in association with

Upper Avoca River Flood Investigation

Summary Report

IS297900-RPT-007-Summary-RevA

16 April 2021

Pyrenees Shire Council

Cover image courtesy of ABC (2010), Avoca River floods in Victoria, https://www.abc.net.au/news/2010-09-04/avoca-river-floods-in-victoria/2248938

Upper Avoca River Flood Investigation

Project No:	IS297900
Document Title:	Summary Report
Document No.:	IS297900-RPT-007-Summary-RevA
Revision:	A
Document Status:	Draft
Date:	16 April 2021
Client Name:	Pyrenees Shire Council
Client No:	
Project Manager:	Michael South
Author:	Michael South
File Name:	IS297900-RPT-007-Summary-RevA.docx

Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
A	16/04/2021	Final	MS	PP	PP	PP

Contents

List of Figures

List of Tables

Definitions

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 cubic metres per second has an AEP of five per cent, it means that there is a five per cent chance (i.e. a 1 in 20 chance) of a peak discharge of 500 cubic metres per second being equalled or exceeded in any one year (also see average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding to about mean sea level.
Average Annual Damages (AAD)	The average annual damage is the average cost in dollars per year that would occur in a particular area from flooding over a long period of time.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, flood with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Benefit-cost ratio	Measure used to assess the economic viability of a mitigation measure.
Catchment	The catchment at a particular point is the area of land that drains to that point.
Design flood	A theoretical flood representing a specific likelihood of occurrence (for example the 1% AEP flood).
Flash flood	Flooding within 6 hours of causal rain.
Flood behaviour	The pattern / characteristics / nature of a flood.
Flood depth	The height or elevation of floodwaters above ground level.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum).
Hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrology	The term given to the study of the rainfall-runoff process in catchments.
LiDAR	Remote (airplane) sensing method that uses light in the form of a pulsed laser to measure distance to the Earth. This is used to generate detailed 3D topographical information across an area.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity occurring during a flood event at a particular location.
RORB	Runoff routing computer model for hydrologic analysis of catchment runoff.
Total Flood Warning System (TFWS)	A flood warning system made up of the following components; Data, Forecast, Modelling, Alert and Response (as defined by the Victorian Floodplain Management Strategy).
TUFLOW	Fully two-dimensional and one-dimensional unsteady flow hydraulic computer modelling software.
Velocity	The speed at which the floodwaters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged

velocity, i.e. the average velocity across the whole river or creek section if a one-dimensional solution is used; and depth average if a two-dimensional solution is used.

Abbreviations

AAD	Average Annual Damages
ARR 2019	2019 release of Australian Rainfall & Runoff
BCR	Benefit-cost ratio
BoM	Bureau of Meteorology
Council	Pyrenees Shire Council
DELWP	Department of Environment, Land, Water and Planning
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EIA	Effective Impervious Area
EMV	Emergency Management Victoria
ERTS	Event-Reporting Radio Telemetry System
GSAM	Generalised Southeast Australia Storm Method
GSDM	Generalised Short-Duration Method
m AHD	meters Australian Height Datum
FFA	At-Site Flood Frequency Analysis
FFWS	Flash Flood Warning System
LiDAR	Light Detection and Ranging
LGA	Local Government Area
m/s	Metres per second (a measure of speed / velocity).
m^3/s	Cubic metres per second (a measure of flow).
MFEP	Municipal Flood Emergency Plan
NCCMA	North Central Catchment Management Authority
NDRGS	Natural Disaster Resilience Grant Scheme
PALS	Portable Automated Logger System
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PRG	Project Reference Group
RCP	Representative Concentration Pathway
RFFE	Regional Flood Frequency Estimate
RRV	Regional Roads Victoria
The Investigation	Upper Avoca River Flood Investigation
The Catchment	Upper Avoca River catchment to the Investigation downstream boundary
TIA	Total Impervious Area
TFWS	Total Flood Warning System

1. Introduction

This report provides a summary of the Upper Avoca River Flood Investigation (the Investigation). The information summarised in this report is detailed in the supporting Investigation technical reports:

- Data Review Report (Jacobs 2020a)
- Flood Modelling Report (Jacobs 2020b)
- Flood Mapping Report (Jacobs 2020c)
- Flood Damages and Structural Mitigation Options Report (Jacobs 2021a)
- Flood Warning Feasibility Assessment Report (Jacobs 2021b)

The reporting is supported by Investigation deliverables including:

- Calibrated and validated RORB hydrologic and TUFLOW hydraulic models and results
- GIS flood mapping and Victorian Flood Database outputs
- Draft planning scheme overlay mapping
- Municipal Flood Emergency Plan updates

1.1 Investigation background

The Upper Avoca River area has a long history of flooding, including experiencing three significant flood events in the recent past: 2010, 2011 and 2016. To date, there has not been a detailed flood assessment completed for this area. To address this a flood study of the Upper Avoca River to inform flood intelligence and planning scheme maps for Amphitheatre, Avoca and Natte Yallock and the rural areas in between was identified as a high regional priority in the North Central Regional Floodplain Management Strategy 2018-2028 (NCCMA 2018).

In response the Pyrenees Shire Council (Council) has received funding from the Victorian and Commonwealth Governments through the Natural Disaster Resilience Grants Scheme (NDGRS), and in partnership with the North Central Catchment Management Authority (NCCMA) have engaged Jacobs to undertake the Upper Avoca River Flood Investigation.

The focus of this Investigation is to assess riverine flooding in the Upper Avoca River catchment with the main objectives to:

- Define flood related controls in the Pyrenees Shire Council 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

1.2 Catchment and investigation area description

The Investigation area (Figure 1.1) is located in the upper reaches of the Avoca River where it flows from the hills of the Great Dividing Range ranges onto the Avoca River floodplain where it remains relatively confined until it breaks out into the wider floodplain north of Charlton. To Archdale Junction (the downstream limit of the Investigation), there is contributing catchment of approximately 1,000 km^2.

The Avoca River is the primary waterway in the catchment area, forming in the hills south of Amphitheatre and flowing north, with several tributaries that join it prior to Archdale Junction, including:

- Homebush Creek
- Brown Hill Creek
- Cherry Tree Creek
- Middle Creek
- Redbank Creek
- Mountain Creek
- Wild Dog Creek
- Sardine Gully
- Fiddlers Creek
- Number One Creek
- Number Two Creek
- Sugarloaf Creek
- Rutherford Creek
- Green-hill Creek
- Forrest Creek
- Glenlogie Creek
- Amphitheatre Creek

In total the Investigation covers an area of approximately 300 km^2 from upstream of Amphitheatre to Archdale Junction, covering the townships of Amphitheatre, Avoca and Natte Yallock as shown in Figure 1.1. These towns have populations of 248, 1,193 and 188 respectively as of the 2016 census. High-resolution modelling was completed for the townships (which are referred to as town models), with coarser modelling for the broader area (which is referred to as the regional model).

