in association with

Upper Avoca River Flood Investigation

Flood Modelling Report

IS297900-RPT-003-Modelling-RevC

4 August 2020

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

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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 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.
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).
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.
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

ARR 2019	2019 release of Australian Rainfall & Runoff
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
GSAM	Generalised Southeast Australia Storm Method
GSDM	Generalised Short-Duration Method
m AHD	meters Australian Height Datum
FFA	At-Site Flood Frequency Analysis
LiDAR	Light Detection and Ranging
m/s	Metres per second (a measure of speed / velocity).
m^3/s	Cubic metres per second (a measure of flow).
NCCMA	North Central Catchment Management Authority
NDRGS	Natural Disaster Resilience Grant Scheme
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

1. Introduction

This Flood Modelling Report details the hydrologic and hydraulic modelling methodology and existing conditions flood mapping (presented in accompanying Flood Mapping Report) for the Upper Avoca River Flood Investigation (the Investigation).

Flood modelling and mapping will be derived 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)

This report builds on the project inception and site visit, and data review and validation tasks of the Investigation as documented in:

- Data Review Report (Jacobs 2019a)
- Flood Mapping Report (Jacobs 2019b)

1.1 Investigation background

The Upper Avoca River area has a long history of flooding, including experiencing three significant flood events over the past decade in 2010, 2011 and 2016. However, 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 is proposed 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).

1.3 Modelling Methodology Summary

A calibrated and validated RORB hydrologic model has been used to convert rainfall to runoff for a given probability to provide the flow rate and timing of inflows into TUFLOW hydraulic model(s). Design event modelling has been 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 probabilistic method for rarer events.

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:

- **Region model –** 10 m grid size model covering the entire Investigation area 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.

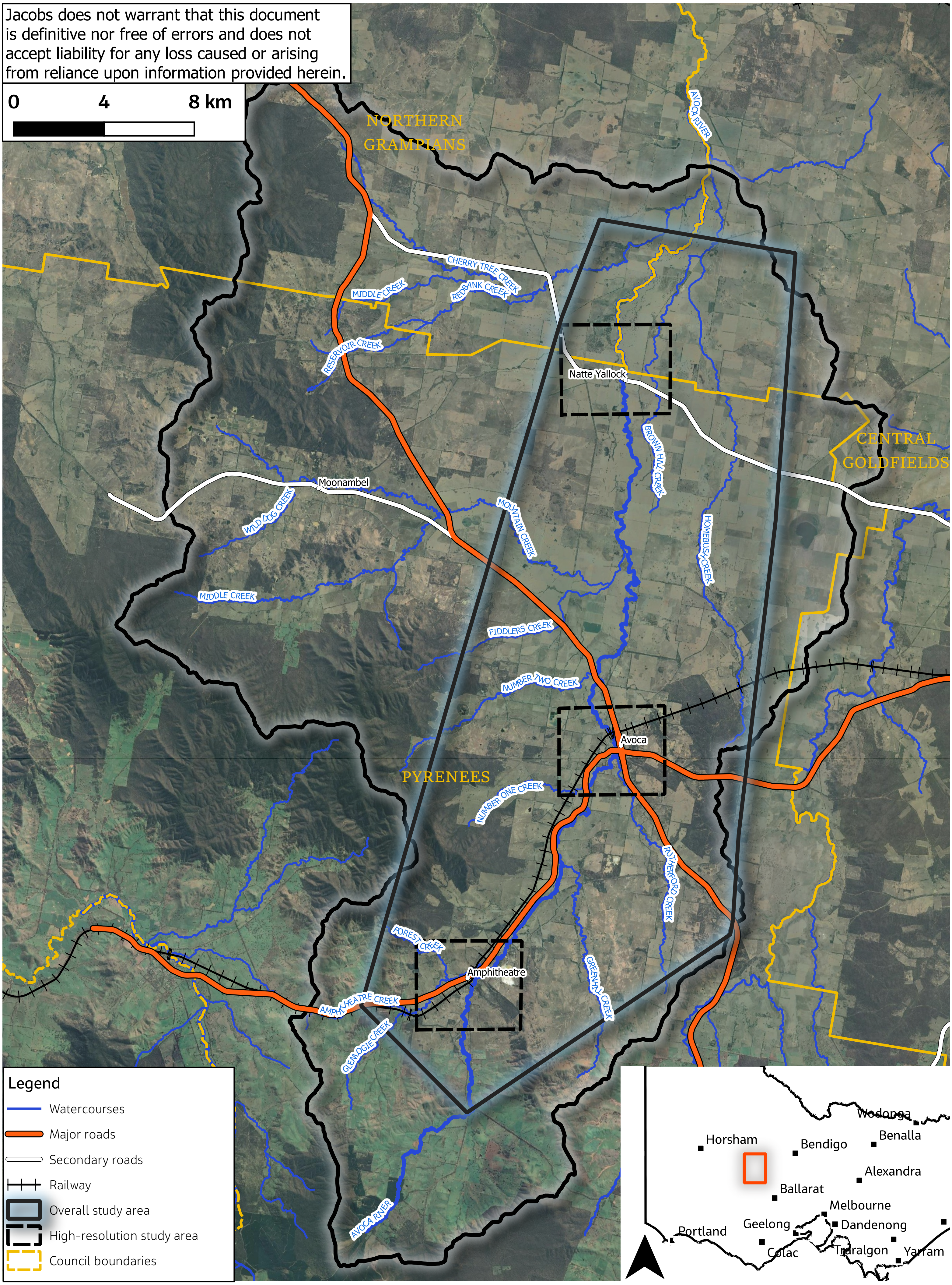

Figure 1.1: Upper Avoca Flood Investigation Overview

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2. 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 has been 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 probabilistic method for rarer events. As shown in Figure 2.1, this approach is consistent with the recommended approaches described in the 2019 release of Australian Rainfall and Runoff (ARR 2019) (Ball, et al. 2019) for design events of frequency between 20% and 0.2% AEP.

