets of area classified by H2 – unsafe for small vehicles.
- 0.5% AEP
  - Extent is similar to 1% AEP, with depth greater by 0.01 – 0.03 m within St Arnaud.
- 0.2% AEP
  - Extent is similar to 0.5% AEP, with depth greater by 0.01 – 0.03 m within St Arnaud.
  - Hazard at Walker Street reaches H2 - unsafe for small vehicles.
- PMF
  - The St Arnaud township is significantly inundated along the determined waterways.
  - Roads and railway are significantly overtopped.

- Hazards within residential area are generally H3 – unsafe for vehicles, children and elderly.
- Hazards along the roads and channel are H5 – unsafe for vehicles and people. All buildings vulnerable to structural damage.

5.4 Sensitivity Analysis

5.4.1 Overview

The hydrologic and hydraulic modelling are based on various assumptions. It is good practice to understand the sensitivity of the model results to these assumptions. This section presents a series of sensitivity analysis undertaken to evaluate the variation of the model results relating to these assumptions.

Sensitivity tests undertaken at part of this assessment included:

- Hydraulic Roughness.
- Structural Blockage.
- Climate change

The following sections detail each sensitivity analysis undertaken and a summary of the outcomes. Mapping of these outcomes can be found in the Design Modelling Report *(R03 - Design Modelling Report)*.

5.4.2 Hydraulic Roughness

The hydraulic roughness within TUFLOW is expressed as a roughness coefficient Manning's "n" which was estimated based on aerial imagery and land use classification. Flood velocity is strongly dependent on the surface resistance to flow. For instance, where a high roughness coefficient is applied to a section of St Arnaud with heavy vegetation, this would result in low flood velocity and generally high water level.

The adopted hydraulic roughness coefficients were detailed in this report. To quantify the impact of hydraulic roughness coefficient on hydraulic modelling as a result of future changes in land use types, the roughness coefficients were increased and decreased by 20% and were modelled for the 1% AEP event. Difference plots were created to present the impacts of changing hydraulic roughness coefficient.

A hydraulic roughness coefficient increase by 20% within St Arnaud resulted in an approximately 2 to 4 cm increase in water level, predominantly north of Inkerman Street in a 1% AEP event. No significant increase to the flood extent was observed within the township.

A hydraulic roughness coefficient decreased by 20% within St Arnaud resulted in an approximately 1 to 3 cm decrease in water level, predominantly north of Inkerman Street for a 1% AEP event. There wsa a minor decrease at the edge of flood extent as a result of water moving faster.

5.4.3 Structure blockage

The performance of structures within the drainage network is heavily impact by blocked from debris and asset failure.

Blockage of drainage was completed as sensitivity test in line with current AR&A 2019 standards for this reason. The details of modelled drainage infrastructure including pits, pipes, culverts and open channel are outlined in this report. A conservative uniform approach was adopted with a 50% blockage factor applied to all modelled 1D components.

The blockage caused a general water level increase ranging from 2 to 10 cm around the drainage infrastructure. However, water levels were slightly decreased around Mill Street as a result of less water flowing from the upstream culverts. There were only minor changes in flood extent, which becomes slightly larger at the location of major culverts, immediately upstream of the railway.

5.4.4 Climate Change Projection

At the time the scope of the project was defined, climate change was incorporated into the project brief as a sensitivity test. The objective of this analysis was to understand how vulnerable the study area is to the potential impacts of predicted changes to climatic conditions. By gaining an understanding of the catchment sensitivity to these changes, future impacts can be considered and the information relied upon for decision-making.

Model runs included projected increased rainfall intensity based on Representative Concentration Pathway (RCP) 4.5 and 8.5 for year 2090. The sensitivity of flood behaviour for all the design events to the two projected climate change scenarios were modelled in RORB, with the input hydrographs of the 1% AEP events 36-hour and 96-hour durations extracted for the hydraulic modelling.

The Climate Change Factors of the RCP4.5 and RCP8.5 scenarios for year 2090 were obtained from the AR & R Data Hub in accordance with the values from the Climate Change in Australia website. The IFD design rainfall depths were updated with the climate change factors for the respective climate change scenarios and the full range of design events. The recommended increased rainfall intensity due to the climate change scenarios for year 2090 is summarised below.

TABLE 5-1 THE INCREASE OF RAINFALL INTENSITY UNDER CLIMATE CHANGE SCENARIOS TO 2090

Year of projection	RCP4.5	RCP8.5
2090	9.2%	20.2%

The climate scenarios were modelled in RORB with the results showing maximum increases in design peak flows at key locations ranging from 10% to 25% (RCP4.5 for year 2090) through to a 20% to 50% increases in peak flows (RCP8.5 for year 2090).

The 1% AEP climate change hydraulic modelling results showed as average increase in flood ranged from 12cm (RCP4.5 for year 2090) to 25cm (RCP8.5 for year 2090) within St Arnaud.

6 FLOOD DAMAGE AND MITIGATION ASSESSMENT

6.1 Overview

Detail around the flood damage and mitigation potential in St Arnaud is documented in the Flood Damage and Mitigation Report *(R05 - Flood Damage and Mitigation Report)*. The nature of the flooding in St Arnaud is such that short duration storm events (e.g. less than 4-6hrs) are the likely to cause flooding and are considered to be "flash flooding" type events. St Arnaud has experienced flash flooding several times over its history. Between 90 and 100 mm of rainfall was recorded in a single day in January 2011 and over 50 mm was recorded over 1 hour in November 2018. These events caused flash flooding in St Arnaud, damaging shops and houses located in proximity to the major waterway.

To classify the impact of flooding and risk to the St Arnaud community, hydraulic flood model results were used to determine the properties and assets likely to be inundated during a range of design events (50% to 0.2% AEP). Given the size of the project area and the nature of flash flooding, the event durations which generate the maximum flood levels and depths vary from 1 to 6 hours.

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. 50% AEP). The roads which are inundated by flooding in events ranging from 50% to 0.2% AEP events and listed by name in the Flood Intelligence Report *(R04 – Flood Intelligence Report)*, these roads are shown in Figure 6-1 and Figure 6-2 for the township and downstream rural area.

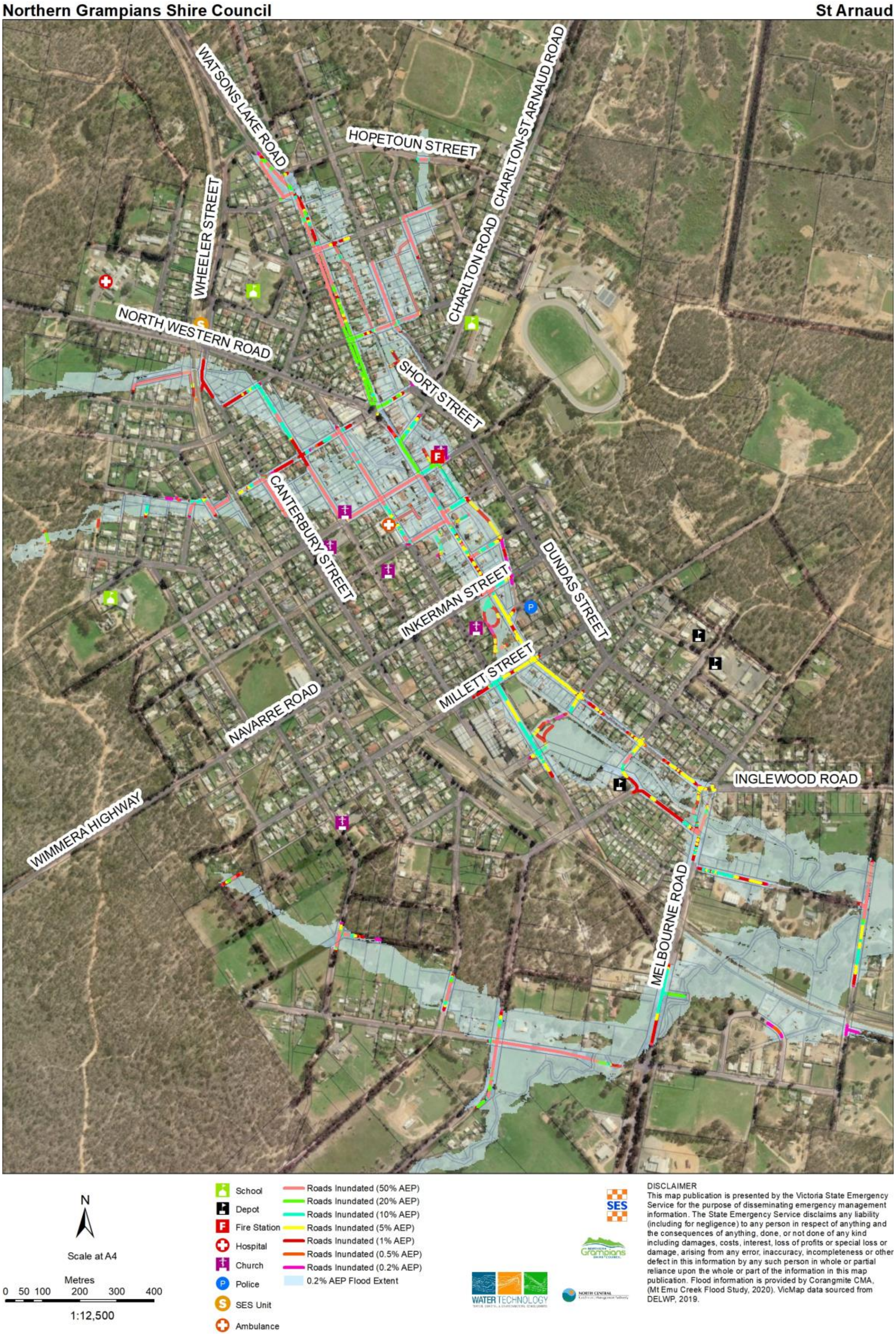

FIGURE 6-1 ST ARNAUD INUNDATED ROADS – TOWNSHIP

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FIGURE 6-2 ST ARNAUD INUNDATED ROADS – RURAL

6.3 Property inundation

Floor level survey of 460 residential and commercial buildings was captured within the study area, including 117 commercial and 343 residential buildings. These buildings were selected for survey based on the preliminary flood modelling undertaken during the early phases of 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 floor level of was captured for each property, outbuildings were not surveyed (i.e. sheds). 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 but do not have an associated building i.e. vacant lots, farm paddocks etc.