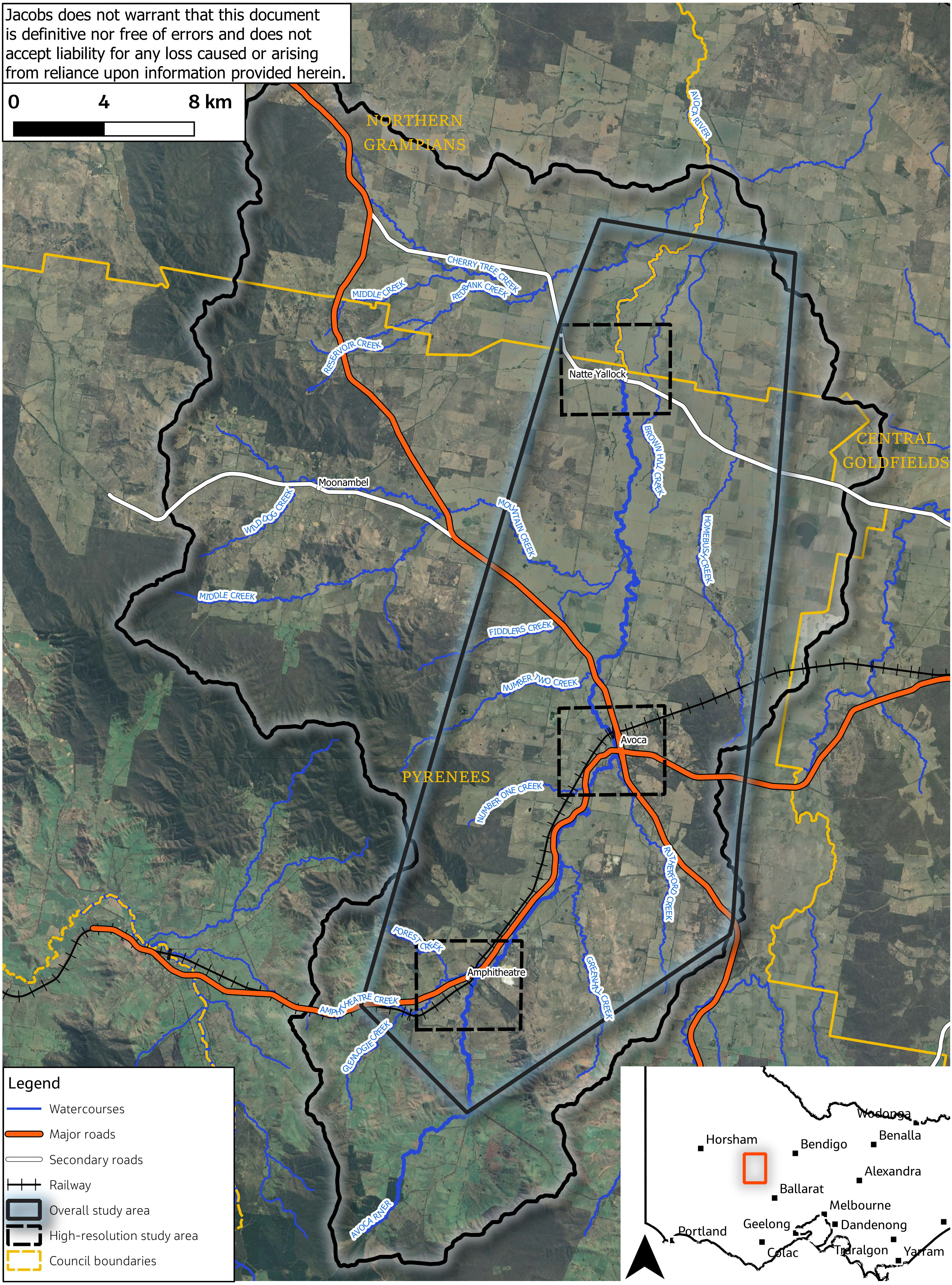


Figure 1.1: Upper Avoca Flood Investigation Overview

Jacobs

1.3 Stakeholder engagement

The support the core team (Council, NCCMA and Jacobs) in completing the Investigation a Project Reference Group (PRG) was established including representatives from the local community, Council, NCCMA, Department of Environment, Land, Water and Planning (DELWP), VicSES and Regional Road Victoria (RRV). Three meetings were held with the PRG throughout the Investigation as summarised in below. The PRG meetings were followed by open community sessions and additionally a community survey for those who could not attend the sessions.

The local knowledge provided by the PRG and broader community were invaluable to the successful completion of this Investigation by providing data inputs to, and validating the outputs of, the flood modelling, and identifying potential structural mitigation and flood warning options for assessment.

1.3.1 PRG meetings

- **PRG Meeting 1 (23 September 2019):** To provide an overview of the Investigation tasks and gather information. During this meeting flood photography taken in Avoca and Natte Yallock was provided along with the identification of potential historic flood level marks
- **PRG Meeting 2 (24 February 2020):** During this meeting the modelling inputs and methods used to produce the draft flood mapping for presentation at Community Session 2.
- **PRG Meeting 3 (12 August 2020):** During this meeting all of the structural mitigation options identified in the pre-feasibility structural mitigation options were considered and the five options for detailed assessment were selected. An overview of flood warning systems was also provided by Michael Cawood and feedback provided by the PRG on current informal actions the community takes as well as the communities expectations from a flood warning system

1.3.2 Community sessions and survey

- **Community Session 1 (23 September 2019):** To provide an overview of the Investigation tasks and gather information. During this meeting flood photography taken in Avoca and Natte Yallock was provided along with the identification of potential historic flood level marks.
- **Community Session 2 (24 February 2020):** During this session the tasks up to the draft flood modelling task were presented including draft flood mapping for which feedback was sought to refine model calibration. Potential flood mitigation options were also identified
- **Community Session 3 (12 August 2020):** During this session the structural flood mitigation options selected by the PRG were presented. An overview of flood warning systems was also provided by Michael Cawood and feedback provided by the PRG on current informal actions the community takes as well as the communities expectations from a flood warning system

To complement Community Session 1, a community flood survey was mailed out to gain a further information regarding the community's past experiences with flooding and the identification of potential mitigation options.

In total there were 36 responses to the surveys; 19 from Avoca, seven from Amphitheatre, one from Natte Yalock, one from Lamplough and eight from unknown locations within the catchment. From these 36 respondents, 15 of them of them had experienced flooding on their property.

The respondents identified to main factors which are seen be contributing to flooding; too much debris including trees in the Avoca River and contributing creeks and poor maintenance of local drainage assets such as culverts and minor drains along roads.

Several potential structural mitigation options were also identified by the community for consideration in the Investigation as described in Section 6.

2. Data review

A comprehensive set of data was collected and reviewed for the Investigation from a broad range of resources including Council, NCCMA, DELWP, RRV, BoM and publicly available datasets such the Water Measurement Information System (WMIS), Victorian spatial data online portal and the National Library of Australia's Trove newspaper online library. This data was supplemented by data provided the PRG and the local community along with data captured during the site visits and field survey. Table 2.1 provides a summary of the data collected and reviewed, while a full description of the data review tasks is provided in the Data Review Report (Jacobs 2020a).

Table 2.1: Data review summary

Data	Comments
Previous studies	No previous detailed flood studies have been undertaken for the Upper Avoca River area; however, several relevant previous studies were identified.
Historic flood data	The following historic flood data was collected and used in the flood model calibration and definition of design flood event magnitude: ▪ Community observations, identified flood marks and photography. ▪ Surveyed flood marks of the 1956, 2010 and 2011 events provided by NCCMA along with flood photography. ▪ The newspaper archives were used to identify significant historic floods prior stream gauge records becoming available.
Topographical data	The following datasets were used in the flood model to represent base topography: ▪ 2009-10 Victorian State-Wide Floodplains LiDAR Project ▪ 2009-10 ISC Rivers LiDAR ▪ VicMap Elevation DTM 10m Verification of the vertical accuracy of the LiDAR data against permanent survey marks and spot heights captured during the field survey confirmed that LiDAR accuracy and coverage is appropriate for use in the flood model.
Aerial photography	Council provided aerial photography covering the Catchment with 20 cm definition dated 15 January 2017 for use in setting up the flood model and presenting outputs.
Stream and rainfall data	Historic stream gauge level and flow data was sourced for the nine sites in the catchment, and rainfall data was sourced for 21 sub-daily (pluviograph) and 14 daily rainfall stations in and around the catchment. The accuracy of the stream and rainfall data was verified as part of the flood model calibration process and used for both model calibration and definition of design flood event magnitude.
Hydraulic structures	Hydraulic structure (culverts and bridges) information for inclusion into the flood model was provided by RRV, Council and NCCMA and supplemented with data captured during the site visit and filed survey.
GIS data	GIS data was sourced for planning zones and overlays, property parcels, road alignments and watercourses.
Site visit	Jacobs, accompanied by Council and the NCCMA, undertook a site visit on 15 July 2019. During this site visit, areas of interest were visited including the stream gauges and hydraulic structures along key waterways and roads.
Field survey	Following the site visit and review of the available data filed survey was captured to infill data gaps and included hydraulic structures, flood marks, gauge zero confirmations and spot heights for confirmation of the LiDAR data.

3. Flood modelling

A calibrated and validated flood model was developed for the Investigation. The flood model comprises two components; a RORB hydologic model to convert rainfall to runoff for a given probability to provide the flow rate and timing of inflows into TUFLOW hydraulic model(s) which simulates the movement of flow through catchment producing flood mapping outputs such as flood extent, level, depth and velocity.

the uncertainty bounds are smaller, while using a rainfall-runoff method for rarer events.

Due to the large area being flood mapped, both a regional model extending across the entire investigation area and three high resolution town models covering Amphitheatre, Avoca and Natte Yallock were developed. This approach allowed for the entire floodplain to modelled and mapped, while providing high resolution mapping in the township areas.

Flood modelling and mapping was completed for the following design events:

- 20% (or 1 in 5) Annual Exceedance Probability (AEP)
- 10% (or 1 in 10) AEP (including RCP 4.5 and 8.5 2100 climate change)
- 5% (or 1 in 20) AEP
- 2% (or 1 in 50) AEP
- 1% (or 1 in 100) AEP (including RCP 4.5 and 8.5 2100 climate change)
- 0.5% (or 1 in 200) AEP
- 0.2% (or 1 in 500) AEP
- Probable Maximum Flood (PMF)

3.1 Hydrologic modelling

The purpose of the hydrologic modelling is to convert rainfall to runoff for a given probability to provide the flow rate and timing of inflows into the hydraulic model. For this Investigation RORB hydrologic modelling has been undertaken to produce inflows to the TUFLOW hydraulic model(s). RORB is a widely used hydrologic modelling package across Victoria and Australia that incorporates many of the rainfall parameters and routines from Australian Rainfall and Runoff 2019 (ARR 2019) (Ball et al., 2019).

The RORB model developed has been calibrated and validated to recorded flood event flows at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges.

Design event modelling was defined by validating Monte Carlo flood frequency analysis results to the at-Site Flood Frequency Analysis results. This allows for higher reliance on the at-site flood frequency analysis (FFA) for more frequent events (i.e. 2% AEP and more frequent) where the uncertainty bounds are smaller, while using a rainfall-runoff method for rarer events.

A detailed description of the hydrologic modelling methodology, calibration and results are provided in Section 2 of the Flood Modelling Report (Jacobs 2020b).

3.1.1 Stream gauge flow verification

There are two active stream gauges in the upper Avoca River catchment; Avoca River @ Amphitheatre and Avoca River @ Archdale Junction. Prior to use of the recorded flows in the FFAs and RORB model calibration the published rating curves based on physical flow gaugings was verified against the hydraulic model.

Based on the verification, the rating curves at high river stages were revised and the recorded flows used in the hydrologic assessment. This is to say for larger flood events the recorded flows at the stream gauges have been revised. It should be noted, that the rating curves for revised for use in the flood modelling undertaken as part of the Investigation and it is not recommended that the revised flows be adopted for other purposes without further consideration.

3.1.2 Flood frequency analysis

The at-site FFAs for the Avoca River @ Amphitheatre Gauge and Avoca River @ Archdale Junction have been undertaken using the guidelines provided in Book 3, Chapter 2 of ARR 2019. The FFA was undertaken using the Flike software package. Flike provides a Bayesian framework for comprehensive at-site flood frequency estimation that allows the inclusion of ungauged historical events.