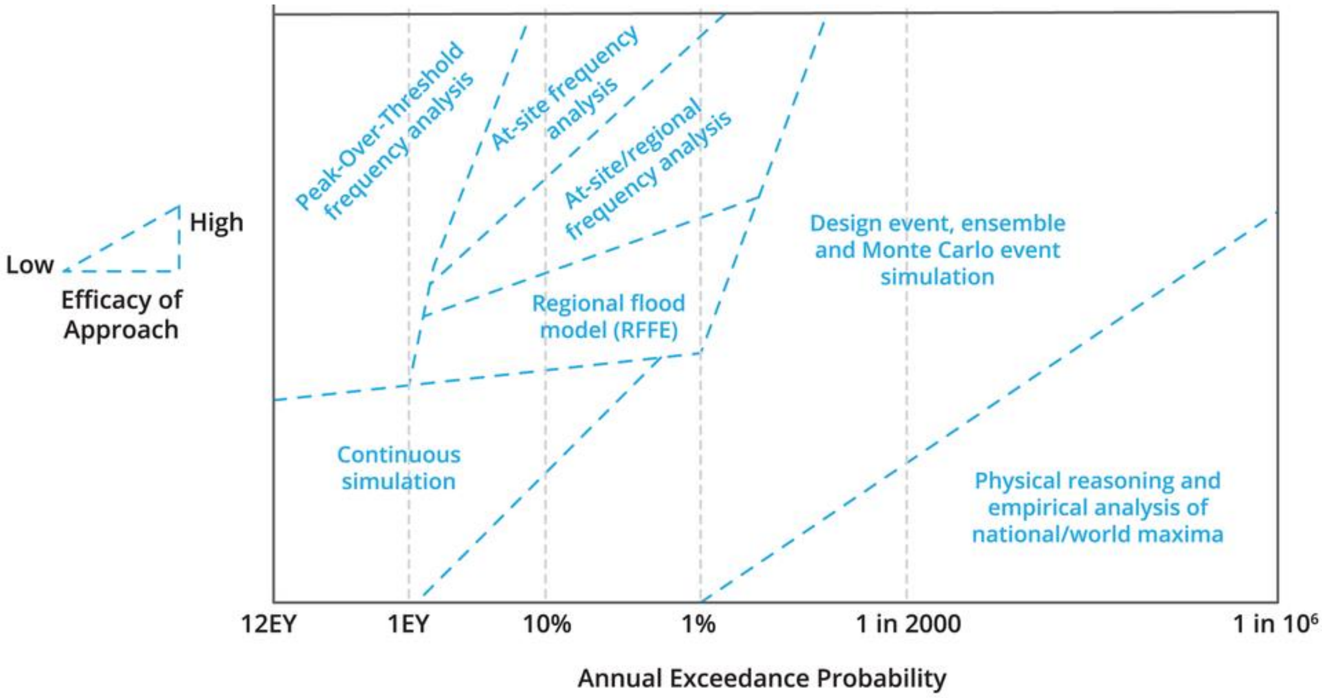

Figure 2.1: Illustration of Relative Efficacy of Different Approaches for the Estimation of Design Floods (Ball, et al. 2019)

2.1 Stream gauge flow verification

As described in the Draft Data Review Report 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 (Section 2.3) and RORB model calibration (Section 2.5) the published rating curves have been verified against the hydraulic model and physical flow gaugings.

2.1.1 Avoca River @ Amphitheatre rating curve verification

The rating curve for the Avoca River @ Amphitheatre stream gauge (Figure 2.2) was most recently published on 3 February 2020. This rating curve is valid from 1 July 2016 and is extrapolated from a gauge level of around 2 m. In total 316 physical flow gaugings have been taken at this gauge since it was opened in 1968, the largest of which was taken at a gauge level of 2.14m on 25 August 1983.

To verify the published rating curve the hydraulics were model was used to output water level-flow series at the gauge location. The regional model results fit well with the physical flow gaugings up to the highest physical gauging of 2.14m, where at these low levels the town model under estimates flows for a given level. However, from a level of approximately 2.5 m, as the floodplain becomes activated, the model results estimate a greater flow for a given level than the published rating curve (Figure 2.2). As such the recorded flows have been revised above a gauge level of 2.5 m to reflect the model results for use in the FFA and model calibration.

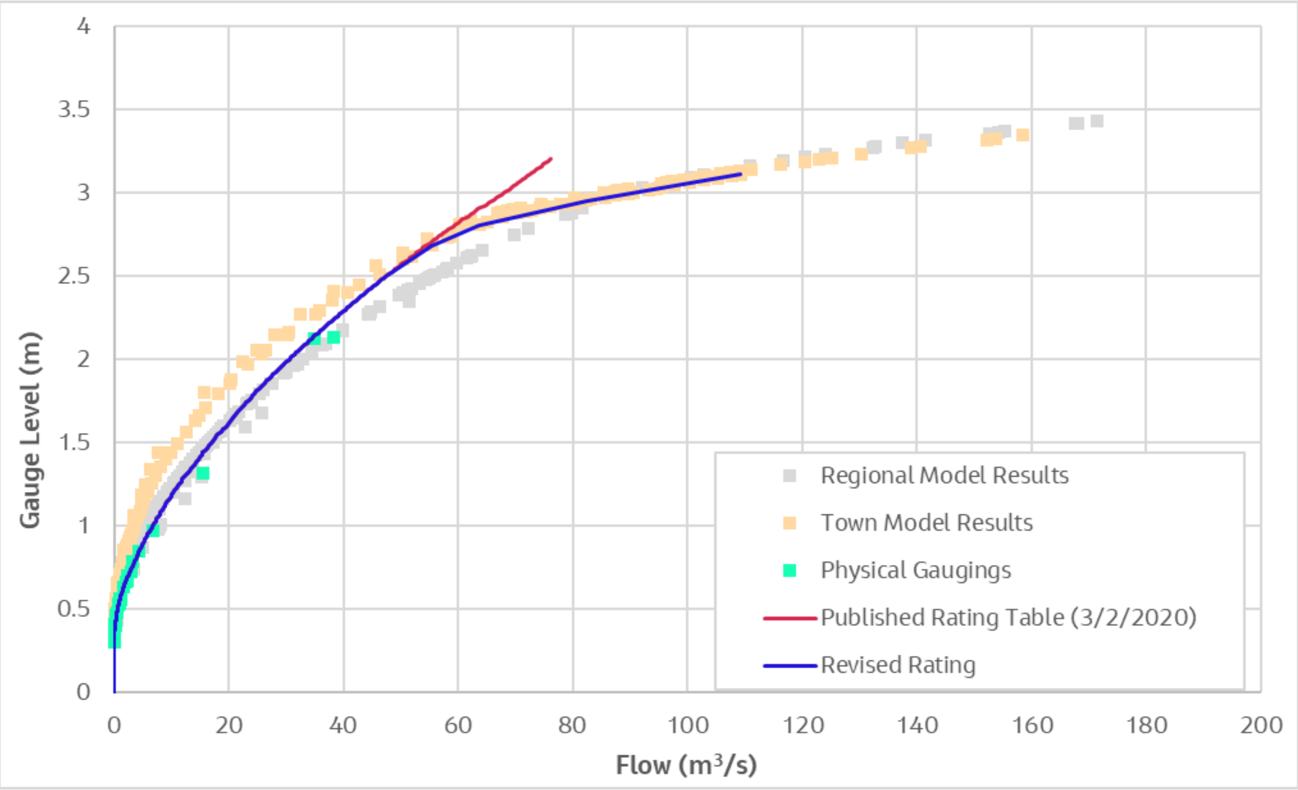

Figure 2.2: Avoca River @ Amphitheatre rating curve verification

2.1.2 Avoca River @ Archdale Junction rating curve verification

The rating curve for the Avoca River @ Archdale Junction stream gauge (Figure 2.2) was most recently published on 10 February 2020. This rating curve is valid from 1 July 2016 and is extrapolated from a gauge level of 4.81 m. In total 56 physical flow gaugings have been taken at this gauge since it was opened in 1987, the largest of which was taken at a gauge level of 5.01 m on 22 June 1987.