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

- Property flooded below floor.
  - This indicates the flood level is below the surveyed floor level but there is inundation of a lot with a surveyed floor level (the inundation might not be under the building but on the lot).
- Property flooded above floor.
  - This indicates the flood level is above the surveyed floor level.

The existing conditions 0.5% AEP flood extent and the properties flooded above floor during the range of modelled design events are shown in Figure 6-3.

Figure 6-3 Flooded Properties at St Arnaud

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6.4 Damage Assessment

A flood damage assessment was undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damage for the range of modelled design events (i.e. 50%, 20%, 10%, 5%, 1%, 0.5% and 0.2% AEP floods).

Model results for all mapped flood events were processed to calculate the number and the locations of properties and roads affected. This included properties inundated above floor, below floor, properties which did not have buildings 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 damage occurring in each of the modelled events has been used to calculate an Average Annual Damage (AAD) for the study area, this is the amount of funding required to be set aside to repair flood damage. It does not include the emotional or mental health cost of flooding which can be significant.

A summary of the flood damage cost to affected roads is included in Section 6.2. The AAD of the study area has been calculated as $395,000.

TABLE 6-1 EXISTING CONDITIONS FLOOD DAMAGES FOR AFFECTED ROADS

	Length Sealed Road (km)		Cost of Damages		
Event	**Major**	**Minor**	**Major**	**Minor**	**Total**
PMF	3.6	13.6	$347,347	$416,047	$763,394
500y	1.9	7.6	$184,580	$233,274	$417,854
200y	1.8	7.3	$179,994	$222,181	$402,175
100y	1.8	7.1	$177,235	$217,275	$394,511
20y	1.5	5.6	$144,284	$171,578	$315,862
10y	1.3	4.3	$124,568	$131,926	$256,493
5y	1.0	3.0	$93,749	$90,690	$184,440
2y	0.3	1.9	$29,125	$58,341	$87,466

TABLE 6-2 EXISTING CONDITIONS FLOOD DAMAGES FOR AFFECTED PROPERTIES

EXISTING CONDITIONS							
ARI (years)	500yr	200yr	100yr	20yr	10yr	5yr	2yr
AEP	0.002	0.005	0.01	0.05	0.1	0.2	0.5
Residential Buildings Flooded Above Floor	18	14	12	2	0	0	0
Commercial Buildings Flooded Above Floor	41	33	24	12	4	2	1
Properties Flooded Below Floor	726	715	710	665	567	434	349
Total Properties Flooded	**785**	**762**	**746**	**679**	**571**	**436**	**350**
Direct Potential External Damage Cost	$1,165,978	$979,001	$887,247	$412,064	$294,270	$159,850	$115,405
Direct Potential Residential Damage Cost	$1,096,957	$807,886	$624,366	$73,316	$0	$0	$0
Direct Potential Commercial Damage Cost	$1,647,438	$1,071,073	$641,460	$173,549	$19,670	$7,320	$861
Total Direct Potential Damage Cost	**$3,910,373**	**$2,857,960**	**$2,153,073**	**$658,929**	**$313,940**	**$167,170**	**$116,266**
Total Actual Damage Cost *(0.8*Potential)*	**$3,128,298**	**$2,286,368**	**$1,722,458**	**$527,143**	**$251,152**	**$133,736**	**$93,013**
Infrastructure Damage Cost	**$417,854**	**$402,175**	**$394,511**	**$315,862**	**$256,493**	**$184,440**	**$87,466**
Total Cost	**$3,546,152**	**$2,688,543**	**$2,116,969**	**$843,005**	**$507,645**	**$318,176**	**$180,479**
Average Annual Damage (AAD)	**$230,421**						

6.5 Mitigation Modelling

6.5.1 Overview

Mitigation measures provide a means to reduce existing flood risk. They reduce existing flood risk by lowering the likelihood of flooding and/or by lowering the flood damages (consequences). It is important to consider that in some circumstances, given the highly developed nature of the St Arnaud floodplain, a significant reduction in the likelihood and or consequence of flooding may not be practical or feasible.

Mitigation measures can be broken into two defined types, structural and non-structural. These are described as follows:

- Structural: Physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk by reducing the likelihood of flooding at given locations. Structural works include improved drainage infrastructure, levees, floodways, retarding basins or, improvements to hydraulic structures.
- Non-structural: Management and planning arrangements between relevant authorities designed to reduce flood related damages. Non-structural measures aim to reduce existing flood risk by lowering the consequences of flooding. Non-structural measures include land use planning, flood warning, flood response and flood awareness.

6.5.2 Structural Mitigation Options

Several structural mitigation options were assessed during this study, focusing on reducing the extent and depth for St Arnaud township. The modelled mitigation options were discussed with Northern Grampians Shire Council (NGSC). The mitigation options were modelled for the 1% AEP design flood event.

The options modelled included:

- Option 1 – Watson Lake Road Levee.
- Option 2 – Instatement of a gully dam north of the central St Arnaud area.
- Option 3 – Reinstatement of the dam west of St Arnaud with a diverting drain.
- Option 4 – Combination of Options 1, 2 and 3.

The water levels produced during each modelled mitigation option were compared to those produced in existing conditions, creating a change in water level map (afflux). The change in modelled water levels for each option were thematically mapped to show a graphical representation of the increases and decreases to understand the impact of each respective mitigation option. Areas that show positive values indicate an increase in water level and negative values indicate a decrease.

6.5.2.1 Option 1 – Watsons Lake Road Levee

The 1% AEP design flood depths in northern St Arnaud are shown in Figure 6-4, indicating water escapes from the waterway at the intersection of Adam Street and Watson Lake Road. Several properties are inundated north of Edwards Street.

A short levee (approx. 30 m) was assessed to protect the properties east of Watsons Lake Road and north of Edwards Street where a small overland flow breaks out to the east, then south. Figure 6-5 shows the location of the modelled levee and mitigated flood depths in this area. The levee proved to be an effective option and inundation of the properties north of Edwards Street was eliminated, as well as two lots south of the road. There was also no adverse impact to adjacent properties, as shown in Figure 6-6.

Water levels against the levee are at approximately 254 m AHD. Should a levee to be constructed the design height would also need to incorporate a 300 – 600 mm freeboard to meet the requirements of the Victorian Levee Management Guidelines[3].

FIGURE 6-4 1% AEP DESIGN FLOOD DEPTH AT ST ARNAUD NORTH – WEST OF BUTCHER STREET

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[3] DELWP (2015), Victorian Levee Management Guidelines

FIGURE 6-5 1% AEP DESIGN FLOOD DEPTH AT ST ARNAUD NORTH WITH LEVEE

FIGURE 6-6 1% AEP WSE DIFFERENCE – WATSONS LAKE ROAD LEVEE

6.5.2.2 Option 2 – Instatement of gully dam south of Hopetoun Street

To mitigate inundation caused by overland flow in the north east of St Arnaud (highlighted in Figure 6-7), a gully dam south of Hopetoun Street was assessed, as shown in Figure 6-8. This option was assessed for all modelled 1% AEP event durations to ensure the dam had enough storage volume available to capture the event, i.e. the 2 hr event might have the largest peak flow but the 6 hr event could have a larger event volume.

FIGURE 6-7 1% AEP DESIGN FLOOD DEPTH AT ST ARNAUD NORTH – NORTH OF EDWARDS STREET

The change in flood levels resulting from the instatement of the gully dam are shown in Figure 6-9. The results show the flood levels between Edwards Street and Powell Streets were reduced by 1 to 5 cm, with the proposed dam capturing runoff from the catchment north of Hopetoun Street. The flood extent was slightly reduced along Clyde Street and Nelson Parade. It should be noted there are decreases in flood levels immediately upstream of the dam due to an increase in conveyance to the dam.

The modelled results suggest that additional 2.1 m of soil is required to be excavated to lower the base of the dam (3.5 m deep in total) to create enough storage to capture all the runoff from the upstream catchment. A dam wall at 258.3 m AHD would be required, with the maximum height of 1.1 m. A conceptual design showing existing and proposed levels along cross section 1 (XS1) and 2 (XS2) are presented in Figure 6-10 and Figure 6-11.