The resulting peak flow estimates are presented in Table 3.1.

3.1.3 RORB model development and calibration

The RORB model extends from the upper catchment limits to the Avoca River – Cherry Tree Creek confluence. The sub-catchment boundaries defined for the Charlton Flood and Drainage Management Plan by BMT WBM (2013) were used as the base for the model development. These sub-catchments were then further refined to meet the requirements of the Investigation, mainly ensuring 3-4 catchments upstream of the main hydraulic model inflows and including interstation areas at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges to facilitate calibration.

The RORB model was calibrated and validated at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges. The RORB model was calibrated against three flood events (September 2010, January 2011 and September 2016) and summary statistics were reviewed to assess the fit of the model. The model was then validated against a further two flood events (August 1992 and September 1996) using the calibrated routing parameters.

The results of the calibration and validation indicate that overall, the RORB model was able to represent the rainfall-runoff characteristics of the catchment and is suitable for providing inflows in to the TUFLOW hydraulic model. However, there are two main points of note:

1) At the Avoca River @ Archdale Junction gauge the RORB model is not able to represent the steep rising limb and slow receding limbs of the recorded hydrographs.
2) For the validation events which occurred in 1990s the lack of sub-daily rainfall data in the catchment may be resulting in the underrepresentation of intense rainfall bursts.

3.1.4 Design flows and critical events

Using the results of the Monte Carlo flood frequency analysis, the adopted design storm events were chosen by selecting the storm duration and areal temporal pattern that best represented the peak flow estimates at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction gauge locations, and an ungauged location at Avoca Township. The adopted design event peak flows and parameters, along with a comparison to the FFA and the Monte Carlo flood frequency analysis peak flow estimates are presented Table 3.1.

The 12-hour PMP storm duration using the Generalised Southeast Australia Storm Method GSAM temporal patterns results in the peak flow at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction gauge locations, and an ungauged location at Avoca Township (Table 3.1).

3.2 Hydraulic modelling

TUFLOW hydraulic models were developed to simulate the movement of flow through catchment producing flood mapping outputs such as flood extent, level, depth and velocity. The TUFLOW models incorporated elements model in both the the 1D and 2D domains to best represent the floodplain/waterway topography and structures such as bridges, culverts, weirs and levees.

Due to the large area being flood mapped, both a regional model extending across the entire investigation area along with three high resolution models covering the townships of Amphitheatre, Avoca and Natte Yallock have been developed. This allows for the entire floodplain to modelled and mapped, while providing high resolution mapping in the township areas. The main characteristics of the models can be summarised as:

- **Regional model –** 10 m grid size model covering the entire Investigation area (Figure 1.1) from south of Amphitheatre to north of the Avoca River @ Archdale Junction stream gauge. The Avoca River and key tributaries are represented as imbedded 1D channels.
- **Town Models –** 2 m grid size models covering the Amphitheatre, Avoca and Natte Yallock towns. The waterways are represented in the 2D model domain. External flow boundaries are sourced from the regional model.

TUFLOW version 2018-03-AE-iSP-w64 was used for this assessment. The models were run with TUFLOW's HPC solver.

3.2.1 TUFLOW model calibration

To calibrate the TUFLOW hydraulic model, catchment inflows from the calibrated RORB model (see Section 3.1.3) were applied to the TUFLOW model. The modelled water levels were then compared to recorded flood levels. Recorded flood levels were available at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction streamflow gauges, as well as surveyed peak flood marks in Avoca and Natte Yallock.

While the 2016 event had the best coverage of rainfall data, there was only one flood mark available in Avoca. For this reason, the September 2010 and January 2011 events were adopted for calibration, and the September 2016 event was used for validation. The calibration events were used to refine model setup and parameters, while the validation was used checked the parameter selection.

The draft calibration event mapping was presented to the PRG and the community on 24 February 2020, where it was identified that the draft flood extents were underestimating Avoca River breakout flows upstream of Natte Yallock. As a result, the flood model was revised and presented to the community for confirmation on 12 August 2020, where the results were accepted.

The hydraulic model calibration and validation results identified the following themes:

- A good fit was achieved to the recorded flood levels at the stream gauges and flood marks for the September 2010 and January 2011 calibration events and the September 2016 validation events for both the town and regional models.
- As a result of limitations in the RORB model been unable to represent the fast rising and slow receding limbs of the recorded hydrographs at the Avoca River @ Archdale Junction, faster receding limbs are also represented in the regional TUFLOW model. This does not affect outputs of this Investigation.

Given the good fit to the recorded flood data the TUFLOW models is suitable for design event modelling.

Table 3.1: Adopted RORB design event peak flows and event parameters

AEP	Avoca River @ Amphitheatre Peak Flows (m^3/s)			Avoca Township (Ungagged) Peak Flows (m^3/s)		Avoca River @ Archdale Junction Peak Flows (m^3/s)			Critical Duration
	FFA Estimate	Monte Carlo FFA Estimate	Adopted Design Event	Monte Carlo FFA Estimate	Adopted Design Event	FFA Estimate	Monte Carlo FFA Estimate	Adopted Design Event	
20%	32	37	**36**	144	**147**	164	239	**228**	24 h
10%	50	52	**56**	204	**201**	334	348	**336**	24 h
5%	74	68	**64**	253	**248**	519	451	**440**	24 h
2%	114	94	**90**	334	**328**	744	584	**553**	24 h
1%	154	109	**109**	399	**401**	886	693	**701**	24 h
0.5%	202	127	**128**	463	**467**	1001	802	**858**	24 h
0.2%	282	150	**146**	545	**528**	1116	985	**957**	24 h
PMP	-	-	**796**		**2901**	-	-	**5206**	12 h

4. Flood mapping and intelligence outputs

4.1 Flood mapping

Flood depth, level, velocity and velocity x depth (hazard) mapping outputs were produced for all modelled flood events as listed in Section 3 and presented in the Flood Mapping Report (Jacobs 2020c). The GIS flood mapping outputs have also been supplied as part of the data handover as well been translated into Victorian Flood Database (VFD2) format.

Flood animations have also been produced as part of this Investigation.

Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 show the 1% AEP flood extent and depth maps for the Upper Avoca River study area (regional), Amphitheatre, Avoca and Natte Yallock respectively. Flooded buildings are also presented on these maps.

The regional mapping shows that the floodplain is well contained along the waterway corridors until approximately halfway between Avoca and Natte Yallock where the flow capacity of the Avoca River channel is reduced resulting breakout flows across the broad floodplain around Natte Yallock. Except for the PMF event, as the design floods increase in magnitude the extent of flooding does not greatly increase in the upper portions of the catchment, rather the depths increase.

In Amphitheatre the floodplain is well contained along Avoca River and Amphitheatre Creek corridors, except for the PMF event. As the design flood events increase in magnitude the depths of inundation increase but there is no significant increase in flood extent or establishment of new flowpaths. In all events this leads to lower portions of several residential properties adjacent to the waterways been inundated but the buildings are not while the driveways/roads to low density residential properties north of Amphitheatre Creek become inundated limiting access.

As with Amphitheatre, at Avoca the floodplain is well contained along Avoca River and contributing tributaries, with the exception of shallow flooding across the paddocks north-east of town. Along the main Avoca River corridor, from the 20% AEP event the backs of the residential properties on the eastern bank are inundated along with the Lions Park which is inundated to depths greater than 1.5 m and the Avoca Public Park where the oval is inundated to depths less than 0.5 m. As the design flood events increase in magnitude the depths of inundation increase resulting in inundation of the Lions Park by greater than 2 m and the Avoca Public Park by greater than 1.5 m in the 1% AEP event. This also results in the inundation of several residential properties immediately south of the Avoca Public Park and further inundation of the properties of the eastern bank of the Avoca River.

In Natte Yallock inundation is characterised by broad flooding across the floodplain on each side of the Avoca River, while the perched river banks themselves either remain dry or are inundated to shallower depths. In the 20% AEP event inundation across the town is generally below 0.5m in deep, primarily in the range of 0.2 – 0.4 m deep while an area or deeper inundation (flowpath) is present west of the township area. From the 2% AEP event, the capacity smaller tributaries and gullies are exceeded resulting in the broad inundation of the floodplain west of Avoca – Bealiba Road. In the 1% AEP event, depths on the east bank of the Avoca River remains below 0.5 m while on the west side are increased to above 0.5 m, primarily in the range of 0.5 – 0.6 m deep with shallower depths closer to the river bank.

Under the 2100 RCP 4.5 climate change scenarios, the 10% AEP event closely resembles that of the current climate 5% AEP event while the 1% AEP event closely resembles that of the current climate 0.5% AEP event. Under the 2100 RCP 8.5 climate change scenarios, the 10% AEP event falls approximately halfway between the current climate 5% and 2% AEP events while the 1% AEP event closely resembles that of the current climate 0.2% AEP event.