The floodplain is complex at the location of the Avoca River @ Archdale Junction gauge with Avoca River flows interacting with flows from Brown Hill Creek on the eastern floodplain and Cherry Tree Creek on the western floodplain, both of which discharge into the Avoca River approximately 2 km downstream of the gauge. Modelling indicated that flows from these smaller tributaries influence flood levels at the gauge as they combine with Avoca River flows across the floodplain. The adopted modelling methodology accounts for this interaction of flows in the TUFLOW model, as opposed to modelling cross sub-catchment diversions in the RORB model.

Given the above, and that the aim of the rating curve verification is to verify recorded flows for use in the FFA and RORB model calibration at the Avoca River @ Archdale Junction gauge location (prior to the tributaries discharging into the Avoca River), water level was sourced from the TUFLOW model with all inflow boundaries applied, while flow was sourced from the corresponding model with inflows from RORB-sub-catchments that discharge into the Avoca River downstream of the gauge excluded. The resulting water level-flow series is shown in Figure 2.3.

The model results fitted well with the physical flow gaugings up to the highest physical gauging of 5.01 m. However, from a level of approximately 4.5 m, the model results estimate a greater flow for a given level than the published rating curve (Figure 2.3). As the floodplain becomes fully activated at levels greater than 5 m, the published rating curve significantly underestimates flows in comparison to the TUFLOW model. As such the recorded flows have been revised above a gauge level of 4.81 m (corresponding to the level where flows are extrapolated within 1.5 of the max flow used for the published rating curve) to reflect the model results for use in the FFA and model calibration.

Please note, as described above the rating curve presented in Figure 2.3 has been developed to undertake FFA and model calibration to the Avoca River @ Archdale Junction stream gauge for this investigation and does not represent the full extent of flow across the floodplain.

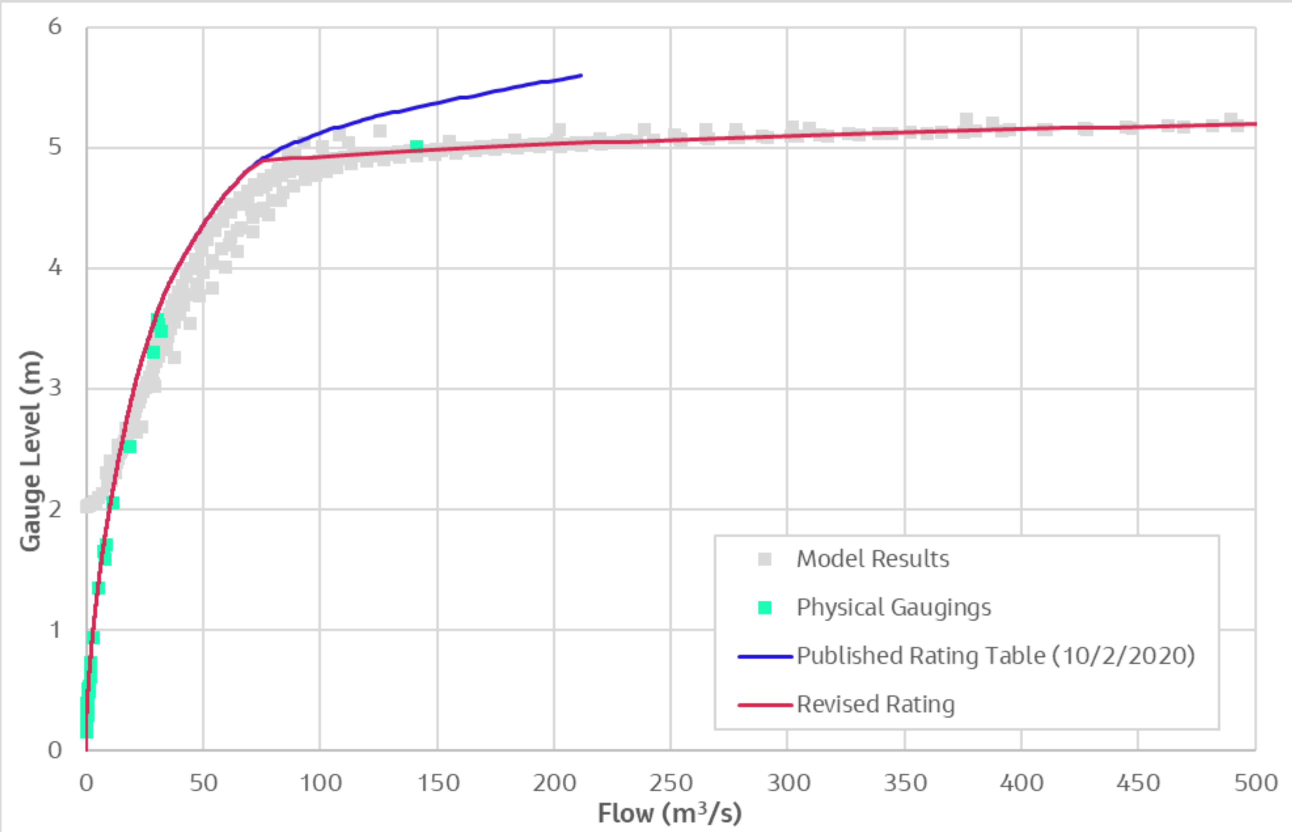

Figure 2.3: Avoca River @ Archdale Junction rating curve verification

2.2 Regional flood frequency estimates

Regional Flood Frequency Estimates (RFFEs) were completed for the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges (Figure 1.1) using the Regional Flood Frequency Estimation Model and the guidelines provided in Book 3, Chapter 3 of ARR 2019.

RFFEs attempt to transfer flood characteristics from a group of gauged catchments to ungauged locations of interest to determine peak flow estimates of design flood events. For this study, the RORB model has been calibrated and validated to stream gauges so the purpose of undertaking RFFEs is to provide prior parameter information to reduce the uncertainty of design flow estimates using the at-site FFA method as described in Section 2.3.

2.3 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 fitting of flood frequency distributions using Flike was undertaken with the following steps:

1) Prepare data:
    a) Collect gauged streamflow data
    b) Collect historic data, including the review of previous studies
    c) Undertake standard data checks on the stream flow data including checking error codes, cataloguing data gaps and undertaking visual inspections
    d) Determine the water year
    e) Extract the annual maximum series and check peaks for independence
2) Using Flike, fit an extreme value distribution to the annual maximum series, including the influence of:
    a) Historic data (data that exists beyond the extent of the annual maximum series)
    b) Censoring low flows with a multiple Grubbs-Beck test
    c) Inputting prior parameters information from the RFFE (Section 2.2)

2.3.1 Avoca River @ Amphitheatre FFA

2.3.1.1 Annual maximum flows

The Avoca River @ Amphitheatre (408202) stream gauge has records available from November 1966 to current providing an annual maximum flow series of 52 years from 1967 to 2018 as presented in Table 2.1. As shown in Figure 2.4 the flow series over this period is relatively complete.