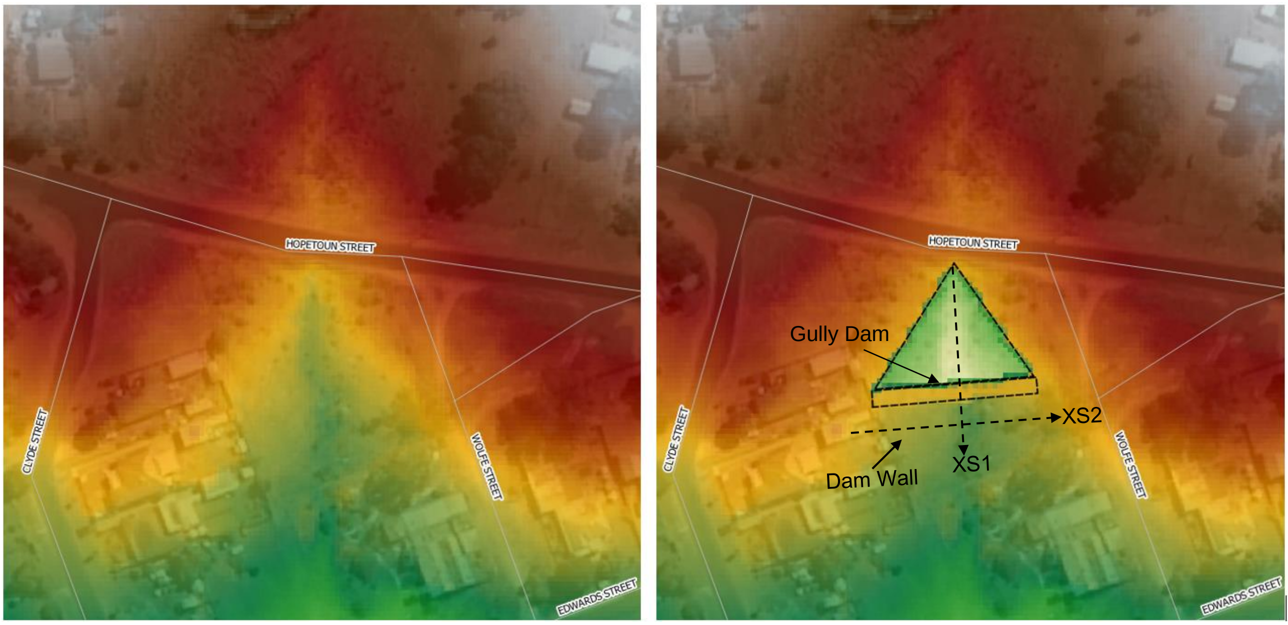

FIGURE 6-8 LEFT: EXISTING TOPOGRAPHY; RIGHT: MITIGATION WITH PROPOSED GULLY DAM

FIGURE 6-9 1% AEP WSE DIFFERENCE – GULLY DAM AT HOPETOUN STREET SOUTH

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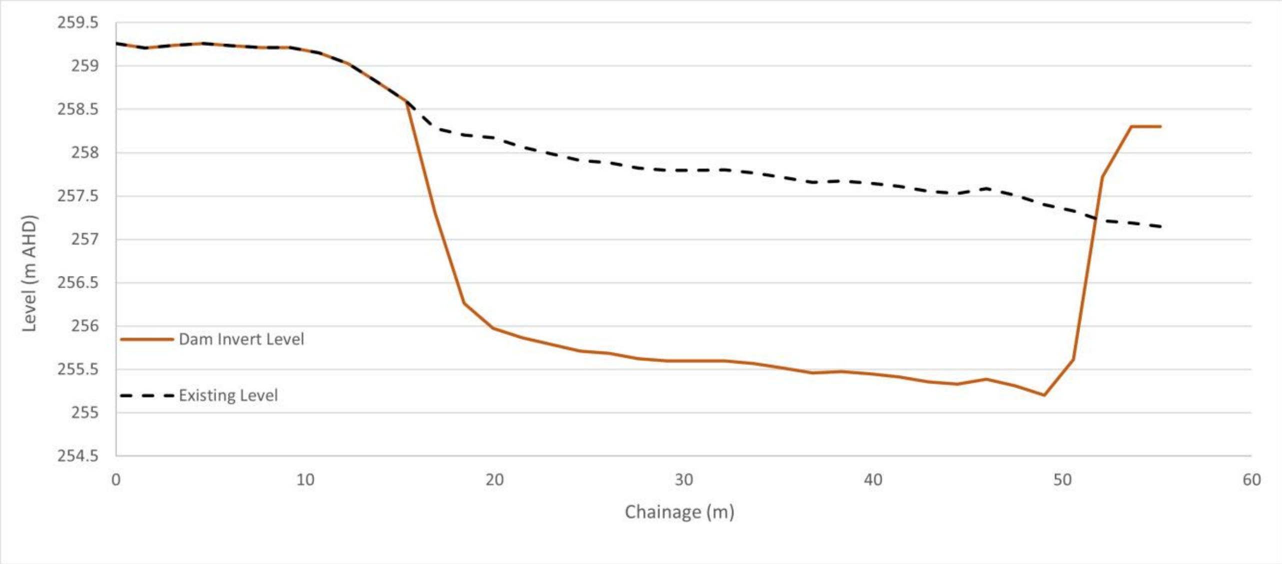

FIGURE 6-10 CONCEPTUAL DESIGN – XS1

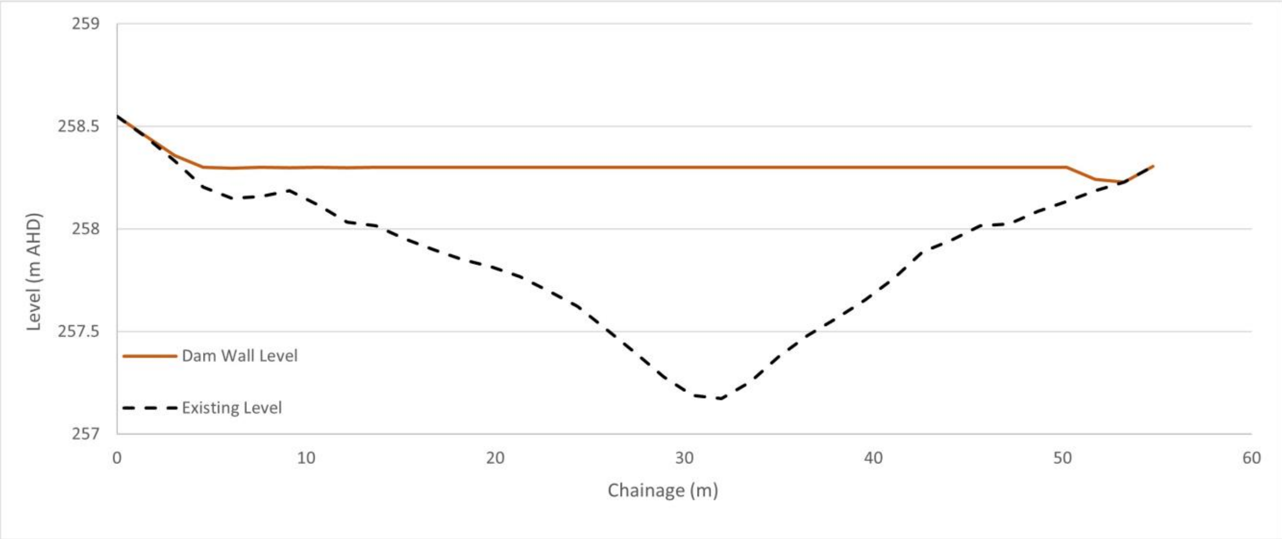

FIGURE 6-11 CONCEPTUAL DESIGN – XS2

6.5.2.3 Option 3 - Reinstatement of the dam/retarding basin west of St Arnaud with a diversion drain

There is an existing dam located west of St Arnaud and south of North Western Road. The dam wall was washed out during flooding in 2011 but was previously used as a flood mitigation measure. Reinstatement of the dam was modelled, with the dam wall set at 262.5 m AHD, with the intent to retard peak flow and mitigate flooding toward the railway. Additional to the dam reinstatement was the installation of a drain diverting runoff from south to the dam maximising its catchment to as large as possible. It should be noted that the catchment area assumed to flow into the dam was intentionally larger than maybe practical (due to the ridge between the catchments and the required excavation), maximising the potential reduction in flood damage which could be achieved. The reinstated dam and area drained to it are shown in Figure 6-12.

The change in flood levels as a result of the dam are shown in Figure 6-13, indicating flood levels reduce significantly upstream of railway, by up to 45 cm. This level of reduction does not extend further than the railway line, with the railway line and associated culverts controlling discharge downstream of this point in both existing and mitigated modelling. The levels are generally reduced by 2 to 5 cm along overland flow path from the railway to Alma Street.

The results also suggests that the proposed diversion drain has a minor impact on the flood extent and levels along the flow path it is diverted from i.e. south of Hill Street.

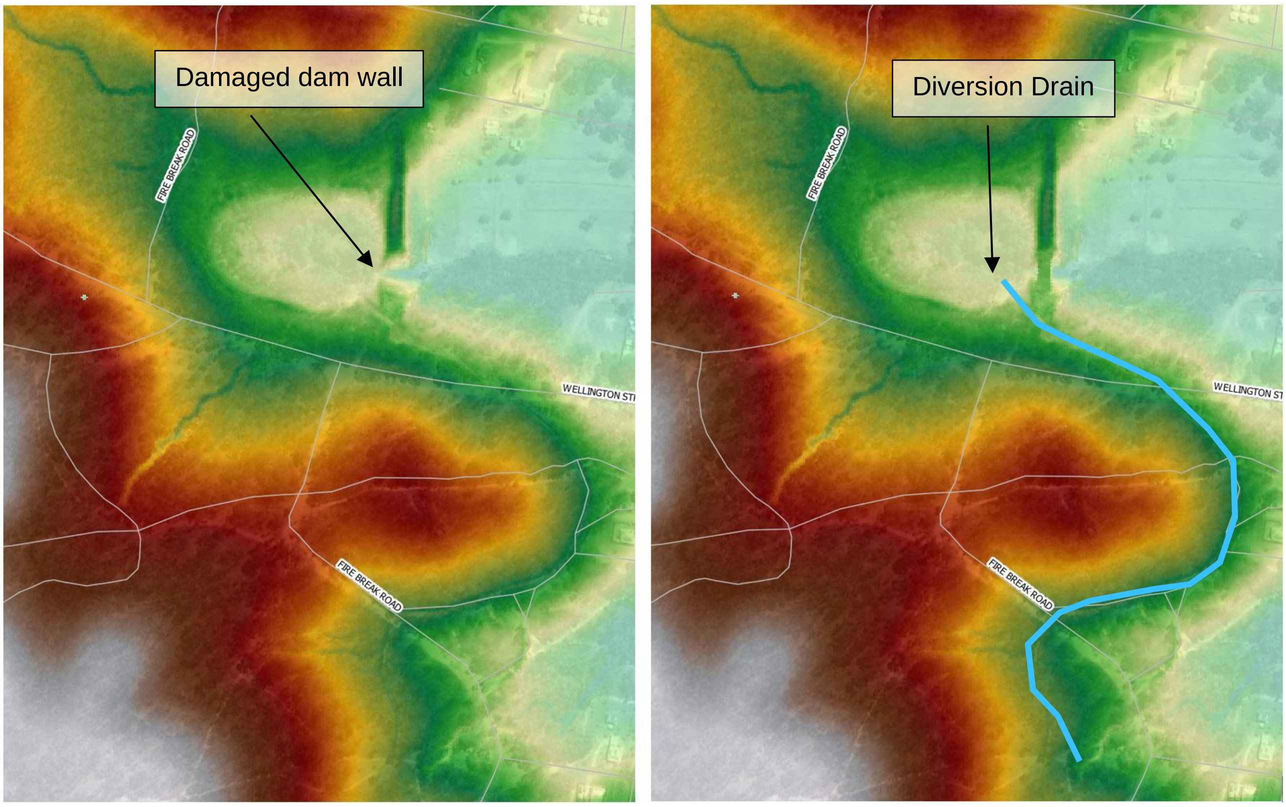

FIGURE 6-12 LEFT: EXISTING TOPOGRAPHY; RIGHT: MITIGATION WITH REINSTATEMNET OF DAM AND ADDITIONAL DIVERSION DRAIN

FIGURE 6-13 1% AEP WSE DIFFERENCE – REINSTATEMENT OF DAM WALL WITH DIVERTING DRAIN

6.5.2.4 Option 4 – Combination of Option 1, 2 & 3

Mitigation Option 1, 2 and 3 were modelled as one option to investigate the combined mitigation effect. Figure 6-14 shows the change in flood levels across St Arnaud. Differences mainly occur to the north of Mill Street. Flood extents and levels were reduced in the northeast of the township with the proposed levee and gully dam. Flood levels were also reduced along the overland flow path from the west and reinstatement of the dam wall, but the impact of the diversion drain was limited.