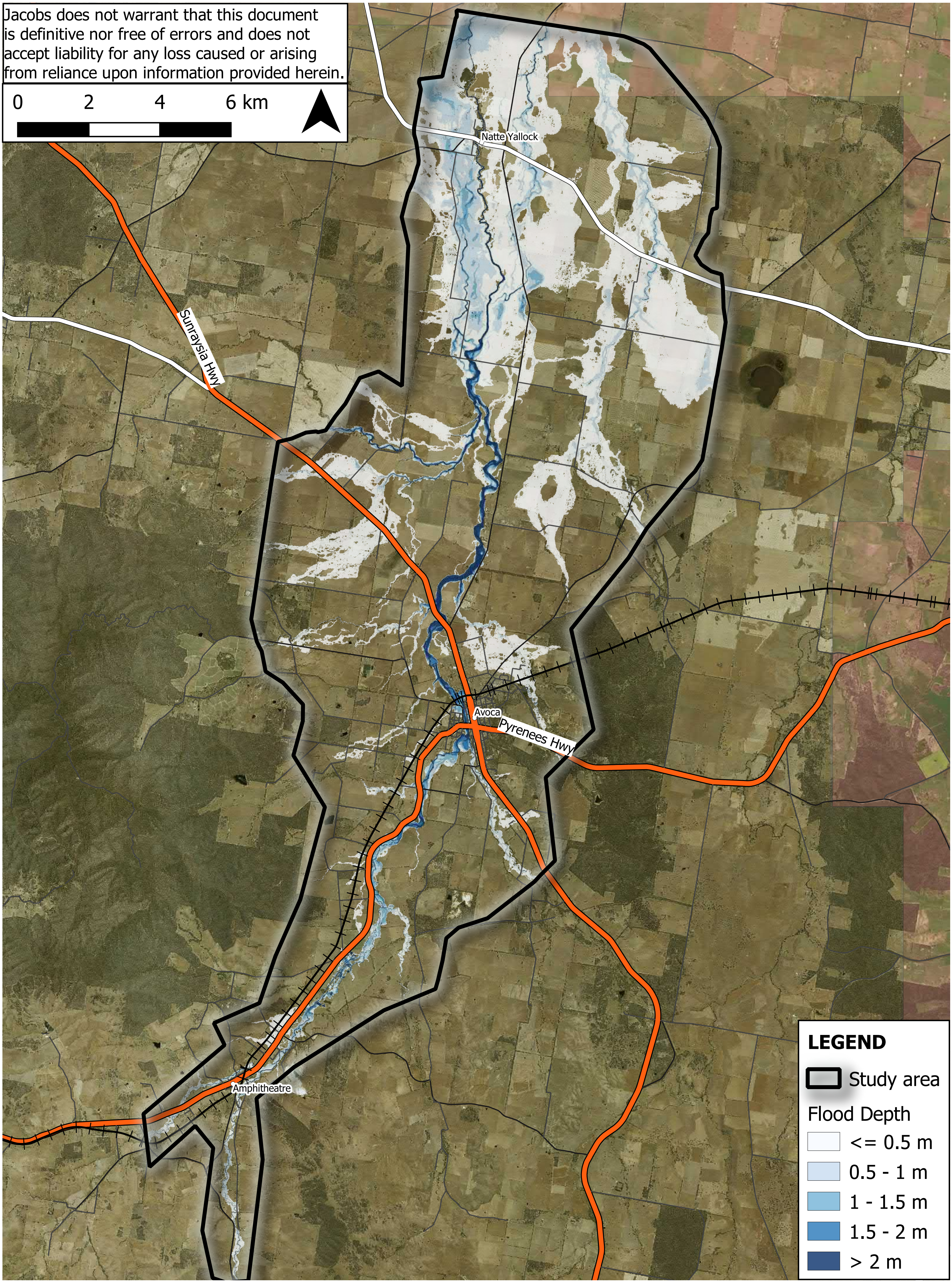
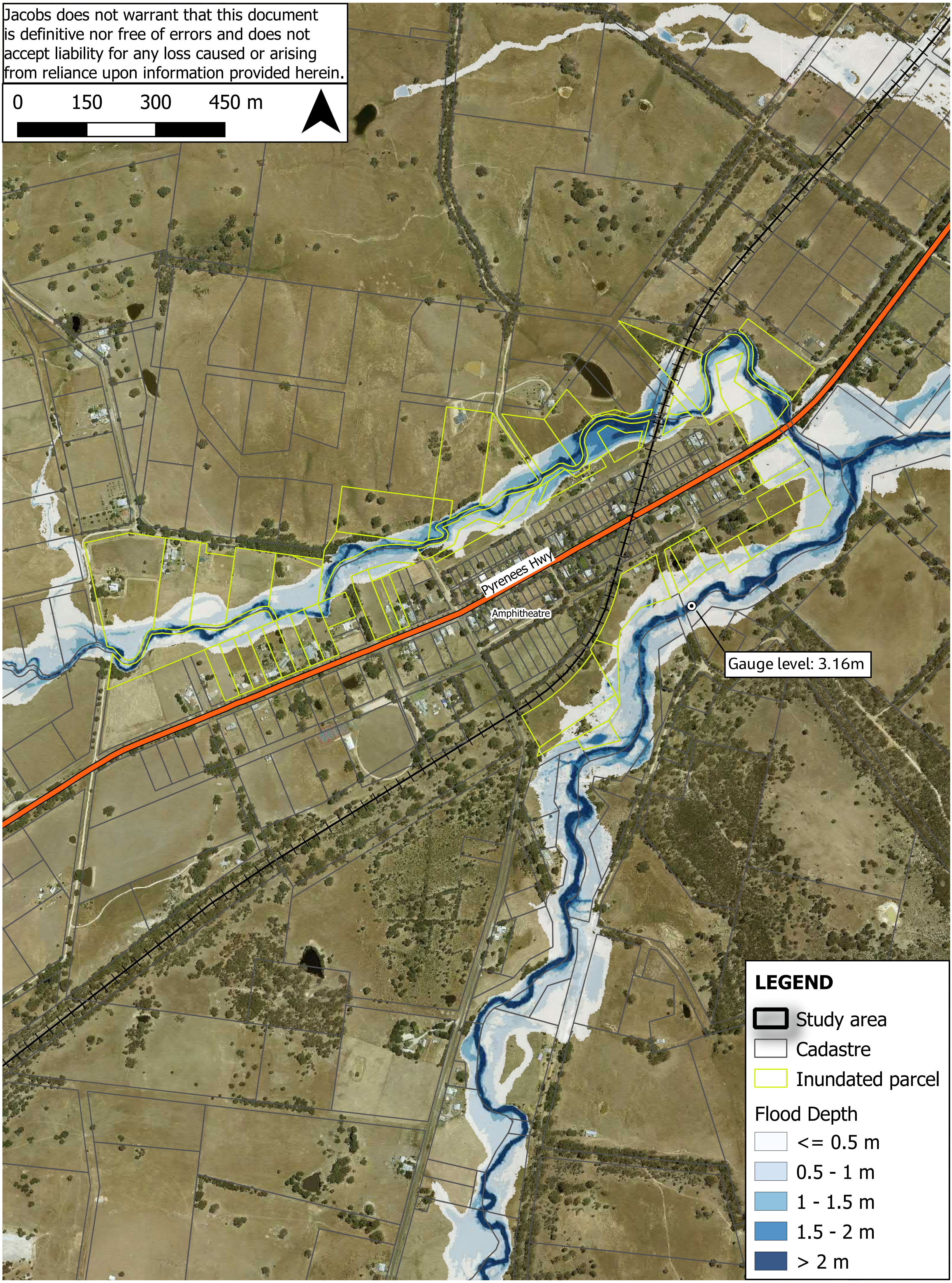


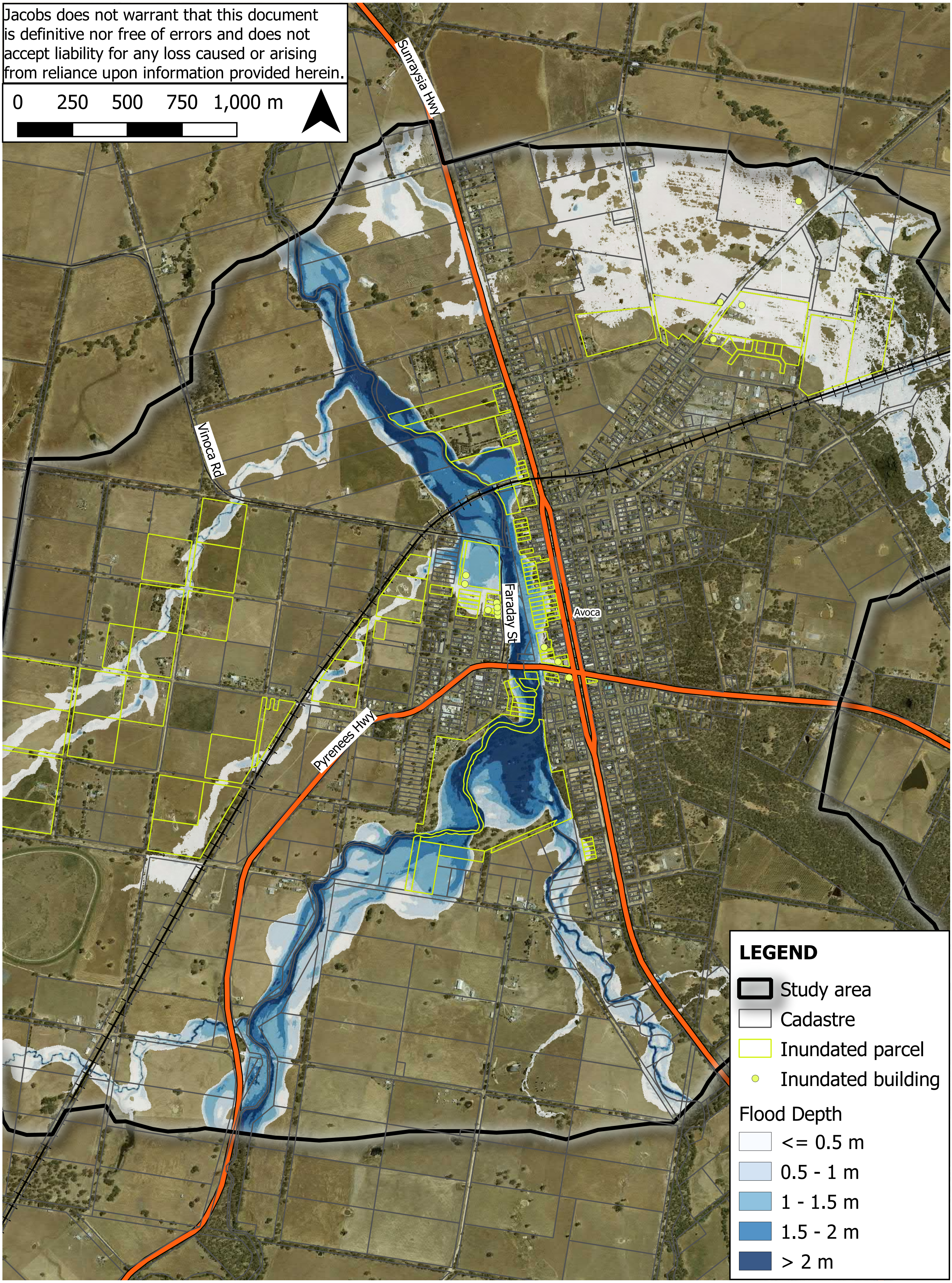
Figure 4.1: 1% AEP regional flood depth map