An analysis of the flow series indicated that the calendar year can be used as the water year.

Table 2.1: Avoca River @ Amphitheatre annual maximum flows

Year	Flow (m³/s)	Year	Flow (m³/s)	Year	Flow (m³/s)
1967	0.2	1985	5.6	2003	21
1968	25	1986	34	2004	0.6
1969	6.5	1987	15	2005	16
1970	2.9	1988	43	2006	0.1
1971	7.4	1989	46	2007	15
1972	5.8	1990	18	2008	0.4
1973	67	1991	22	2009	15
1974	40	1992	51	2010	60
1975	45	1993	29	2011	NA[1]
1976	1.5	1994	1.0	2012	3.4
1977	5.5	1995	11	2013	2.4
1978	19	1996	22	2014	0.6
1979	20	1997	13	2015	1.0
1980	48	1998	10	2016	64
1981	36	1999	7.8	2017	1.3
1982	58	2000	9.7	2018	6.6
1983	62	2001	0.8		
1984	20	2002	0.4		

1. Gauge failed on rising limb of hydrograph during the January 2011 flood event, refer to Section 2.3.1.2 for further description.

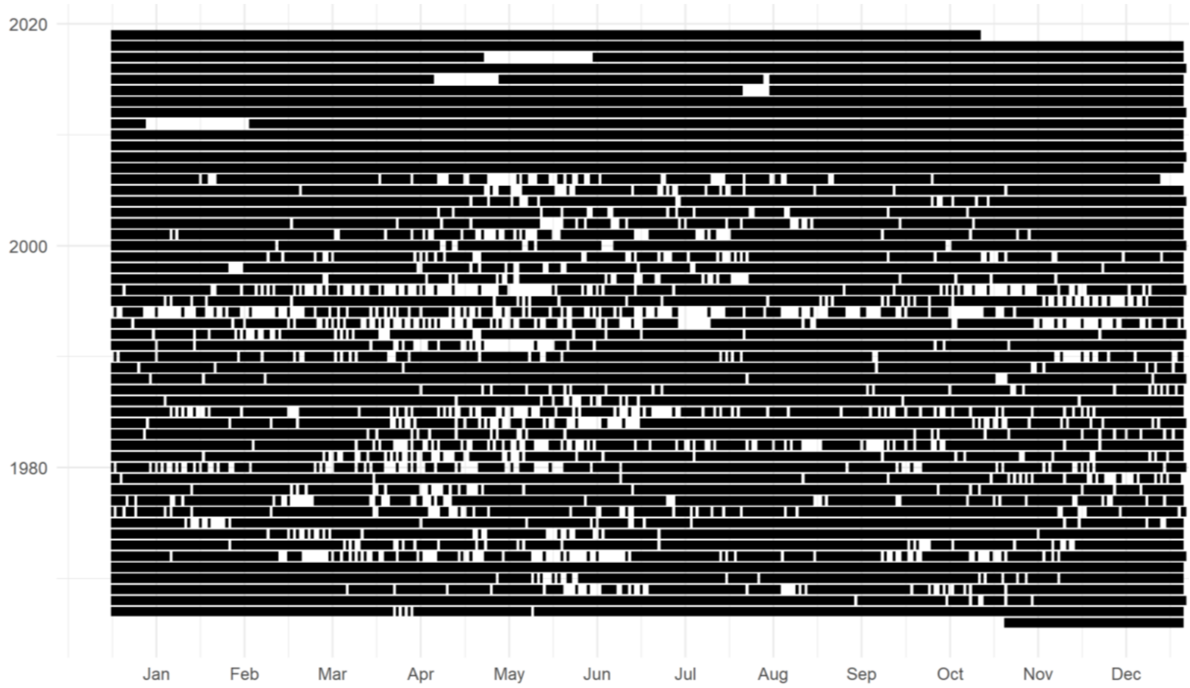

Figure 2.4: Avoca River @ Amphitheatre flow series gaps

2.3.1.2 Historic information

Following a review of flood information provided by NCCMA and newspaper archives as described in the Data Review Report it was found that there were no historic flood events with sufficient information available that can be reliably used to extend the recorded gauges levels at Amphitheatre.

During the 2011 event, the highest on record, the gauge malfunctioned at a flow of 115.9 m^3/s when the gauge experienced a rapid increase in water levels immediately prior to failing. As a result, the peak flow of the January 2011 flood event is not known, and the reading in the lead up to the gauge failure have been considered inaccurate. To account for this 2011 was removed from the annual maximum flow series and incorporated as censored data by assuming over a period of one year there was one event larger than the largest complete event recorded in in 1973 (67.1 m^3/s).

2.3.1.3 Removal of probable influential low flows

During the period of record there were several low flow years. As recommend in ARR 2019, low flows were censored from the dataset to ensure that these did not unduly affect the fit of the flood frequency curve. A discharge censor below 9.61 m^3/s was determined by using the multiple Grubbs-Beck test which resulted in 21 events being censored. The removal of such a large proportion of the annual maxima series is expected in area with highly variable flows that do not have a flood every year.

2.3.1.4 Prior parameters information

The Log Pearson Type III parameters derived from the RFFE (Table 2.2) were used as prior information to the Bayesian framework in Flike. A gauged record with a reasonable length, greater than 10 to 15 years contains enough information to reliably estimate the mean annual flood and will provide a better estimate than a regional estimate such as from the RFFE. To account for this in the Bayesian Framework, a very large prior standard deviation is assigned to the Mean ($\log_e$ flow) which informs Flike that there is no prior information about the mean annual flood.

Table 2.2: Avoca River @ Amphitheatre prior parameters

Parameter	Mean	St Dev	Correlation		
Mean ($\log_e$ flow)	3.1680	$1x10^{15}$	1.000		
St dev ($\log_e$ flow)	-0.3524	0.27596	-0.469	1.000	
Skew ($\log_e$ flow)	0.138	0.030	0.170	-0.398	1.000

2.3.1.5 Flood frequency analysis results

The results of the FFA for the Avoca River @ Amphitheatre gauge are shown in Table 2.3 and Figure 2.5. The best fit to the annual maximum data series was achieved using Bayesian framework and a Log Pearson III (LP3) probability model.