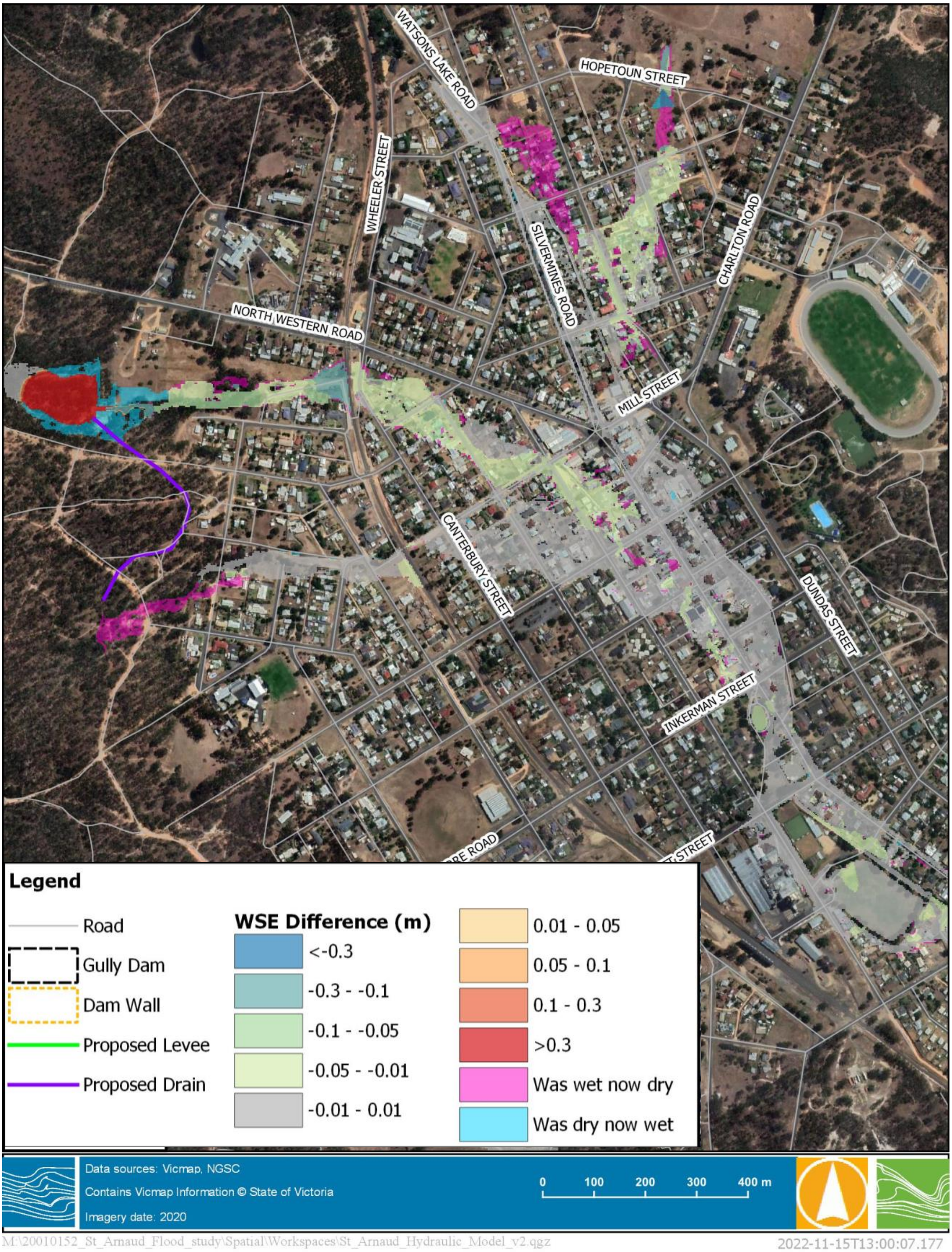

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FIGURE 6-14 1% AEP WSE DIFFERENCE – COMBINED OPTION

6.5.2.5 Cost Benefit Analysis - Mitigation Option 4 – Combined Option 1, 2 & 3

6.5.2.5.1 OVERVIEW

As discussed in Section 6.5.2.4, Mitigation Option 4 contained a combination of structural mitigation measures as separate components, this included:

- Watsons Lake Road Levee.
- Instatement of a gully dam south of Hopetoun Street.
- Reinstatement of the dam/retarding basin west of St Arnaud and construction of a diversion drain to the dam.

This option was progressed to costing and a cost benefit analysis. Due to the increases caused by a levee along Mill Street it was not included. Each of the individual options had an indicative cost determined using industry standard rates for construction, Melbourne Water estimated costs for earthworks and construction, and comparison to cost estimates for similar works for other flood studies. Given they are largely separate the costs were determined for each component individually.

The potential reduction in flood damage was assessed with all the potential options combined, presented as a revised Average Annual Damage (AAD). The change in AAD (reduction in annual damage) was then compared to the cost of the mitigation measures to form a cost-benefit ratio.

6.5.2.5.2 COSTING

Watson Lake Road Levee

As discussed in Section 6.5.2.1, the Watsons Lake Road Levee is relatively short at around 30m. An indicative construction costing of the levee was made using the dimensions outlined in Table 6-3.

TABLE 6-3 WATSONS LAKE ROAD LEVEE DIMENTIONS

Assumption/Dimensions	Measurement
Water Face Batter Slope	1:4
Outside Face Batter Slope	1:4
Freeboard	0.3m
Crest Width	1 m
Length	30 m
Average Depth	0.2m
Max. Depth	0.4m
Min. Depth	0.0m
Average Width	2.4m
Max Width	4.1m
Total Volume	51 m^2
Total Area	116 m^2

The determined levee dimensions were used to calculate a preliminary cost of the levee. The costing was based on standard industry rates used by Melbourne Water for earthworks and construction and comparison to cost estimates for similar works for other flood studies.

The estimated cost of the Watsons Lake Road levee is show in Table 6-4, outlining the determined construction costs on a unit rate basis, total cost and inclusion of engineering, administration and contingency costs. A construction and compaction cost of $100/m^3 for the levee costing was used given the small volume of earthworks required.

TABLE 6-4 WATSONS LAKE ROAD LEVEE COSTING

Description	Qty	Unit	Rate	Estimated Cost	Estimated Cost including Engineering, Administration & Contingencies
			($/unit)	$	$
Construction and Compaction	51	m^3	$100	$5,127	$7,964
Top soiling (100mm)	12	m^3	$20	$232	$361
Grassing	116	m^2	$1	$116	$180
Subtotal				**$5,475**	**$8,506**

Instatement of a gully dam south of Hopetoun Street

As discussed in Section 6.5.2.2, the gully dam south of Hopetoun Street retards flows from the area upstream An indicative construction costing of the dam was made using the dimensions outlined in Table 6-5.

TABLE 6-5 WATSONS LAKE ROAD LEVEE DIMENTIONS

Assumption/Dimensions	Measurement
Dam wall height	258.3 m AHD
Maximum dam wall height (on existing topography)	1.4 m (including 0.3 freeboard)
Water Face Batter Slope	1:4
Outside Face Batter Slope	1:4
Maximum excavation depth	2.2 m
Crest Width	4m
Dam Length	50 m
Average Depth	0.5m
Max. Depth	0.4m
Min. Depth	0.0m
Average Width	7m
Max Width	15.4m

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Assumption/Dimensions	Measurement
Total Volume	352 m^2
Total Area	531 m^2
Piped outlet	300mm, 20m

The determined retarding basin dimensions were used to calculate a preliminary construction cost. The costing was based on standard industry rates used by Melbourne Water for earthworks and construction and comparison to cost estimates for similar works for other flood studies.

The estimated cost of the Hopetoun Street retarding basing is show in Table 6-6, outlining the determined construction costs on a unit rate basis, total cost and inclusion of engineering, administration and contingency costs. A construction and compaction cost of $25/$m^3$ for the levee costing was used given the much larger scale of the works (in comparison to the Watson Lake Road levee).

TABLE 6-6 HOPETOUN STREET RETARDING BASIN COSTING

Description	Qty	Unit	Rate	Estimated Cost	Estimated Cost including Engineering, Administration & Contingencies
			($/unit)	$	$
Retarding Basin Wall Construction and Compaction	352	m^3	$50	$17,586	$27,319
Wall Top soiling (100mm)	53	m^3	$20	$1,063	$1,651
Grassing	531	m^2	$1	$531	$825
Excavation and disposal	2,525	m^3	$12	$30,300	$47,071
Pipe outlet	20	m	$148	$6,566	$10,200
Land acquisition	1	each	-	$60,000	$70,000
Subtotal				**$116,045**	**$146,866**

Reinstatement of the dam/retarding basin west of St Arnaud

As discussed in Section 6.5.2.3, an existing dam to the west of St Arnaud was washed out during flooding in 2011. An indicative construction costing of the dam reinstatement was made using the LiDAR data. It is estimated approximately 750 m^3 of fill would be required to reinstate the dam to a level of 262.5 m AHD, this is an increase of 3.6m from the currently estimated eroded height of 258.9 m AHD.

Excavation of the drain extending the catchment area for the drain was reviewed based on the available LiDAR data. The drain location could be identified in the LiDAR but the topographic data was not of sufficient accuracy to determine the required earthworks to enable the drain to function adequately. The location of the drain in respect to the dam is shown in Figure 6-15.