Jacobs



Jacobs

Figure 4.2: 1% AEP Amphitheatre flood depth map



Jacobs

Figure 4.3: 1% AEP Avoca flood depth map

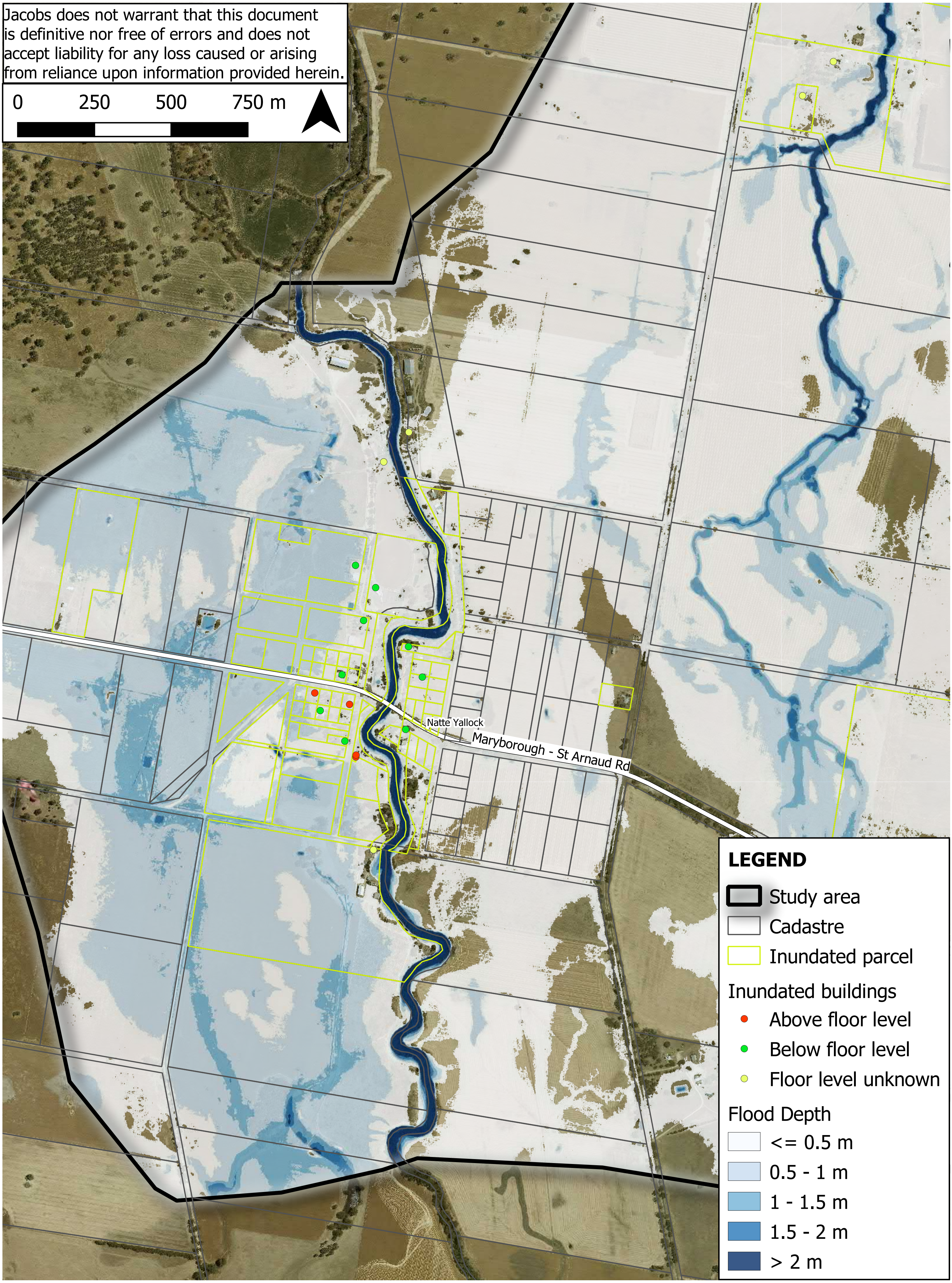


Figure 4.4: 1% AEP Natte Yallock flood depth map

Jacobs

4.2 Gauge levels

The peak flood levels at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges and other key locations in the study area are presented in Table 4.1. Historic event levels, recorded levels presented at the gauges, are coloured blue while the climate change scenarios are coloured red.

Table 4.1: Peak flood levels

Event	Avoca River @ Amphitheatre		Avoca (US Pyrenees Hwy bridge) (m AHD)	Avoca (US Sunraysia Hwy bridge) (m AHD)	Natte Yallock (US Maryborough-St Arnaud Rd bridge) (m AHD)	Avoca River @ Archdale Junction	
	m AHD	Gauge Level (m)				m AHD	Gauge Level (m)
20% AEP	268.11	2.42	230.25	225.79	209.09	200.04	5.06
September 2016	268.50	2.81	230.77	226.44	209.09	200.13	5.15
September 2010	268.45	2.76	230.86	226.57	209.09	200.14	5.16
10% AEP	268.52	2.84	230.58	226.22	209.09	200.11	5.13
5% AEP	268.59	2.91	230.71	226.37	209.09	200.14	5.16
10% AEP RCP 4.5	268.61	2.92	230.76	226.44	209.09	200.15	5.16
10% AEP RCP 8.5	268.69	3.01	230.97	226.70	209.10	200.19	5.21
2% AEP	268.77	3.08	231.15	226.90	209.10	200.23	5.24
1% AEP	268.85	3.16	231.36	227.16	209.10	200.30	5.31
January 2011[1]	-	-	231.46	227.26	209.10	200.30	5.32
1% AEP RCP 4.5	268.91	3.23	231.52	227.37	209.10	200.34	5.35
0.5% AEP	268.91	3.23	231.54	227.37	209.10	200.36	5.37
0.2% AEP	268.99	3.30	231.78	227.63	209.10	200.41	5.42
1% AEP RCP 8.5	268.99	3.31	231.78	227.63	209.10	200.40	5.42
PMF	270.68	5	234.58	229.44	209.17	201.86	6.88

1. Avoca River @ Amphitheatre stream gauge failed during the January 2011 flood event.

4.3 Travel times

The design event travel times to the Avoca River @ Amphitheatre stream gauge, Avoca Township, Natte Yallock Township, Avoca River @ Archdale Junction stream gauge are presented in Table 4.2. Please note that travel times can vary significantly for individual flood events as a result of several factors including:

- Catchment antecedent (wetness) conditions, including waterway baseflow; altering the time to convert rainfall to runoff
- Storm durations; intense short duration storms are likely shorter travel times than longer less intense storms

- Temporal patterns; the time distribution of rainfall within a storm event can alter the travel times
- Spatial patterns; the location of storm in the catchment can alter travel times. For example, a storm centred over the upper Avoca River catchment is likely to have a longer travel time to Natte Yallock than a storm centre over Mountain Creek

Noting the above and based on the design event modelling at Amphitheatre there is a 10-hour travel time for flood waters to start to rise in more frequent events (20% and 10% AEP events) which is reduced to 5-7 hours in rarer events. The travel times to Avoca are similar to those to Amphitheatre. The travel times to Natte Yallock are 18-17 hour in more frequent events (20% and 10% AEP events) which is reduced to 10-13 hours in rarer events.

Table 4.2: Design event (24 hour duration) travel times

AEP	Avoca River @ Amphitheatre		Avoca Township		Natte Yallock Township		Avoca River @ Archdale Junction	
	Start of rise (Hrs)	Flood peak (Hrs)	Start of rise (Hrs)	Flood peak (Hrs)	Start of rise (Hrs)	Flood peak (Hrs)	Start of rise (Hrs)	Flood peak (Hrs)
20%	10	22	10	23	18	26	18	32
10%	10	18	10	19	17	24	15	27
5%	8	22	8	23	13	28	10	24
2%	9	17	9	18	15	25	12	25
1%	7	17	8	18	13	21	10	24
0.5%	5	17	5	18	10	22	9	24
0.2%	6	17	7	18	12	21	8	24
PMF	3	9	3	9	7	11	4	13

4.4 Road inundation

Road inundation depths are presented in Table 4.3 for the locations shown in Figure 4.5. The roads that have been inundated to a depth greater than 0.3 m have been highlighted in red.