Table 2.3: Avoca River @ Amphitheatre FFA Results

AEP	Expected Quantile (m^3/s)	Lower 90% Quantile Confidence Limits (m^3/s)	Upper 90% Quantile Confidence Limits (m^3/s)
20%	**32**	25	43
10%	**50**	38	71
5%	**74**	53	111
2%	**114**	78	185
1%	**154**	100	262
0.5%	**202**	127	362
0.2%	**282**	168	540

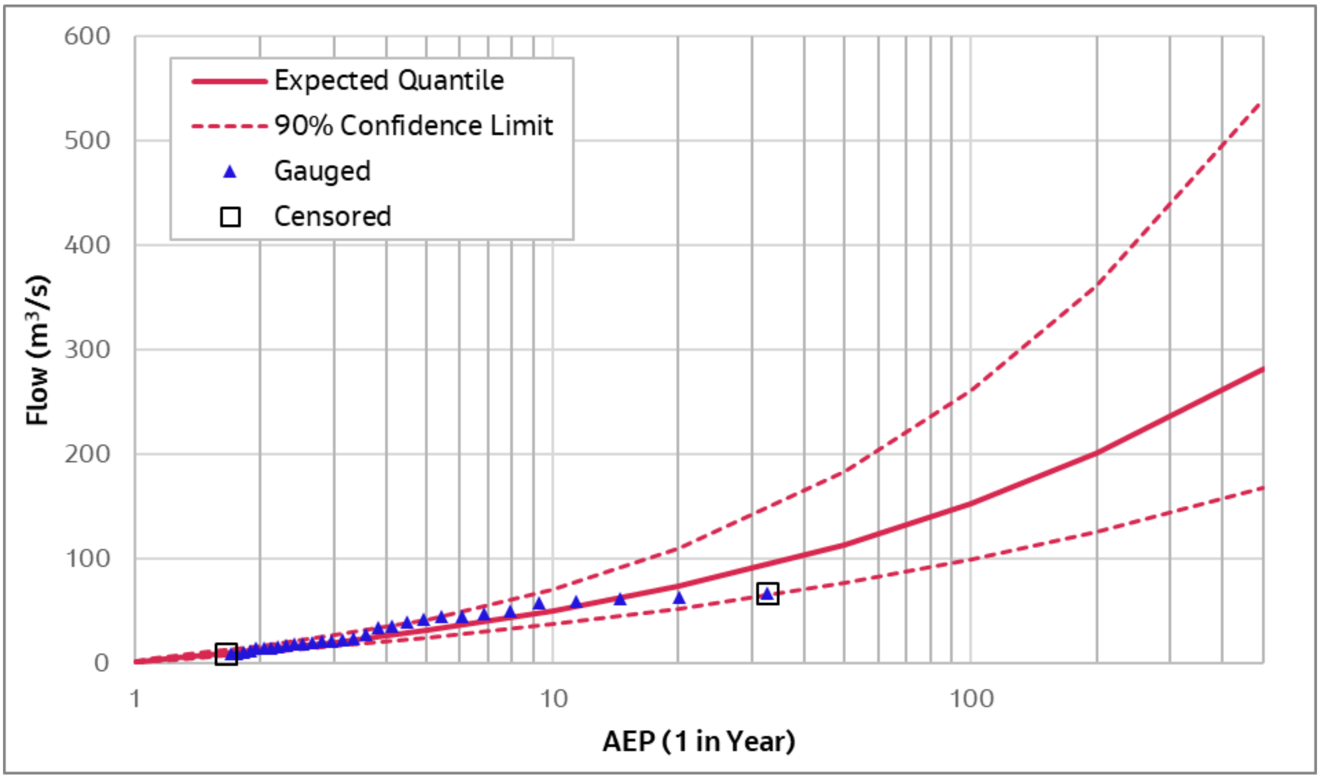

Figure 2.5: Avoca River @ Amphitheatre FFA Results

2.3.2 Avoca River @ Archdale Junction FFA

2.3.2.1 Annual maximum flows

The Avoca River @ Archdale Junction (408206) stream gauge has 32 years of records available from 1987 to 2018 as presented in Table 2.4. As shown in Figure 2.6 the flow series over this period is relatively complete with the exceptions of the first half of 2003, 2004 and 2005 and the majority of 2006. The United States Federal Emergency Management Agency (FEMA) states that including years of missing data in an FFA may be acceptable if the years with missing data make up less 25% of annual maximum series and that missing data isn't as a result of a significant flood event causing the gauge failure (FEMA 2004) so these years were included.

Seven years of incomplete instantaneous monthly maximum flow between 1967 and 1973 is also available in Victorian Surface Water Information to 1987 'Blue Book' (RWC 1990). Due to a time period between 1973 and 1983 with no data, this information was not used to extend the annual maximum flow series. There were also no significant flow events recorded during this time period.

An analysis of the flow series indicated that the calendar year can be used as the water year.

Table 2.4: Avoca River @ Archdale Junction Annual Maximum Flows

Year	Flow (m^3/s)	Year	Flow (m^3/s)	Year	Flow (m^3/s)
1987	211	1998	35	2009	5.7
1988	401	1999	232	2010	413
1989	372	2000	17	2011	780
1990	68	2001	2.7	2012	5.4
1991	43	2002	0.3	2013	0.5
1992	275	2003	69	2014	0
1993	179	2004	2	2015	3.5
1994	1.3	2005	23	2016	393
1995	65	2006	0	2017	0.6
1996	209	2007	16	2018	0
1997	18	2008	0		