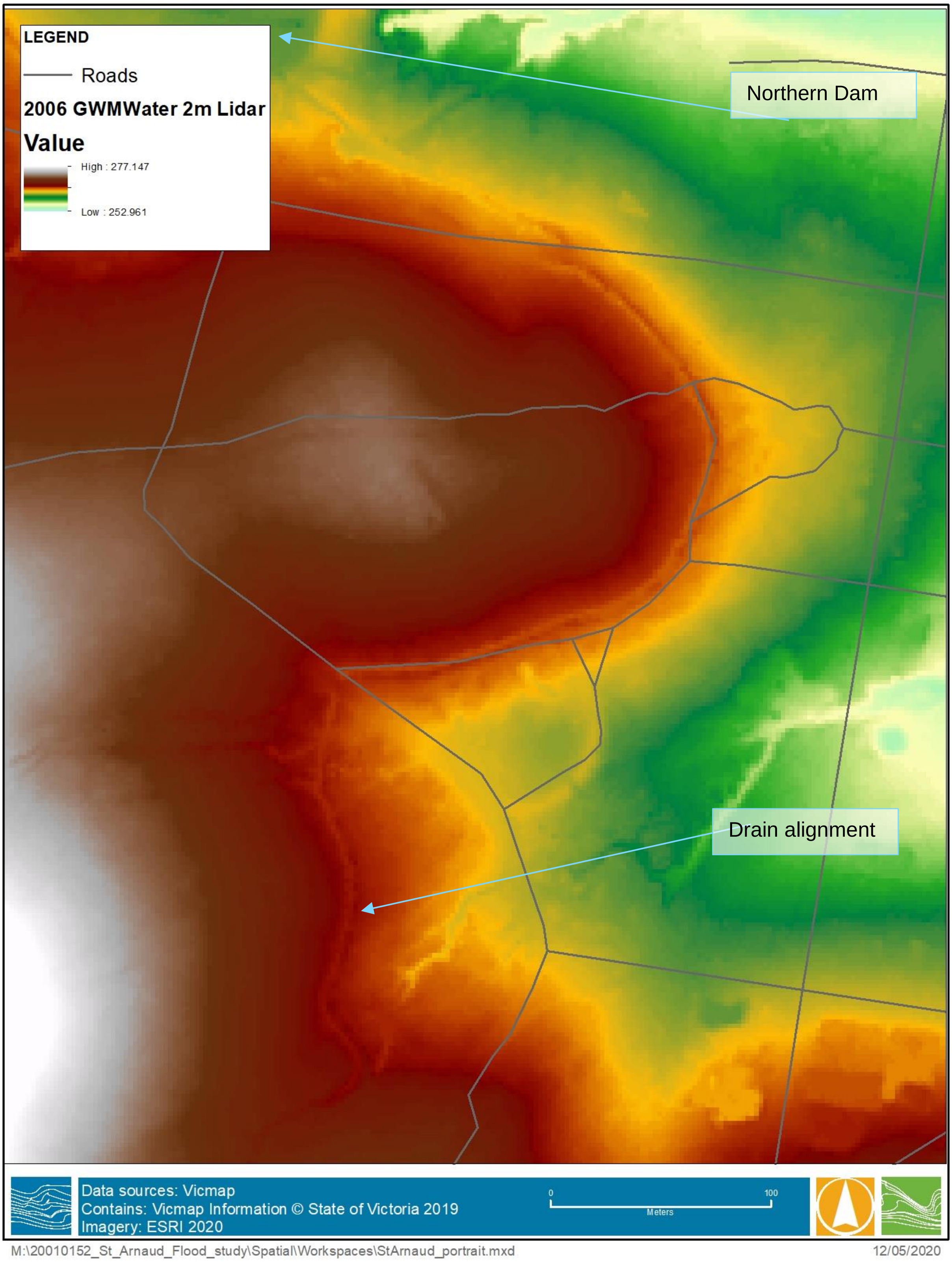

FIGURE 6-15 DRAIN REQUIREING REINSTATMENT

The determined levee dimensions were used to calculate a preliminary cost of the dam reinstatement. The costing was based on standard industry rates used by Melbourne Water for earthworks and construction and comparison to cost estimates for similar works for other flood studies.

The estimated cost of the northern dam reinstatement is show in Figure 6-7, outlining the determined construction costs on a unit rate basis, total cost and inclusion of engineering, administration and contingency costs. A construction and compaction cost of $50/m^3 was used for the embankment costing. No cost could be determined for the drain reinstatement due to the lack of detail in the LiDAR and likely vegetation removal costs. It should also be noted the drain does not provide a significant decrease in downstream flood levels due to the limited additional catchment it captures. Figure 6-16 shows the various catchment areas contributing, potentially contributing and unable to contribute to the dam, this includes:

- The area currently flowing through the dam – 85.4 Ha.
- The additional area diverted to the dam with the reinstated drain – 16.6 Ha.
- The area unable to be captured by the reinstated drain (upstream of St Arnaud Creek) – 41.6 Ha.

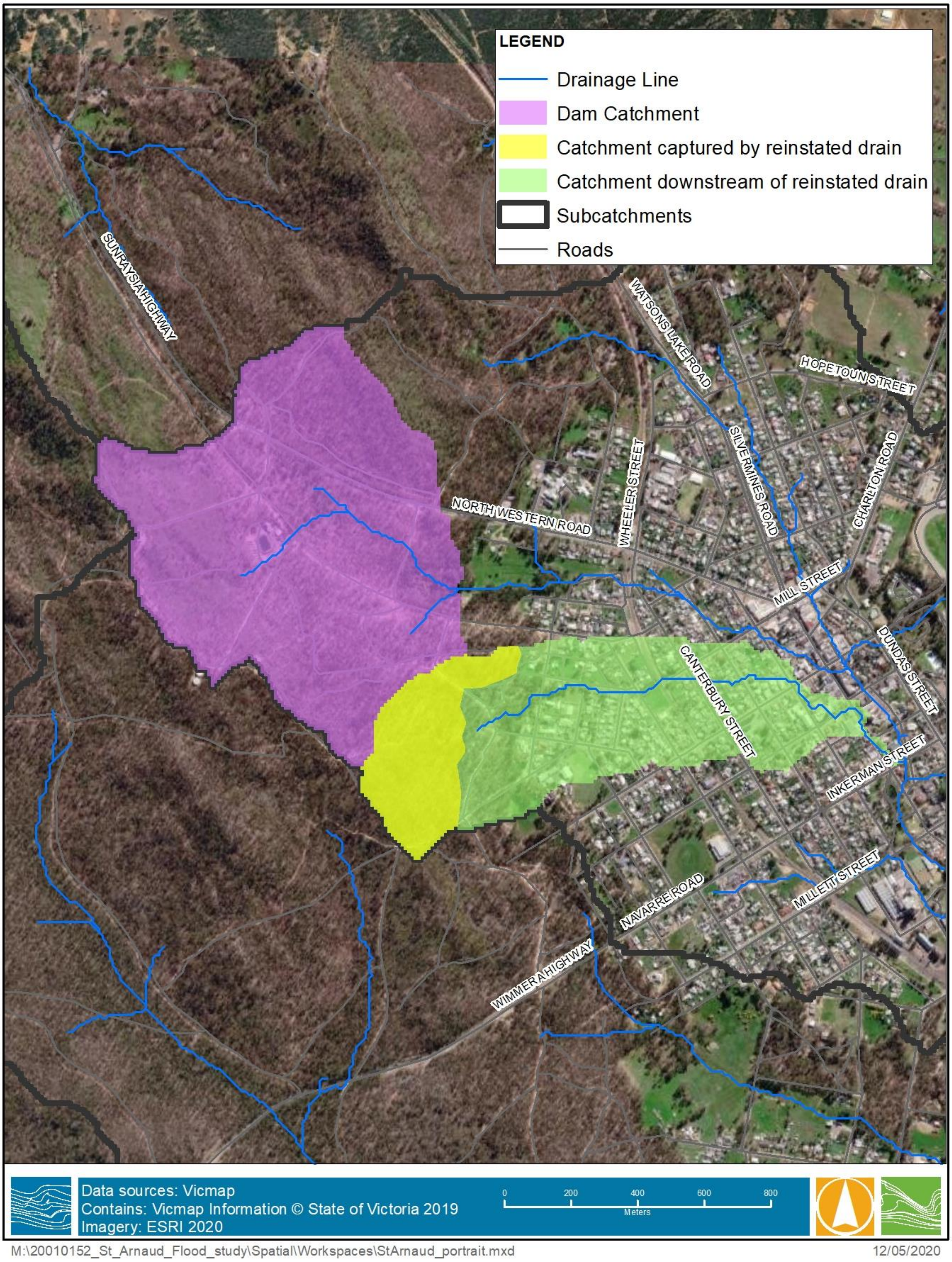

FIGURE 6-16 DAM CONTRIBUTING AND NON-CONTRIBUTING CATCHMENT AREAS

TABLE 6-7 DAM REINSTATEMENT COSTING

Description	Qty	Unit	Rate	Estimated Cost	Estimated Cost including Engineering, Administration & Contingencies
			($/unit)	$	$
Construction and Compaction	750	m^3	$50	$37,500	$58,256
Top soiling (100mm)	100	m^3	$20	$3,000	$3,107
Grassing	1,000	m^2	$1	$1,000	$1,554
Piped outlet	50	m	$148	$14,908	$23,160
Subtotal				**$55,408**	**$86,076**

Reduction in Damages

As discussed in Section 6.4, the Average Annual Damage (AAD) of a flood event within the study area was estimated at $230,000. The AAD was recalculated with the inclusion of the combined mitigation options, as shown in Table 6-8, determining a mitigated AAD of approximately $222,000. There isn't a large change in the AAD, with a reduction of around $8,000. This is largely due to the inability of the options assessed to reduce the number of properties flooded above floor. Under mitigated conditions the number of properties flooded above floor was reduced from 36 to 32, with the properties moving to flooded below floor.

TABLE 6-8 MITIGATED CONDITIONS FLOOD DAMAGES FOR AFFECTED PROPERTIES

EXISTING CONDITIONS							
ARI (years)	500yr	200yr	100yr	20yr	10yr	5yr	2yr
AEP	0.002	0.005	0.01	0.05	0.1	0.2	0.5
Residential Buildings Flooded Above Floor	17	14	12	1	0	0	0
Commercial Buildings Flooded Above Floor	38	30	20	12	4	2	1
Properties Flooded Below Floor	730	718	714	666	567	434	349
Total Properties Flooded	**785**	**762**	**746**	**679**	**571**	**436**	**350**
Direct Potential External Damage Cost	$1,141,646	$944,626	$843,947	$405,184	$288,725	$158,452	$115,599
Direct Potential Residential Damage Cost	$1,024,192	$780,644	$614,854	$38,000	$0	$0	$0
Direct Potential Commercial Damage Cost	$1,582,869	$686,462	$504,455	$174,999	$19,998	$7,320	$861
Total Direct Potential Damage Cost	**$3,748,707**	**$2,411,732**	**$1,963,256**	**$618,183**	**$308,723**	**$165,772**	**$116,460**
Total Actual Damage Cost *(0.8*Potential)*	**$2,998,966**	**$1,929,386**	**$1,570,605**	**$494,546**	**$246,978**	**$132,618**	**$93,168**
Infrastructure Damage Cost	**$419,499**	**$403,125**	**$395,233**	**$315,972**	**$258,809**	**$179,878**	**$83,241**
Total Cost	**$3,418,464**	**$2,332,511**	**$1,965,838**	**$810,519**	**$505,788**	**$312,495**	**$176,409**
Average Annual Damage (AAD)	**$222,257**						

6.5.2.5.3 COST BENEFIT RATIO

The benefit-cost ratio was undertaken to demonstrate the financial viability of undertaking mitigation works. For this analysis, a net present value model was used, applying a 6% discount rate (Net Present Value) over a 30 year project life. A benefit cost ratio should ideally be equal to or greater than 1, meaning the long-term benefit of flood mitigation equals or exceeds the long-term costs. Maintenance of the modelled mitigation has been assumed to cost $5,000/year as an indicative sum, this maintenance will likely be undertaken as part of the existing Council maintenance works.