Table 4.3: Road inundation depths

AEP	**Location and flood depth in m**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
20%	0.03	0.10	1.18			0.03			0.76	0.68			0.16		0.09	0.07	0.14	0.37	0.04
10%	0.03	0.35	1.63			0.04			0.96	0.83			0.18	0.01	0.15	0.22	0.23	0.59	0.05
5%	0.03	0.43	1.70		0.01	0.04			1.02	0.88			0.19	0.17	0.18	0.26	0.26	0.64	0.05
2%	0.03	0.63	1.98		0.03	0.05	0.32		1.17	0.99			0.21	0.81	0.39	0.45	0.30	0.86	0.05
1%	0.03	0.73	2.08		0.09	0.05	0.45		1.23	1.04			0.22	1.10	0.54	0.57	0.32	1.05	0.05
0.5%	0.04	0.82	2.16		0.12	0.05	0.55		1.27	1.07			0.24	1.33	0.65	0.65	0.35	1.17	0.05
0.2%	0.05	0.91	2.24		0.17	0.06	0.65	0.01	1.31	1.10			0.31	1.57	0.79	0.73	0.36	1.26	0.05
10% AEP RCP 4.5	0.03	0.43	1.72		0.01	0.04			1.03	0.88			0.19	0.26	0.22	0.30	0.26	0.66	0.05
10% AEP RCP 8.5	0.03	0.53	1.88		0.01	0.05	0.17		1.12	0.95			0.20	0.57	0.31	0.38	0.28	0.76	0.05
1% AEP RCP 4.5	0.04	0.82	2.15		0.11	0.05	0.55		1.27	1.07			0.24	1.32	0.63	0.64	0.34	1.14	0.05
1% AEP RCP 8.5	0.06	0.92	2.25		0.17	0.06	0.65	0.01	1.31	1.10			0.31	1.57	0.78	0.73	0.36	1.25	0.05

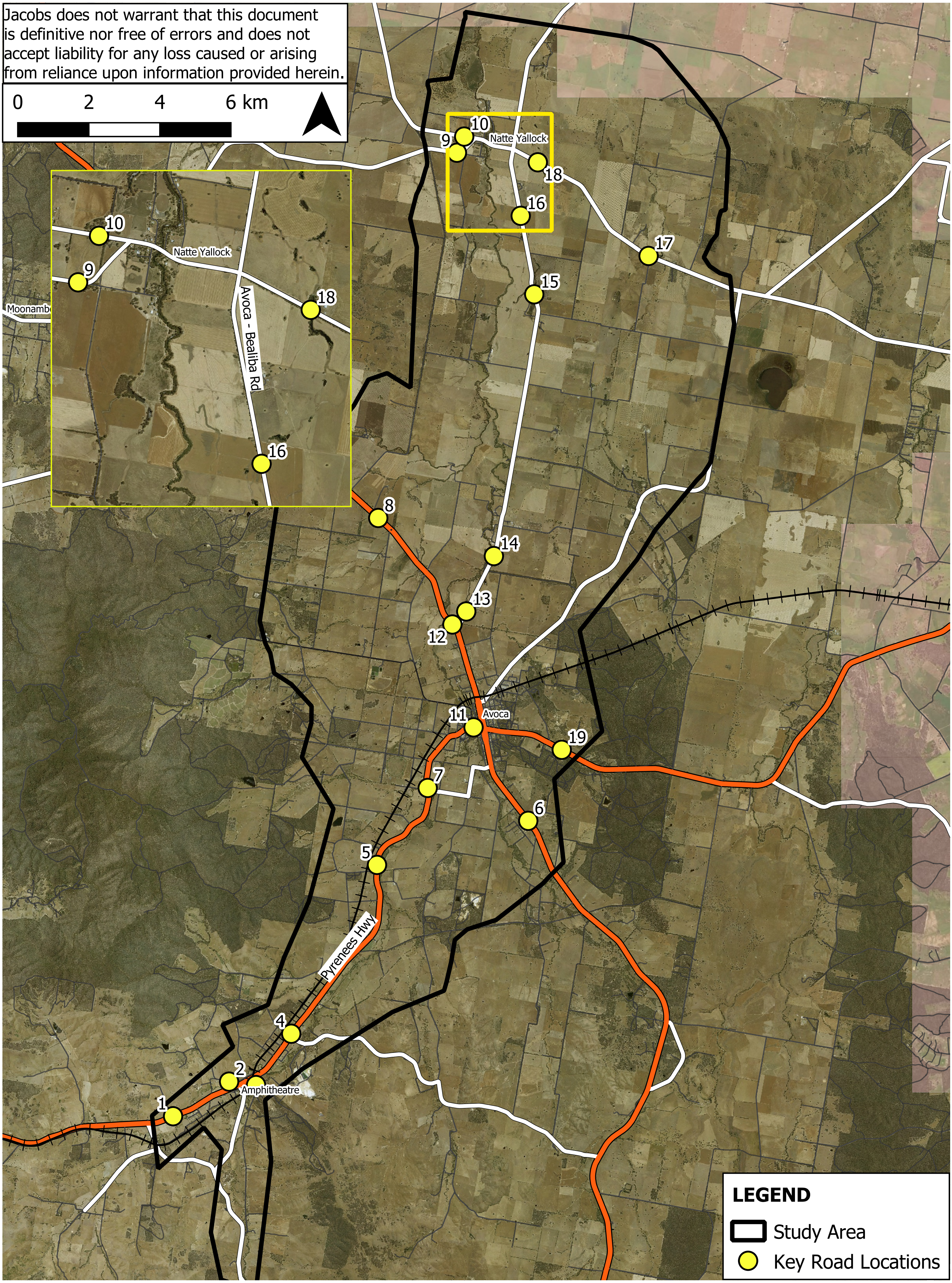


Figure 5.1: Road inundation reporting locations

Jacobs

5. Existing conditions flood damages assessment

The flood damage assessment is an important component of the Investigation as it enables floodplain managers and decision makers to gain an understanding of the monetary cost of flooding. The information determined in the damages assessment is also used to inform the selection of mitigation measures via a cost benefit analysis (Section 6). As the objective of the structural mitigation options assessed was to mitigate flood impacts in the township areas, the flood damages assessment was setup to focus on the damages to the towns. A detailed description of the flood damages assessment methodology, economic inputs and results is provided in Section 2 of the Flood Damages and Structural Mitigation Options Report (Jacobs 2021a).

Average annual damages (AAD) are the average damages per year that would occur in a particular area from flooding over an extended period of time. Estimation of AAD provides a basis for comparing the effectiveness of different management measures using a transparent and repeatable method (i.e. the reduction in the AAD) using benefit cost analysis.

AADs are calculated as the area under the probability-damage curve, estimated by determining the flood damages for each of the design events assessed. The existing condition AAD for Amphitheatre, Avoca and Natte Yallock are presented in Table 5.1.

Table 5.1: Existing conditions average annual damages (AAD)

Location	AAD
Amphitheatre	$95,000
Avoca	$558,000
Natte Yallock	$760,000

6. Structural mitigation options assessment

6.1 Pre-feasibility structural mitigation options assessment

The pre-feasibility structural mitigation options assessment was undertaken to identify the structural mitigation options for detailed assessment. The pre-feasibility assessment detailed in Section 3 of the Flood Damages and Structural Mitigation Options Report (Jacobs 2021a) was undertaken in two stages:

3) Identification of potential structural mitigation options throughout the preceding tasks of the project as detailed in Jacobs (2020a) from the following sources:
   - Local community at community meetings 1 and 2 and the community surveys
   - Project Reference Group (PRG) at PRGs meetings 1 and 2
   - Project team (Council, NCCMA and Jacobs)
4) Presentation of all the potential structural mitigation options to the PRG at PRG Meeting 3 (held on 12 September 2020), for selection of options for detailed assessment based on the following criteria:
   - Likely improvements in flood risk
   - Economic feasibility
   - Social considerations
   - Environmental considerations

6.2 Detailed structural mitigations assessment

Of the 13 potential structural mitigation options assessed as part of the pre-feasibility assessment, 5 five options were selected for detailed assessment in the hydraulic model:

1) Avoca Public Park bund
2) Channel clearing (tree and debris removal)
3) Raise levee banks along the Avoca River
4) Flow training levees upstream of Natte Yallock
5) Moonambel – Natte Yallock Road bermed corner lowering and tree removal

Using the flood model, each structural mitigation option was assessed against its effectiveness in reducing the risk of flooding, the economic benefit and the social and environmental advantages and disadvantages.

The economic viability of a scheme is initially assessed by calculating the monetary benefit-cost ratio (BCR). A benefit-cost ratio of 1.0 indicates that the monetary benefits are equal to the monetary costs. A ratio greater than 1.0 indicates that the benefits are greater than the costs while a ratio less than 1.0 indicates that the costs are greater than the benefits.

In floodplain management, a BCR substantially less than 1.0 may still be considered viable because the economic analysis does not include all of the benefits gained by flood mitigation works.

A comparison of the BCR for the structural mitigation options is presented in Table 6.1. Please note that the BCR for channel clearing was not assessed.