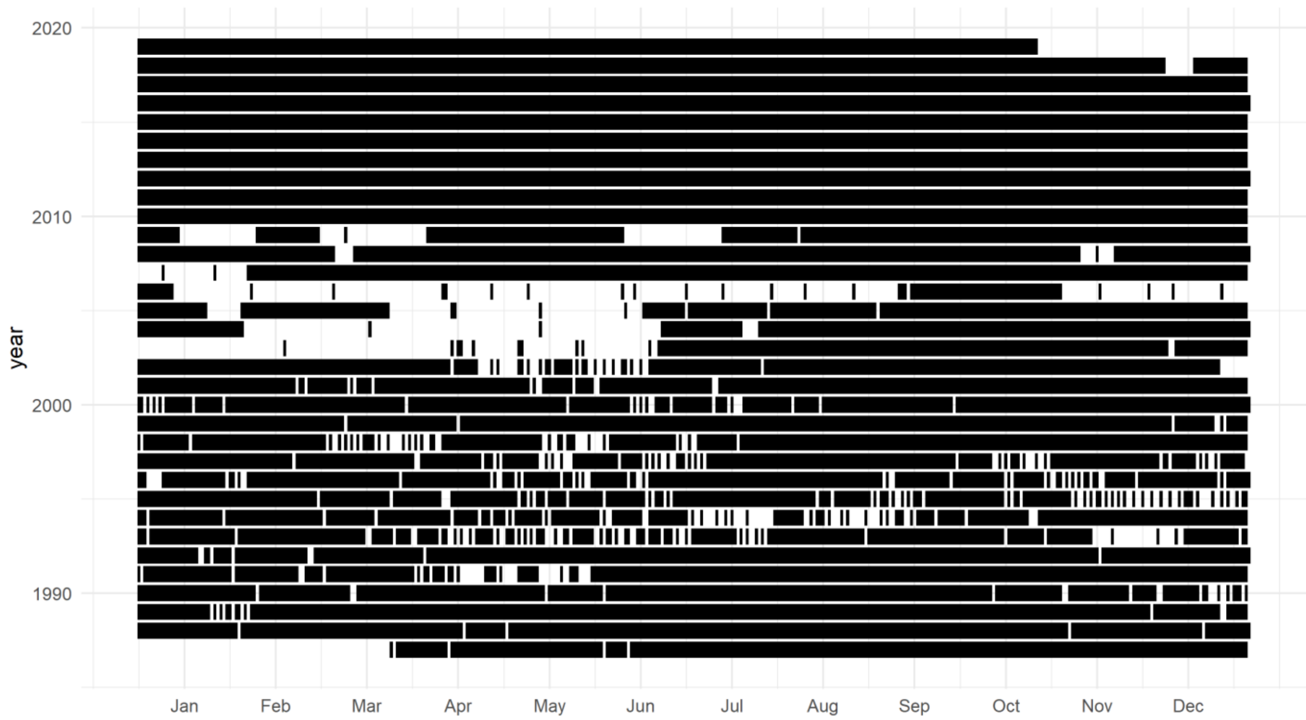

Figure 2.6: Avoca River @ Archdale Junction flow series gaps

2.3.2.2 Historic information

The historic flood marker in Avoca (see Jacobs 2019a) indicates that the peak flood levels of the 1956 flood event were similar to those of the September 2010 flood event. This information was incorporated into Flike by identifying that 1956 event was the only one above the threshold flow of 412.6 m^3/s (September 2010) in the 31 year period from 1956 to 1987.

2.3.2.3 Removal of probable influential low flows

During the period of record there were several low flow years. As recommend in ARR 2019, low flows were censored from the dataset to ensure that these low flows did not unduly affect the fit of the flood frequency curve. A discharge censor below 16.2 m^3/s was determined by using the multiple Grubbs-Beck test which resulted in 13 events being censored.

2.3.2.4 Prior parameters information

A better fit to the recorded annual maximum flows was achieved without the use of prior parameter information to the Bayesian framework in Flike.

2.3.2.5 Flood frequency analysis results

The results of the FFA for the Avoca River @ Archdale Junction gauge are shown in Table 2.5 and Figure 2.7. The best fit to the annual maximum data series was achieved using Bayesian framework and a Log Pearson III (LP3) probability model.

Table 2.5: Avoca River @ Archdale Junction FFA Results

AEP	Expected Quantile (m^3/s)	Lower 90% Quantile Confidence Limits (m^3/s)	Upper 90% Quantile Confidence Limits (m^3/s)
20%	**164**	94	296
10%	**334**	204	545
5%	**519**	355	860
2%	**744**	542	1277
1%	**886**	644	1662
0.5%	**1001**	716	1966
0.2%	**1116**	798	2259

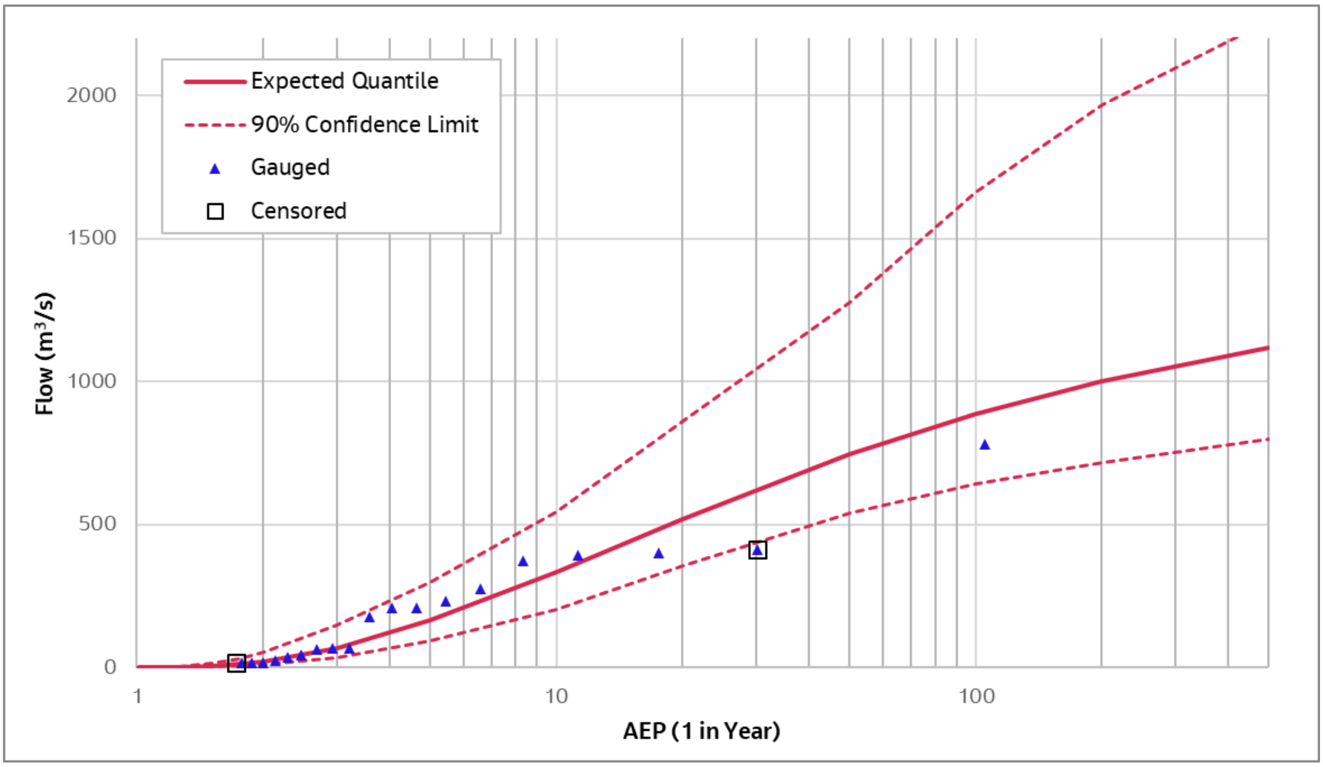

Figure 2.7: Avoca River @ Archdale Junction FFA Results

2.4 RORB model development

The RORB model (Figure 2.8) extends from the upper catchment limits to the Avoca River – Cherry Tree Creek junction. 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 this 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.

Total impervious area (TIA) values were assigned to landuse types using the planning scheme and checked against aerial photography. Effective impervious area (EIA) has been assumed to be 60% of TIA. The adopted values are presented in Table 2.6.

Table 2.6: Fraction impervious values applied per Planning Zone

Zone	Total Impervious Area Fraction	Effective Impervious Area Fraction
Rural conservation, public conservation, public park and recreation, farming	0	0
Low density residential, rural living, rural activity	0.2	0.12
Public use – service and utility	0.3 – 0.5	0.18 – 0.3
Public use – other, public use – health and community, public use – education, township, general residential	0.4	0.24
Roads, public use – transport, industrial, commercial	0.9	0.54

RORB Reach Type 1, representing natural channels, were used throughout.