The mitigation cost benefit ratio analysis is outlined in Table 6-9.

TABLE 6-9 COST BENEFIT RATIO FOR ST ARNAUD

Component		Cost		
Watsons Lake Road Levee		$ 5,475.24		
Hopetoun Street Dam		$ 116,045.41		
Northern Dam Reinstatement		$ 55,408.00		
		$176,928.65		
Engineering Fee	15%	$26,539.30		
Administration Fee	9%	$15,923.58		
Contingencies	30%	$53,078.60		
Total Cost	**Ex GST**	$272,470.12		
Maintenance standard figure	$ 5,000.00			Annual Maintenance
		$ 230,421.00		AAD
		$ 8,000.00		Annual Saving
		$ 112,499.31		NPV 6%
		$ 272,470.12		Capital Cost
			0.41	**B-C Ratio**

6.5.2.6 Additional option assessment – Option 5

Following further discussion with Northern Grampians Shire Council an additional flood mitigation option was added to the analysis as a concept test. This option included capturing all flow upstream of the northern dam including the additional area captured by the reinstated drainage line. While this may not be feasible it was completed to better understand the maximum benefit these options could achieve.

The 1% AEP, 6 hour duration event was used as a reference for the feasibility of the option, comparing existing and mitigated water levels. The water level comparison is shown in Figure 6-17, indicating general reductions in flood level from the model inflow points to St Arnaud Creek. Along the northern flow path (downstream of the dam), there are decreases in extent and decreases in water level up to 30cm upstream of the railway line. Downstream of the railway ling there is a large decrease in extent but only relatively small decreases in water level, at around 5cm.

Along the southern flow path (from the catchment diverted by the reinstated dam) there are decreases of up to 13cm upstream of the railway line, but these are decreased to around 3cm downstream of the railway.

Along St Arnaud Creek the water level decreases are around 2cm.

The peak flow into the dam at the top of the northern flow path is around 3.7 m^3/s, while the southern flow path is 0.75 m^3/s, during the 1% AEP, 6hr duration event. Over the course of the event around 32 ML is contributed from the catchment upstream of the dam and 5.7 ML from the southern flow path.

FIGURE 6-17 CHANGE IN 1% AEP, 6HR WATER LEVELS DUE TO THE REMOVAL OF FLOW CONTRIBUTION FROM THE WESTERN ST ARNAUD CATCHMENTS

6.5.2.7 Discussion and Summary

Of the modelled mitigation options, the following summaries were determined:

- Option 1 (Watsons Lake Road levee) – viable option for decreasing flood extent and risk at the properties east of Watsons Lake Road and north of Edwards Street. No perceivable increase to flood levels or extents to nearby properties as a result of this option. This option was determined as worth further consideration.
- Option 2 (gully dam at south of Hopetoun Street) – reduction in flood levels between Edwards Street and Powell Streets by 1 to 5 cm. This option may provide more benefit during lower flood events.
- Option 3 (reinstatement of the dam at west with a diversion drain) – significant reduction in flood levels upstream of railway and reasonable reduction between the railway and Alma Street. The impact of the diversion drain is limited and the works requires (including vegetation costs) may not be worth the necessary investment, as well as the potential maintenance costs.
- Option 4 (combination of Options 1, 2, and 3) – the reduction in flood levels are mainly located to the north of Mill Street. Cost and benefit analysis suggests a relatively minor reduction in AAD but a reasonable Cost Benefit ratio.
- Option 5 (concept dam improvements) – The concept dam improvements show some promising results along the northern flow path, downstream of the dam. Review of the model results show a 300mm pipe in the dam to release low flows would enable around 0.28 m^3/s to flow from the storage, this would result in around 26ML of storage required to hold the 1% AEP event (i.e. around 6ML would be able to flow through the pipe over the 6hrs).

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There are a number of flood prone buildings in St Arnaud less suitable for widespread structural mitigation options as a result of highly densified development and the nature of flash flooding, leaving very limited space for mitigation options.

It is recommended property specific mitigation be considered rather than broad mitigation. Consideration should be given to elevating pavement, kerb and channel or the use of sandbags, prepared to act immediately after intense rainfall is occurring. This is particularly relevant for the main shopping area.

If residents are able and capable to defend their homes from flash flooding, they will want access to sandbags as soon as possible after it becomes apparent that flooding is likely. Residents using sandbags need to be aware of the correct way to lay sandbags and also be aware that due to the length of inundation some water will pass through the bags. A Flood Response Plan should be prepared for properties in the vicinity to St Arnaud Creek to inform the community on appropriate actions before, during and after the flood.

7 FLOOD INTELLIGENCE

7.1 Overview

The Flood Intelligence Report (*R05– Flood Intelligence Report*) provides a detailed description of the flood behaviour in the study area and the impact flooding has on people and assets throughout the catchment.

During significant rainfall events, the catchment to the northwest and north of St Arnaud begins to contribute runoff which accumulates and flows towards St Arnaud Creek. Intelligence information collected from this study will be used to update the Municipal Emergency Management Plan, the VicSES St Arnaud Local Flood-Guide, and general information which can be utilised by agencies for flood warning and response purposes. It can also be used to be distributed to the public for education purposes including building community resilience.

7.2 Methodology

The flood modelling outputs, combined with the surveyed floor level information were used to develop a series of flood response tools. Above floor flooding was provided as a separate spreadsheet. It should be noted the above floor flooding impacts described do not consider individual flood protection measures such as local flood walls or levees which protect individual homes (sandbagging, flood gates, sealed fencing etc.). For this reason, such measures cannot be assumed to be in place and operating effectively under design conditions. Mapping of the above floor flooding in St Arnaud is discussed Section 6.3, property specific detail should be sought from Flood Intelligence Report.

7.3 Warning Time

The riverine flooding at St Arnaud is caused by overbank flows from St Arnaud Creek through the town and Lexel Creek at south. Due to the nature of the critical storm within the catchment, the warning time of the flash flooding at St Arnaud is limited to less than half an hour.

7.4 Municipal Flood Emergency Plan Tables

A set of summary tables and maps were developed for St Arnaud, 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. An example of this (Table 7-1), if the reader is wishing to understand the consequences of a 20% AEP event, then the flood characteristics should be read for the 50% and 20% AEP events in succession.

TABLE 7-1 EXAMPLE OF SUMMARY OF FLOOD BEHAVIOUR FOR DESIGN EVENTS (50% & 20% AEP)

Flood Event	Characteristics – Flood Behaviour	Key Response Actions
20% AEP (Appendix B)	■ Flood extent has very minor increase on the 50% AEP event. ■ Water flows in the roadside drain along Silvermines Road, joining the main channel at Alma Street. ■ Minor ponding at the intersection of Lexel Creek and railway. ■ No impassable Roads (depth above 0.3 m) added to the list. ■ 2 commercial properties are flooded above floor. .	■ Continue to monitor rainfall and water levels ■ Issue minor flooding alert pertaining to driving through flood waters and property inundation ■ Place "Water over road" signs for Inundated Roads listed as inundated for 20% AEP event ■ With regard for expected severity of flooding, remove furniture etc from buildings likely to be flooded over-floor or to begin sandbagging and revisit evacuation plan ■ Prepare deployment of signage for remaining roads traversing St Arnaud Creek and consider closing roads depending on rainfall and water levels ■ Communicate/check in with residents/businesses potentially flooded above floor and provide assistance where required ■ Sandbags should be placed across the front of the door for the properties flooded above floor for 20% AEP event.

7.5 Flood Warning Tool

The Intensity Frequency Duration (IFD) design rainfall data used in the development of the St Arnaud Flood Investigation Project can be utilised along with forecast and observed rainfall data (at the new BoM subdaily rainfall gauge, Howitt Street (579030), as an early warning tool. The data can be used to identify the likely magnitude of flooding and resultant consequences.

The Intensity-Frequency-Duration (IFD) design rainfall data used to develop the hydrology used in the Bonshaw Creek Flood Mapping Project, can be utilised along with forecast and observed rainfall data as an early warning tool. This can be used to identify the likely magnitude of flooding and possible consequences. Figure 7-1 is the representation of the cumulative rainfall and durations that lead to flooding events. The user can monitor the rainfall depths over different durations and plot it on Figure 7-1. Whichever curve it intersects (or is closest too), is the likely AEP of flooding. It is likely that when plotting various rainfall depth/duration combinations, the AEP will differ. The user should use the maximum AEP for planning purposes to be conservative. It should be noted that in short duration rainfall bursts it is possible that the rainfall observed may indicate a rare event, but the storm may not have enough volume to produce flooding of that magnitude, particularly at the lower end of the catchment.

For example, if the 40 mm of rainfall over a period of 6 hours was observed, the flash flood early warning tool predicts a 20% AEP event occurring and contact houses within the affected areas. Although this is a helpful method in the prediction of flood events no flood is the same, flooding will be dependent of catchment conditions.