Table 6.1: Detailed structural mitigation option assessment BCR summary

Option	Benefit (Per annum)	Total Benefit (Present Value)	Capital Cost	Total Cost (Present Value)	BCR
Avoca Public Park bund	$84,000	$873,000	$550,000	$629,000	1.39
Raise levee banks along the Avoca River	-$177,000 (increase in AAD)	-$1,854,000	$4,400,000	$5,033,000	-0.37
Flow training levees upstream of Natte Yallock	$78,000	$1,042,000	$2,330,000	$2,796,000	0.37
Moonambel – Natte Yallock Road bermed corner lowering and tree removal	-	-	$1,159,000	$1,159,000	-

6.3 Recommended structural mitigation options

Following the detailed assessment of the five selected mitigation options it is recommended that a bund to protect the Avoca Public Park from inundation is further investigated (described below). While the other selected mitigation did not result in significant improvements in flood risk as assessed it is also recommended that:

- Where required channel clearing of individual blockages, particularly at critical locations such as upstream of bridges should be investigated.
- Remediation works should be investigated for sections of the existing Avoca River bank levee that are degrading.
- Where appropriate public or private local levees/bund to protect specific areas and assets can be further investigated.

6.3.1 Avoca Public Park bund

The proximity of the Avoca Public Park to the nearby Avoca River has rendered it subject to frequent flooding, with the 2010, 2011 and 2016 floods causing notable damage. These events correspond to the oval becoming inundated from approximately the 20% AEP events, resulting in considerable expense, with maintenance and repairs costing an estimated $150,000 by Council.

While primarily impacted by out of bank flow from the Avoca River that crosses Faraday Street from the east, the Avoca Public Park is also impacted by inundation from the north and to a lesser extent local flows from the west.

A bund is proposed to reduce the frequency of this inundation, with the assessed alignment running along the Avoca Public Park's eastern boundary (along Faraday Street) and northern boundary (along Vinoca Road) along with raising the access track on the western boundary, as shown in Figure 6.1.

The proposed bund is set to the 20% AEP flood level resulting in a height of approximately 0.8m and is positioned such that floodwaters from the river are trained along the eastern then northern perimeter of the oval, to join those flows from the west. The bund extends across the Faraday Street entrance requiring a regrading of the entrance to go over the bund (temporary levees could also be used to block the entrance).

The access track that runs along the western edge of the Avoca Public Park is proposed to be raised by approximately 1m to the 20% AEP flood level.

It is estimated that to construct the bund there will be a capital cost of $550,000 and ongoing maintenance cost of $11,000. However, it is expected that much of this maintenance cost is already outlaid as part of the existing park maintenance requirements.

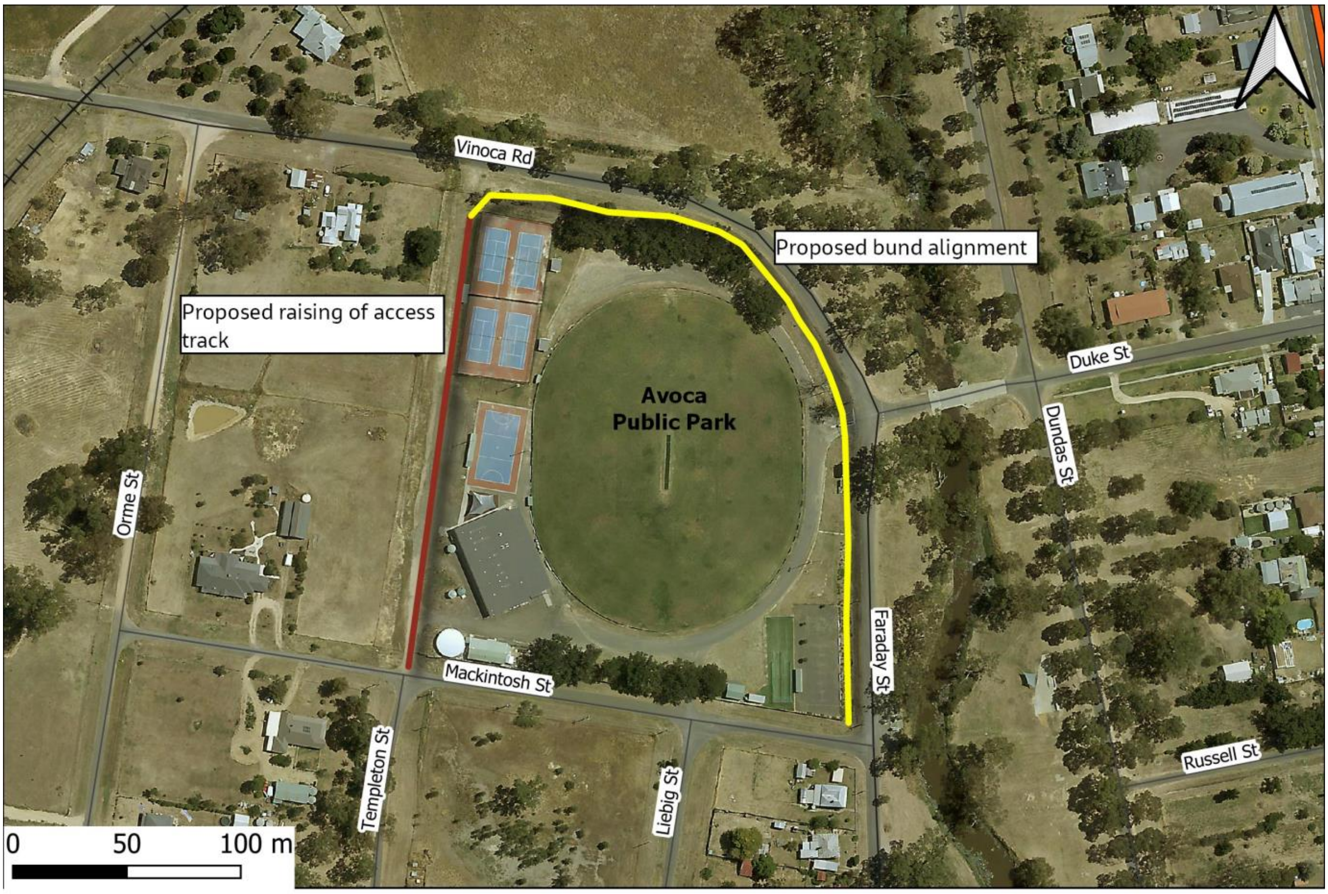


Figure 6.1: Avoca Public Park bund layout

7. Flood warning feasibility assessment

A flood warning or alerting system does not currently exist for the Upper Avoca River other than in a very generalised form. For example, all communities in the area receive the Bureau of Meteorology's Flood Watch and Severe Weather warnings, as well as messaging from VICSES. While these warnings and messages are important, they have been described as too broad and not very useful.

It is suggested that an "accurate" forecast is not the key to achieving an increase to personal safety and flood damage reduction within the Upper Avoca River communities. Rather it is timely alerting and access to relevant data and easy-to-use indicative tools that. As such the Total Flood Warning System (TWFS) feasibility assessment for this investigation identifies feasible options for improving local capability to act in a timely manner and improving future response to impending floods within the Upper Avoca River, thereby potentially reducing future flood risk. As presented in Table 7.1 (described in detailed in the Flood Warning Feasibility Assessment Report (Jacobs 2021b)), identified potential improvement Actions for the Upper Avoca River are presented as:

- Achievable in the NEAR term with minimum investment
- Achievable in the MID term with a greater level of investment
- Achievable LONGER term – fully developed option requiring significant investment

Discussions during the community engagement stages of this Investigation did contemplate the possibility of a flood warning system for Natte Yallock that was (almost) totally independent of existing gauge infrastructure and systems and very heavily locally driven and managed. The Landcare Group were seen as a key part of such a system. The Group remains a key part of the approach proposed herein. However, the inability to discriminate between small and big floods based on water levels at the Maryborough – St Arnaud Road Bridge demonstrates that a local river gauges have limited benefits. Similarly, the number and distribution of telemetered rain gauges upstream of Natte Yallock that are managed through the Water Partnership suggests that adding more rain gauges (either manual or automated) will not lead to a more robust solution. The key is seeking for BoM to make data from those existing rain gauges available through the BoM website at frequent intervals. The rainfall and upstream water level based indicative flood tools can then be used locally leading to increased flood warning lead time and community resilience, and a reduction in avoidable flood damages. The basis already exists for a robust locally driven flood warning system for communities in the upper Avoca catchment.

Table 7.1: TFWS Building Blocks and Staged Suggested Actions for the Upper Avoca River

TFWS Building Blocks	Potential Improvement actions for the Upper Avoca River
Achievable in the NEAR term with minimum investment	
DATA COLLECTION & COLLATION	Pyrenees Shire Council to approach BoM (with support from VICSES, NCCMA, DELWP and Central Goldfields Shire Council) to request necessary changes to enable near real-time (e.g. with 15 minute updates) public access via the BoM website to: ▪ Rain data from the eight rain gauges located in or in close proximity to the Upper Avoca River (refer to Section 5.1 of the Flood Warning Feasibility Assessment Report (Jacobs 2021b)) ▪ River level data from the four stream gauges within the Upper Avoca River Provide guidance to the local community (through a locally focussed flood awareness brochure and website) on how to interpret and use available rain and river level data and the indicative flood guidance tools, along with information about the flood warning system and how it will assist in reducing risk.
DETECTION & PREDICTION (i.e. Forecasting)	Pyrenees Shire Council to provide the indicative flood guidance tools and instructions for their use to Council staff, VICSES and local CFA for routine use. Provide training in use as appropriate. Pyrenees Shire Council and VICSES to agree who will maintain the tools and how.
INTERPRETATION	Mapping and intelligence from the Upper Avoca River Flood Investigation has been captured to the MFEPs. The indicative flood guidance tools together with the MFEPs enable those at risk to determine the likely effects of a potential flood with some lead time. Pyrenees Shire Council to ensure flood inundation maps and relevant MFEP Appendices along with the flood information cards for the upper Avoca catchment are readily available to the at-risk communities.
MESSAGE CONSTRUCTION	The initial alert within the at-risk communities of potential flooding is likely to come from a combination of environmental indicators (e.g. observance of heavy rain) and from consideration of rain data, the flood inundation maps, the indicative flood guidance tools and the flood intelligence in the MFEP and/or from observing a water level rise in local streams.
MESSAGE DISSEMINATION	Establish a Pyrenees Shire Council championed community flood action group. The Landcare Group at Natte Yallock may be in a position to take on this role. Use social media. A role remains for the Emergency Alert (EA) during a severe flood event.
RESPONSE	Following (or perhaps in concert with) acceptance of the MFEP by Pyrenees Shire Council and VICSES, encourage and assist residents to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.