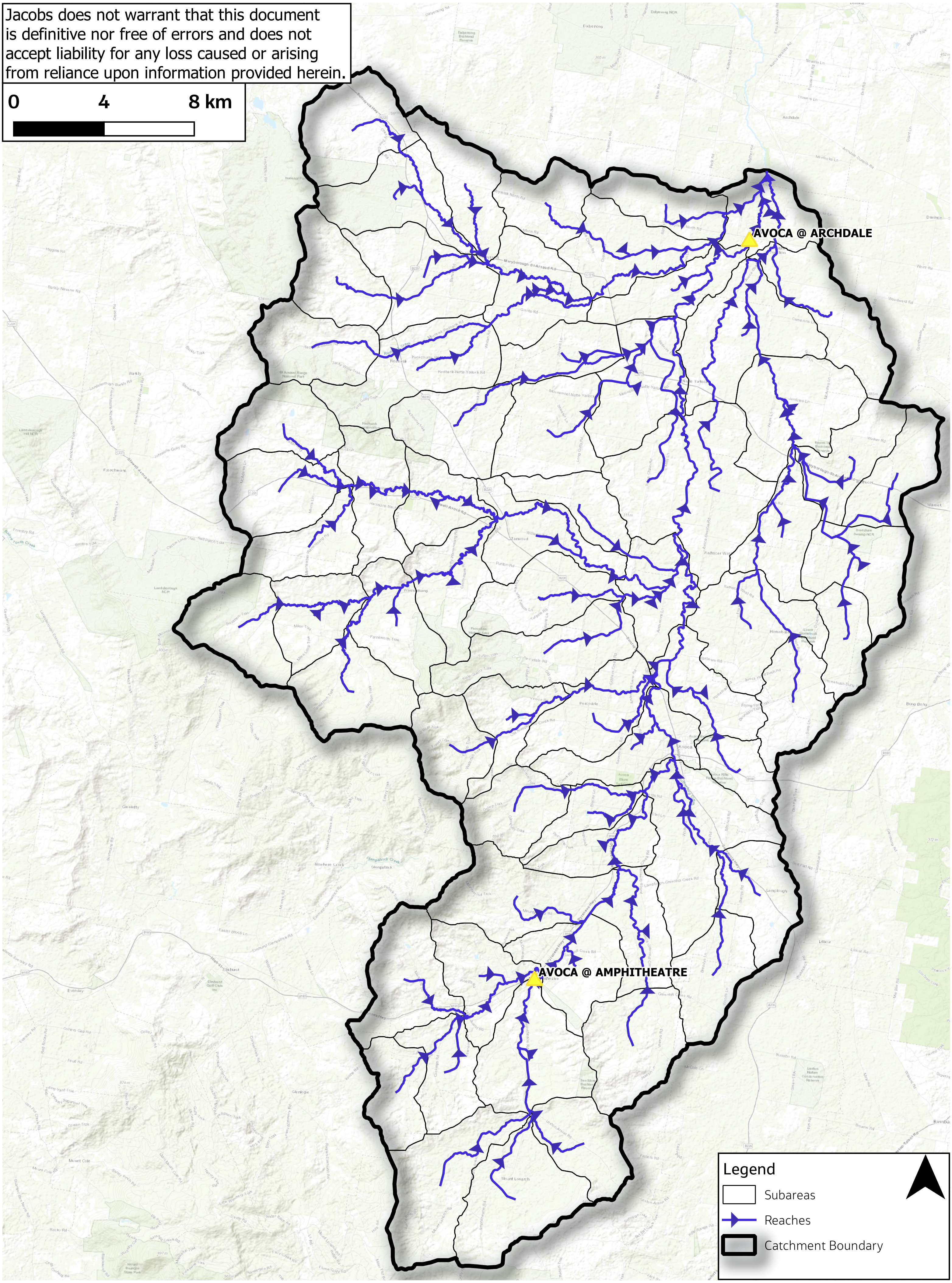

Figure 2.8: RORB Layout

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2.5 Calibration and validation

To determine the 'K_c' and 'm' routing parameters for design event modelling and establish a degree of confidence that the RORB model is suitably representing the runoff behaviour of the catchment and providing reasonable inputs for the design event modelling, model calibration and validation was undertaken. Initially, the model was calibrated by applying recorded rainfall to the model and adjusting model parameters, using reasonable values, until the model suitably replicated the recorded flow at the stream gauges. The routing parameters determined in the calibration were then used in the validation events and the model results examined.

The RORB model has been calibrated and validated at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges, the locations of which are shown in Figure 2.9. The RORB model was calibrated against three flood events and summary statistics were reviewed to assess the fit of the model. The model was then validated against a further two flood events using the calibrated routing parameters.

Selection of flood events for model calibration and validation was guided by the following factors:

1) Magnitude of flood events with priority given to the largest flow events as they are most representative of the design events been assessed in the Investigation
2) The coverage of daily and sub-daily rainfall data available for a given event
3) Priority given to the most flood events as they are more likely to represent current catchment conditions and be better recollected by the community

The September 2010, January 2011 and September 2016 flood events were chosen for calibration and August 1992 and September 1996 were chosen for validation. The peak flow, event flow rank and estimated AEP for each event is shown in Table 2.7. The spatial distribution of the daily and sub-daily rainfall gauges used for each event are shown in Figure 2.9 and a summary of the rainfall data is provided in Appendix A.

Table 2.7: Selected calibration and validation events

Event	Start Date[1]	End Date[1]	Catchment Average Total Rainfall (mm)	Avoca River @ Amphitheatre			Avoca River @ Archdale Junction		
				Flow (m^3/s)	Event Flow Rank	Estimated AEP	Flow (m^3/s)	Event Flow Rank	Estimated AEP
Calibration Events									
September 2010	4/9/2010	6/9/2010	84.8	60	5	7%	413	2	7%
January 2011[2]	10/1/2011	16/1/2011	208	NA	NA	NA	780	1	2%
September 2016	13/9/2016	16/9/2016	89.2	64	3	6%	392	9	8%
Validation Events									
August 1992	30/8/1992	1/10/1992	41.4	51	6	10%	274	5	13%
September 1996	29/9/1996	2/10/1996	57.7	22	16	31%	209	7	17%

1. Storm event dates begin and end at 9:00 am on the recorded day to coincide with daily rainfall readings.
2. Gauge failed on rising limb of hydrograph resulting peak flow not been recorded.

2.5.1 Calibration parameters

RORB has the ability to manually adjust the 'Kc' and 'm' routing parameters along with the initial (IL) loss values (RORB automatically adjusts the continuing loss (CL) to maintain the water balance) until an acceptable fit to the recorded hydrographs is achieved. To calibrate the model the following characteristics have been assessed; hydrograph shape, peak flow, hydrograph volume and the Nash-Sutcliffe Efficiency (NSE).