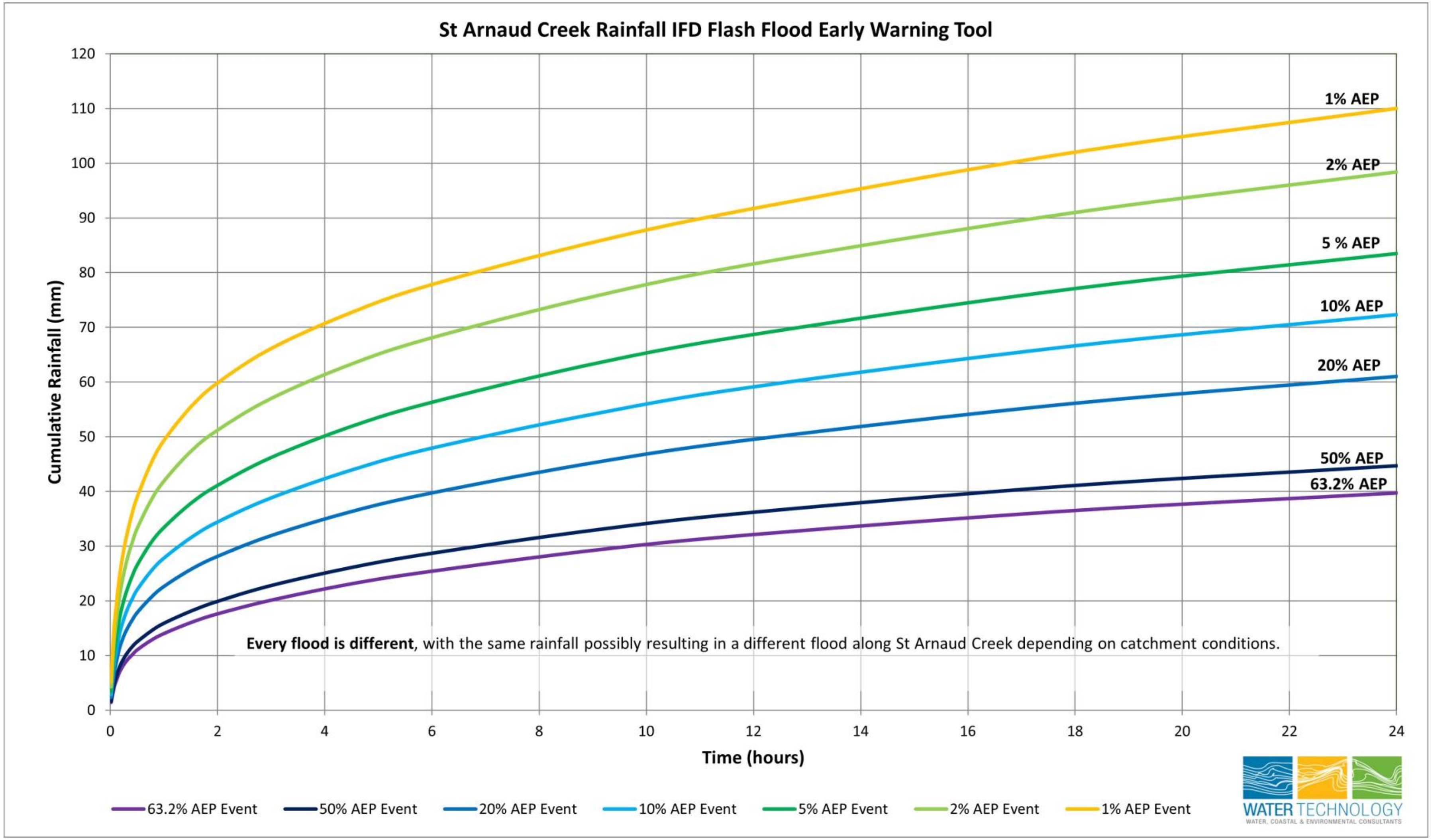

FIGURE 7-1 ST ARNAUD CREEK FLASH FLOOD EARLY WARNING TOOL

7.6 Summary

The flood intelligence report was compiled using existing resources combined with the hydrological and hydraulic flood modelling undertaken as part of this project. The report aimed to provide a standalone document to provide information on flood behaviour, design flood extents and potential consequences related to rainfall intensity. Flood warning is limited and is currently issued as a Severe Weather Warning or Severe Thunderstorm Warning by BoM. The report was also developed in a manner that will allow for inputs into an update of the MFEP and the St Arnaud Flood Guide in conjunction with the VicSES.

The Flood Intelligence component of the study should not only inform staff and volunteers involved in emergency management, but to also raise awareness to the broader community of flood risk within the study area.

8 FLOOD WARNING

8.1 Overview

The Flood Warning Assessment Report *(R06 – St Arnaud Flood Warning Report)* documented the existing flood warning system for the study and potential improvements.

Flood warning systems are necessary to ensure the safety of the public and enhance readiness in the event of a flood. An effective flood warning system will provide communities with time to protect themselves and if time permits, their property. A review of the available data (rainfall, streamflow and intelligence data) for the study area was undertaken before several recommendations for potential flood warning information was also provided.

8.2 Existing data availability

There were no streamflow gauges available within the study area. In predicting the likely magnitude of flooding on the St Arnaud Creek through the township, the real time rainfall gauge network and rainfall forecasts is more useful than an upstream streamflow gauge network. The nature of the flooding in St Arnaud is such that short duration storm events (e.g. less than 4-6hrs) are the likely to cause flooding and are considered to be "flash flooding" type events. Therefore, the warning time is too short for monitoring of streamflow to be of any use.

There are several rainfall gauges shown in Figure 8-1 in proximity to the St Arnaud catchment which are useful for predicting floods in the study area, these include:

- St Arnaud (Howitt Street) (579030) – Active
- St Arnaud (079040) – Active
- Beazleys Bridge (079003) – Active
- St Arnaud (Coonooer Bridge) (080131) – Active
- Slaty Creek (079041) – Closed
- Gowar west (079060) – Closed
- Gowar east (Rahina Farm) (079059) – Closed
- Emu Rail (Dalyenong) (079091) – Closed
- Trainors Lagoon (079068) – Closed

The Wunderground database, contains two sub daily rainfall gauges in proximity to St Arnaud, as shown in Figure 8-1. The Currawong Hill gauge does not cover the time period of the recent flood events. The St. Arnaud Wunderground station (IVCTSAIN7: -36.62, 143.25) is central to the township, this gauge has been active since January 2018.

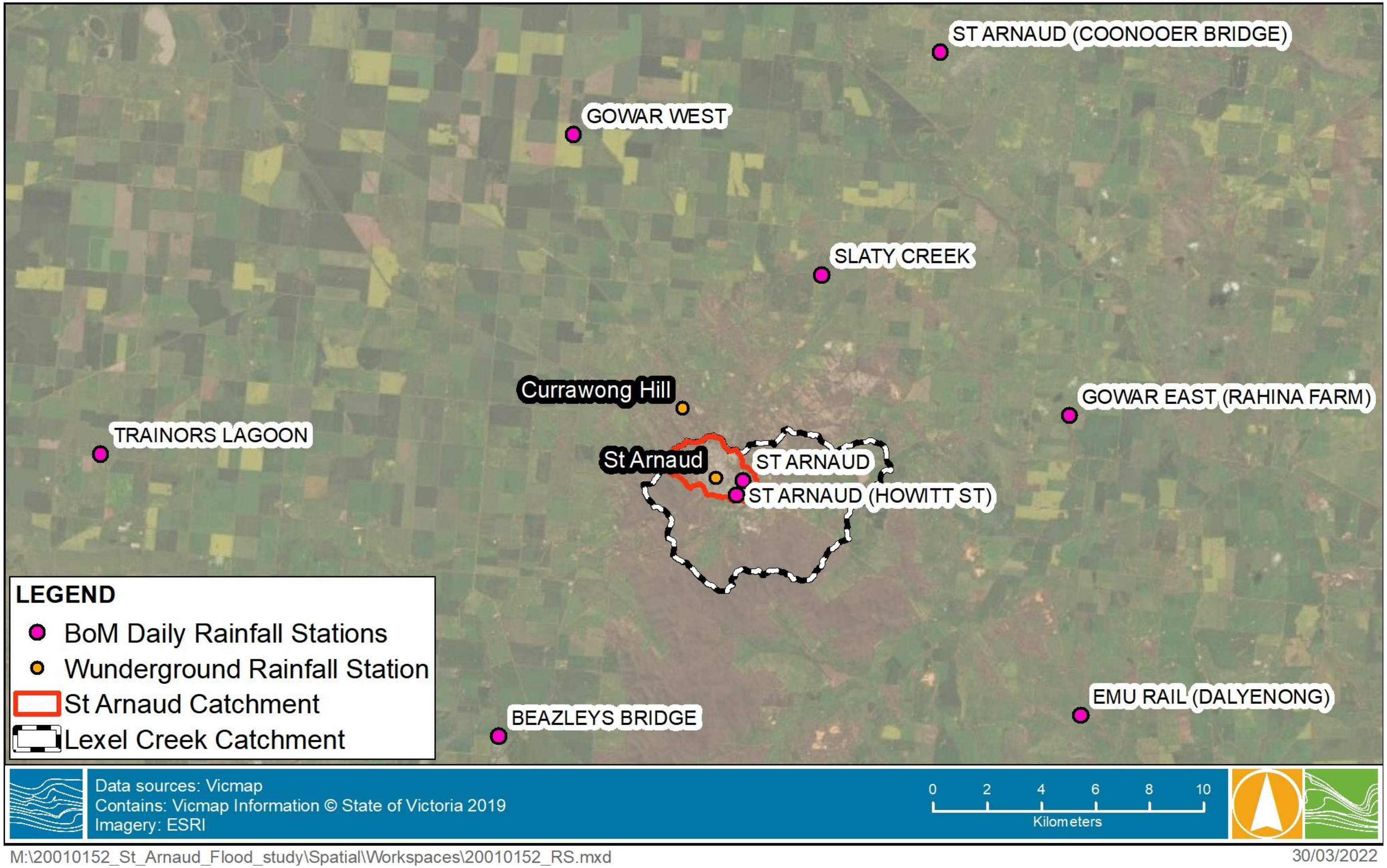

FIGURE 8-1 WEATHER STATION LOCATIONS

Table 8-1 below shows the typical travel time along St Arnaud Creek. It should be noted that the travel time from upstream locations to anywhere in the St Arnaud Creek through the township are almost the same, within 30 mins. This is because several flow paths contribute to the St Arnaud creek from different directions and inflows along the creek contribute simultaneously.

TABLE 8-1 TIMING OF PEAK FLOW ON THE ST ARNAUD CREEK

Location From	Location To	Typical Travel Time	Comments
Riverine Flooding – St Arnaud Creek			
Start of rainfall	Upper Township (Hopetoun Street)	1 to 2 hours	Shorter rainfall durations (1 – 2 hours) are more critical around this location.
Start of rainfall	Middle Township (Inkerman Street)	1.25 to 2.25 hours	Shorter rainfall durations (1 – 2 hours) are more critical around this location.
Start of rainfall	Lower Township (Melbourne Road)	1.5 to 2.5 hours	Relatively longer rainfall duration such as 6 hours could potentially be more critical around this location.