<table>
<tr><th>TFWS Building Blocks</th><th>Potential Improvement actions for the Upper Avoca River</th></tr>
<tr><td>REVIEW</td><td>Review and update of local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that triggers a response. Best driven by Pyrenees Shire Council with input from VICSES, NCCMA, CFA and the Council championed community flood action group.
Pyrenees Shire Council to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system, including the MFEP.</td></tr>
<tr><td>AWARENESS</td><td>VICSES to prepare and print Local Flood Guides for the Amphitheatre, Avoca and Natte Yallock communities.
Make relevant parts of the MFEP publicly available (e.g. Council offices, library, website).
Pyrenees Shire Council and VICSES to:
▪ Load and maintain material including the MFEP to the Pyrenees Shire Council and VICSES websites with appropriate links to relevant useful sites
▪ Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice
▪ Routinely repeat distribution of awareness material and consider other measures</td></tr>
<tr><td colspan="2">Achievable in the MID term with a greater level of investment</td></tr>
<tr><td>DATA COLLECTION & COLLATION</td><td>In addition to the above:
▪ Pyrenees Shire Council to arrange for the installation of a set of staff gauges on the upstream side of the Pyrenees Highway Bridge in Avoca and on the upstream side of the Sunraysia Highway Bridge downstream from Avoca. The staff gauges should be installed such that the gauge boards can be read from the road for small and larger (i.e. 1% AEP) floods
▪ Develop and maintain a website (and social media?) presence for the FWS that includes guidance from the previously prepared locally focussed flood awareness brochure (see above) along with (a link to) flood mapping and intelligence outputs from the Upper Avoca River Flood Investigation
▪ Pyrenees Shire Council in consultation with NCCMA to decide on the datum to be used for any new river level gauges: AHD or local</td></tr>
<tr><td>DETECTION & PREDICTION (i.e. Forecasting)</td><td>In addition to the above:
▪ Pyrenees Shire Council to lead the determination of flood class levels for Amphitheatre and at the Pyrenees Highway Bridge at Avoca and the Sunraysia Highway Bridge downstream from Avoca. Will involve coordination between Council, VICSES, NCCMA and BoM and is a relatively straight-forward process
▪ Pyrenees Shire Council to maintain contact with VICSES on progress with the Automated Alerting Project with a view to implementation for upper Avoca catchment communities</td></tr>
</table>

TFWS Building Blocks	Potential Improvement actions for the Upper Avoca River
INTERPRETATION	In addition to the above: ▪ If local datum has been chosen for river level gauges, Pyrenees Shire Council to lead update of the MFEP and indicative flood guidance tools. This will assist local interpretation and the determination of likely flood impacts during future events
MESSAGE CONSTRUCTION	In addition to the above: ▪ If monitoring equipment with SMS capability is installed, the initial (or confirming) alert may come from the unit's SMS'ed message as rain and / or river levels exceed triggers with the above acting to reinforce and add value to resident's assessments and decision processes. Alternatively, and subject to resolution of VICSES and EMV roles in the initiation and dissemination of (flash) flood warnings, the initial alert may come via electronic and social media ▪ If a marginally more formal alerting system is deemed appropriate for the upper Avoca communities, Pyrenees Shire Council in conjunction with VICSES to: Champion formation of an upper Avoca catchment flood action group (or similar) Lead establishment of a Twitter and/or Facebook account for the upper Avoca catchment TFWS so that information can be shared within the community and by VICSES (say, following use of the indicative flood guidance tools) on likely flood severity, impacts and appropriate actions
MESSAGE DISSEMINATION	In addition to the above: ▪ If an SMS enabled gauge is active, Pyrenees Shire Council to identify / nominate key community members (in addition to VICSES and perhaps CFA) to receive SMS or email alerts on exceedance of alarm trigger values
RESPONSE	In addition to the above: ▪ Initiate a community engagement program to communicate how the FWS will work
REVIEW	As above.
AWARENESS	In addition to the above: ▪ Develop, maintain and renew flood awareness through activities and materials that emphasise personal safety, where rain, river and rain radar data is available, how that interpret and use that data, what any warnings/alerts mean and what individuals should do to stay safe and protect their property including how to fill and lay sandbags
Achievable LONGER term – fully developed option requiring significant investment	
DATA COLLECTION & COLLATION	In addition to the above:

TFWS Building Blocks	Potential Improvement actions for the Upper Avoca River
	▪ Pyrenees Shire Council to arrange purchase and installation of an ERTS river (or rain-river) gauge on the upstream side of the Pyrenees Highway Bridge in Avoca. At the same time, Pyrenees Shire Council with support from VICSES, NCCMA, DELWP and Central Goldfields Shire Council to approach BoM to provide near real-time public access to data from that gauge via its website ▪ Pyrenees Shire Council to arrange purchase and installation of an ERTS river (or rain-river) gauges on the upstream side of the Sunraysia Highway Bridge downstream from Avoca. As above, Pyrenees Shire Council with support from VICSES, NCCMA, DELWP and Central Goldfields Shire Council to approach BoM to provide near real-time public access to data from those gauges via its website ▪ Alternatively and instead of the ERTS equipment, Pyrenees Shire Council to arrange installation of different commercially available equipment (e.g. DipStik) to monitor (and alert on) rainfall and/or water level in the river at the locations described in the above two bullets ▪ As appropriate and depending on the monitoring and alerting equipment installed, Pyrenees Shire Council to invite upper Avoca catchment residents, along with VICSES, local CFA and Police, to opt-in to receive SMS or other alert messages direct from the installed equipment ▪ Pyrenees Shire Council to consider the addition of “sirens and/or flashing lights” options (triggered by exceedance of pre-set rainfall rates and depths, and river levels and rates of rise) for the automated gauge installed at the bridges as an alternative or additional means of alerting the community to imminent flooding
DETECTION & PREDICTION (i.e. Forecasting)	As above.
INTERPRETATION	As above.
MESSAGE CONSTRUCTION	As above.
MESSAGE DISSEMINATION	In addition to the above: ▪ If alternate commercially available water level (and rain) monitoring equipment is installed, Pyrenees Shire Council to establish and maintain an opt-in system that must be heavily community driven
RESPONSE	As above.
REVIEW	As above.
AWARENESS	As above.

8. Recommendations

This report provides a summary of the Upper Avoca River Flood Investigation (the Investigation). For a detailed description of the Investigation inputs, approach, and outcomes the accompanying detailed technical reports should be referred to.

The key recommendations of the Investigation are:

- A good calibration to the recorded data has been achieved for both the RORB hydrologic and TUFLOW hydraulic models and the resulting flood mapping is appropriate to be used for floodplain management purposes including:
  - Incorporation of the flood mapping and intelligence outputs into emergency response procedures and actions, including update of the Municipal Flood Emergency Plan (MFEP)
  - Incorporate the flood mapping into the planning scheme (Draft planning scheme overlays have been developed as part of this Investigation)
  - Use of the Investigation inputs and outputs to further educate/inform the local community of the flood risk in the Upper Avoca River
  - Use the flood models developed to undertake future assessments such as further investigation of potential structural mitigation options or infrastructure design
- A bund to protect the Avoca Public Park from inundation and reduce flood damages is further investigated.
- While structural mitigation options other than the Avoca Public Park did not result in significant improvements in flood risk as assessed it is recommended that:
  - Where required channel clearing of individual blockages, particularly at critical locations such as upstream of bridges should be investigated
  - Remediation works should be investigated for sections of the existing Avoca River bank levee that are degrading
  - Where appropriate public or private local levees/bund to protect specific areas and assets can be further investigated
- The possible actions identified in the flood warning feasibility assessment for the establishment of Total Flood Warning System be further investigated by Council and the local community, with support other relevant authorities as required

9. References

BMT WBM (2013), *Charlton Flood and Drainage Management Plan – Draft Flood Study*, BMT WBM.

Jacobs (2018), *Floodplain Management – Economic Appraisal Guidelines*, Prepared for the Department of Environment, Land, Water and Planning.

Jacobs (2020a), *Upper Avoca River Flood Investigation Data Review Report*, Doc. Ref: IS297900-RPT-001-DataReview-RevB.docx, Jacobs.

Jacobs (2020b), *Upper Avoca River Flood Investigation Flood Modelling Report*, Doc. Ref: IS297900-RPT-003-Modelling-RevC.docx, Jacobs.

Jacobs (2020c), *Upper Avoca River Flood Investigation Flood Mapping Report*, Doc. Ref: IS297900-RPT-004-Mapping-RevA.docx, Jacobs.

Jacobs (2021a), *Upper Avoca River Flood Investigation Flood Damages and Structural Mitigation Options Assessment Report*, Doc. Ref: IS297900-RPT-005-Mitigation-RevA.docx, Jacobs.

Jacobs (2021b), *Upper Avoca River Flood Investigation Flood Warning Feasibility Assessment Report*, Doc. Ref: IS297900-RPT-006-Warning-RevA.docx, Jacobs.

Contact Us:

Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com