8.3 Potential Improvements

The existing flood warning system has the hallmarks of a robust flood warning system. The St Arnaud Flood Intelligence Report *(R04)* and its associated flood intelligence cards provide improved flood data and interpretation for a local flood warnings. However, there are several suggested actions that will improve the existing flood warning system these include:

- Enable community members to access flood risk property information after amendments to Northern Grampians Shire Council's planning scheme.
- Incorporate flood intelligence cards from the St Arnaud Flood Intelligence Report into the Northern Grampians Shire Council Flood Emergency Plan.
- Ensure that the flood-prone infrastructure should all have their own emergency plans that include protective actions related to triggers. These plans should be updated based on the flood intelligence cards from the St Arnaud Flood Intelligence Report (R04).
- Produce the St Arnaud Local Flood Guide based on the St Arnaud Flood Intelligence Report.
- Conduct other future community flood education activities across the study area based on findings of the Report.
- Ensure that flood communication (e.g. Flood Bulletins) should be in simple language talking about impacts of potential flooding on the local communities in the study area and required actions including possible evacuation. It should consistently advise people of recorded rainfall.
- Ensure that all people in the community (including newcomers and renters) be included in any prior community flood education and engagement during and after the flood event.
- Check that the Vulnerable Persons Register is updated and used during a flood emergency.
- Regularly educate the community about the risks of entering floodwaters.
- Consider other ways in which the community can participate in the design, implementation and review of the flood warning system.
- Amend the Municipal Flood Emergency Plan to describe the practical integration of the local flood warning system.

8.4 Summary

It is recommended that Council investigate and document the feasibility of a flash flood warning service for St Arnaud. While it was not the scope of this project to develop a comprehensive flash flood warning system for the township, it has been considered at a high level. To better manage and understand flood warning in St Arnaud it is recommended the three rainfall gauges with telemetry within the St Arnaud Creek catchment be investigated for their use in a flash flood warning system. This along with hydrological models and rating curves developed during the St Arnaud Flood Investigation, could provide the information required for a flash flood warning system.

The system could be kept simple, with the estimated rainfall storm AEP used to select flood maps to predict likely flood impacts, as developed in this project and detailed in Section 7. The system could also be slightly more complex and could use a combination of rainfall gauges and radar rainfall, along with the hydrological models run in forecast mode, generating automated alerts.

9 LAND USE AND PLANNING CONTROLS

9.1 Overview

The North Central CMA and Northern Grampians Shire Council have a responsibility to assess and if possible, manage flood risk. In some cases, flood risk is unable to be reduced or eliminated by structural means. In St Arnaud the result of the flood investigation indicates a widely spread flooding risk which is difficult and costly to manage with typical structural mitigation measures. Where residual risk remains, planning and building controls provide an important role in ensuring that development within areas known to be at risk is appropriately managed and measures are taken to ensure potential damage and loss of life mitigated.

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

Section 6(e) of the Planning and Environment Act 1987 enables planning schemes to 'regulate or prohibit any use or development in hazardous areas, or likely to be hazardous'. As a result, planning schemes contain State planning policy for floodplain management requiring, among other things, that flood risk to be considered in the preparation of planning schemes and in land use decisions.

Guidance for applying flood controls to Planning Schemes is available from the Department of Environment, Land Water and Planning (DELWP) Practice Note on Applying Flood Controls in Planning Schemes and The Victorian Floodplain Management Strategy, released by the DELWP in 2016. The objective of the state planning policy framework[4] for floodplain management is to assist in the protection of:

- Life, property and community infrastructure from flood hazard.
- The natural flood-carrying capacity of rivers, streams and floodways.
- The flood storage function of floodplains and waterways.
- Floodplain areas of environmental significance or of importance to river health.

9.2 Existing Controls

An assessment of the existing planning controls for St Arnaud was undertaken. Within the study area no flood related planning overlays including the Floodway Overlay (FO), Land Subject to Inundation Overlay (LSIO) and Special Building Overlay (SBO) have been applied.

9.3 Identified Risk and Available Controls

The State Planning Policy framework floodplain management policy currently recognise the 1% AEP flood event as the design flood event by which planning and building controls should apply. There are a number of available land use and development controls which enable authorities to regulate development so that the likelihood and consequences of flooding to community safety and property are considered and where possible minimised.

In assessing how controls should be applied within St Arnard, consideration must be given to both the extent of the 1% AEP flood event as produced by the study result and the nature of the flood risk. Each of the available

[4] Victorian Floodplain Management Strategy (2016) , accessed from: https://www.water.vic.gov.au/__data/assets/pdf_file/0021/53715/Victorian-Floodplain-Management-Strategy-Part-1-to-5.pdf

flood provisions (VPP) provides differing degrees of flexibility for the development of flood affected land which directly relates to the identified flood risk. Available controls include:

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

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

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

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

- **Special Building Overlay (SBO)** – defines flooding within the urban environment from overland flow results from stormwater

*Purpose: The Special Building Overlay (SBO) identifies land in **urban areas** liable to inundation by overland flows that exceed the capacity of the drainage system. The purpose of the SBO is to ensure that future developments allow the free passage of floodwaters, minimise flood damage, are compatible with flood hazard and local drainage conditions, and will not cause a significant rise in flood level or flow velocity*.

- **Urban Floodway Zone (UFZ)** – defines flooding high hazard areas and major flow paths within the urban areas

Purpose: To identify waterways, major flood paths, drainage depressions and high hazard areas within urban areas which have the greatest risk and frequency of being affected by flooding.

It is recommended that the planning scheme and building controls for St Arnaud and the broader study area be updated to reflect the flood risk identified by this project. Selection of the most appropriate planning controls must consider both the nature of the flood risk (riverine or urban stormwater) and the flood hazard in accordance with Australian Rainfall and Runoff safety limits[5]. For the purposes of this assessment, hazard category H1 has been considered to be safe with hazard categories H2-H6 being acknowledged as being unsafe. It is recommended Northern Grampians Shire Council implement both LSIO and FO layers for St Arnaud, as shown in Figure 9-1.

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[5] Australian Rainfall and Runoff, www.arr.org.au

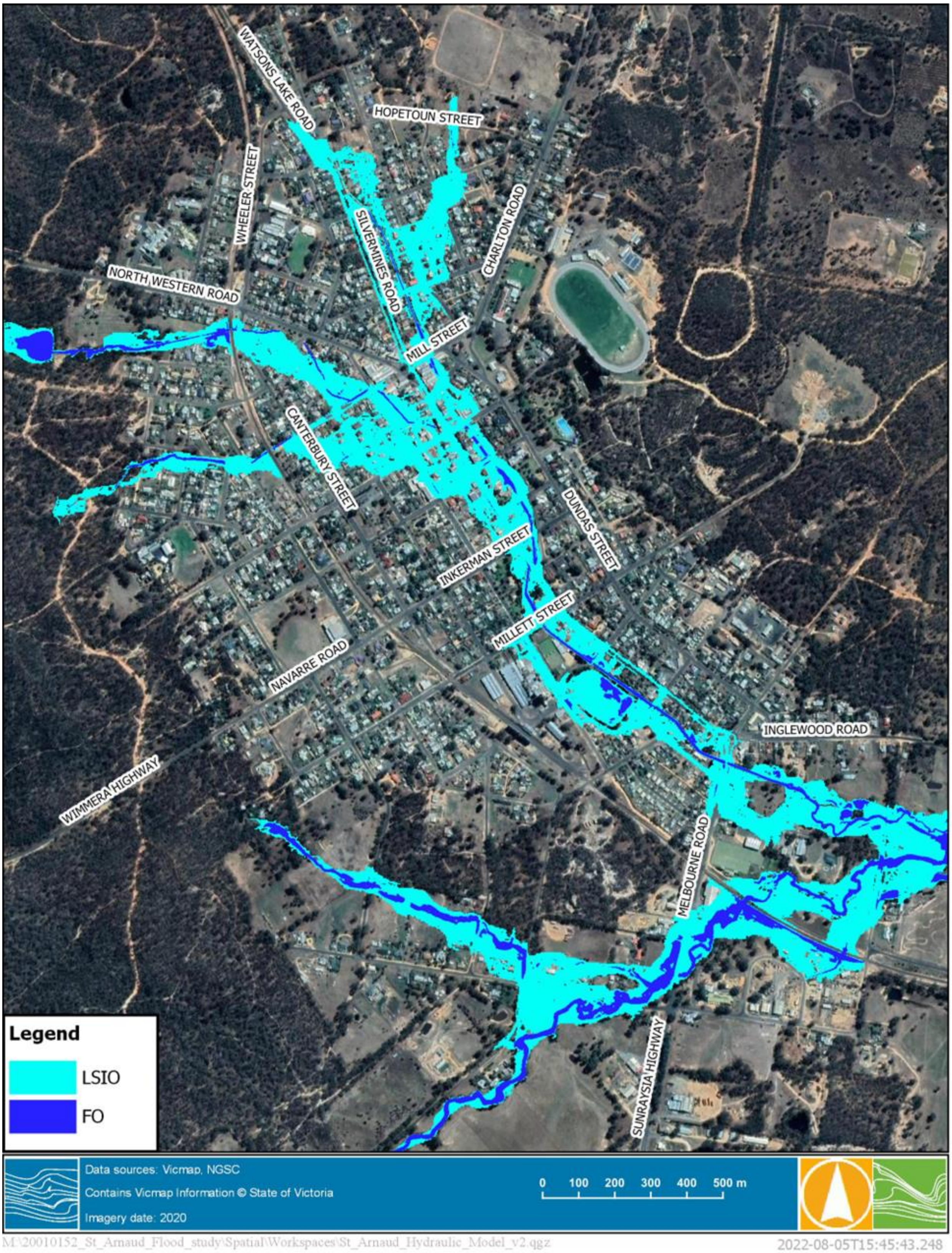

FIGURE 9-1 RECOMMENDED LSIO AND FO EXTENTS

10 RECOMMENDATIONS

Recommendations from the St Arnaud 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 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 CCMA for the consideration of the potential Flash Flood Warning system for St Arnaud.
  - Review the information within the Flood Warning and Intelligence 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.
  - Assess funding options to pursue the mitigation options discussed in this report.
- **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.