NSE is a statistical measure to evaluate a model's performance against recorded data. A value of 1 indicates a perfect fit to the model data, whereas, a value of zero indicates simply modelling the average value would perform equally well. A value of less than 0 indicates poor model performance. NSE is defined as:

$$NSE = 1 - \frac{var(Res)}{var(Hyd)} \qquad \text{Equation 1}$$

where var(Res) is the variance of the model residuals or the difference between the observed and calculated flows, and var(Hyd) is the variance of the observed hydrograph. Ladson (2008) provides a guide to assessing model performance based on NSE as shown in Table 2.8.

Table 2.8: NSE model performance criteria

Classification	NSE Calibration	NSE Validation
Excellent	> 0.93	> 0.93
Good	0.8 – 0.93	0.8 – 0.93
Satisfactory	0.7 - 0.8	0.6 – 0.8
Passable	0.6 – 0.7	0.3 – 0.6
Poor	< 0.6	< 0.3

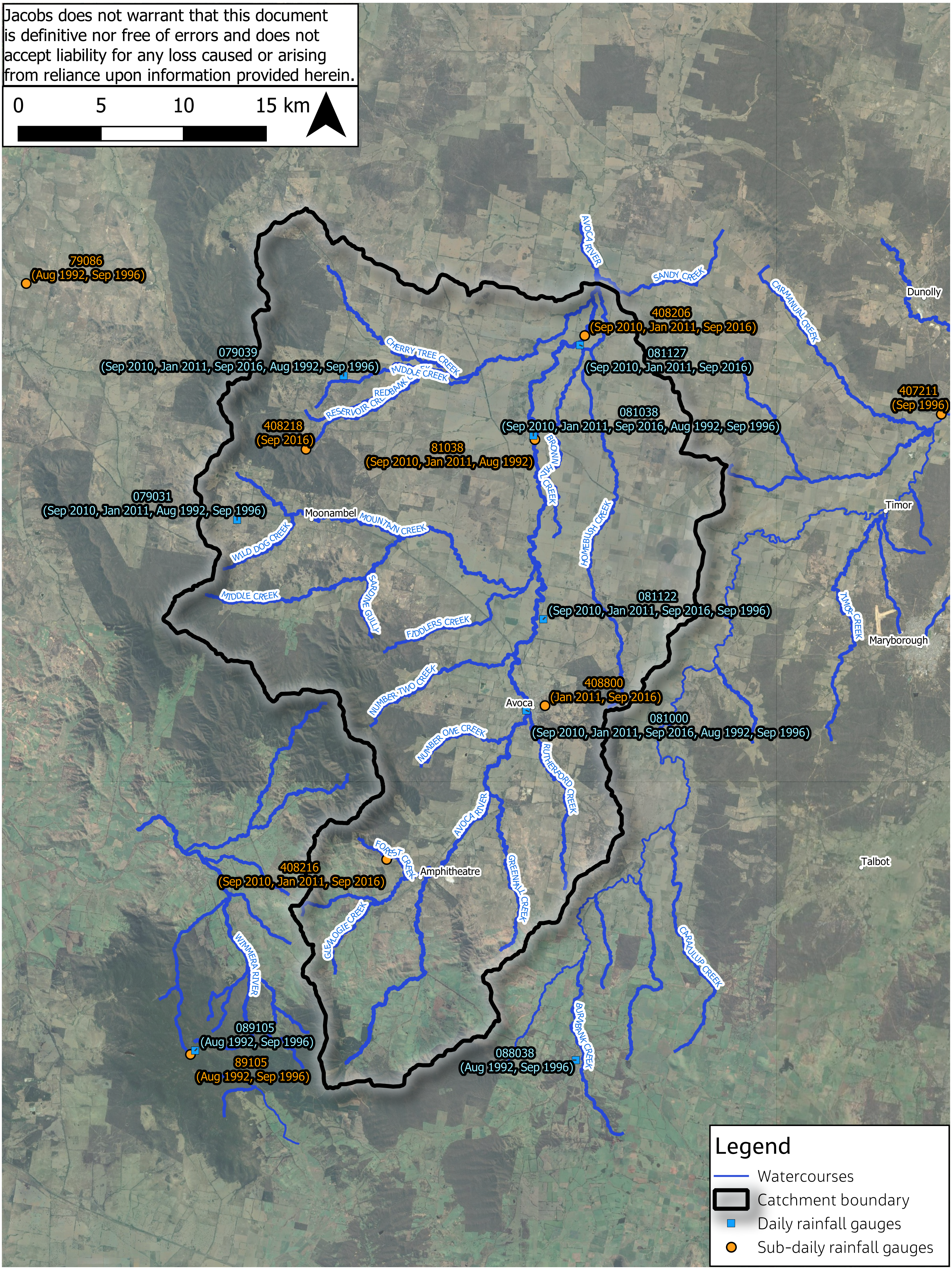


Figure 2.9: Calibration and Validation Event Rainfall Gauges

2.5.2 Calibration results

The sections below present the results of the September 2010, January 2011 and September 2016 RORB calibration modelling.

2.5.2.1 September 2010 calibration results

To calibrate the September 2010 event, the RORB model was run with the rainfall described in Appendix A for this event. As outlined above, the rainfall was spatially distributed across the catchment and the RORB model parameters were adjusted until the best fit was obtained.

The best fit for the calibration parameters is presented in Table 2.9 and a comparison of the recorded and modelled flows at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges is shown in Figure 2.10.

An excellent fit based on the NSE was achieved at Avoca River @ Amphitheatre gauge with the volume closely matching that recorded. As shown in Figure 2.10 at the Avoca River @ Amphitheatre Gauge the model is overestimating peak flow due to the second modelled flow peak been higher, where the first flow peak was higher for the recorded flows. Varying routing and loss parameter did not enable the model to represent a higher first flow peak and calibrating peak flow to the second peak was detrimental to modelled flow volume and hydrograph shape. This indicates that the rainfall recorded at the Forest Creek @ Amphitheatre Reservoir H.G. was not representative of the entire upper catchment.

An excellent fit based on the NSE was achieved at the Avoca River @ Archdale Junction gauge and the peak flow closely matched that recorded. The model underestimated the hydrograph volume, which was due to difficulties in representing a sharply rising and slow receding hydrograph in RORB (Figure 2.10). This is most likely due the RORB model's inability to represent hydraulic controls such the bridge downstream of the gauge, or inflows from tributaries creating a backwater effect.

While the routing parameter 'm' was varied, the best fit was achieved with the recommended value of 0.8 in the RORB User Manual (Laurenson, et al. 2007).

Table 2.9: September 2010 calibration event results

Gauge	K_c	m	IL (mm)	CL (mm)	Peak Flow Gauge (m^3/s)	Peak Flow Model (m^3/s)	Peak Flow Diff.	Volume Gauge (m^3)	Volume Model (m^3)	Volume Diff.	NSE
Avoca River @ Amphitheatre	13.0	0.8	5.0	2.52	59	64	7.4%	3.17×10^6	3.17×10^6	0.0%	0.96
Avoca River @ Archdale Junction	42.9	0.8	30.0	0.15	409	419	2.4%	3.34×10^7	3.18×10^7	-4.8%	0.94

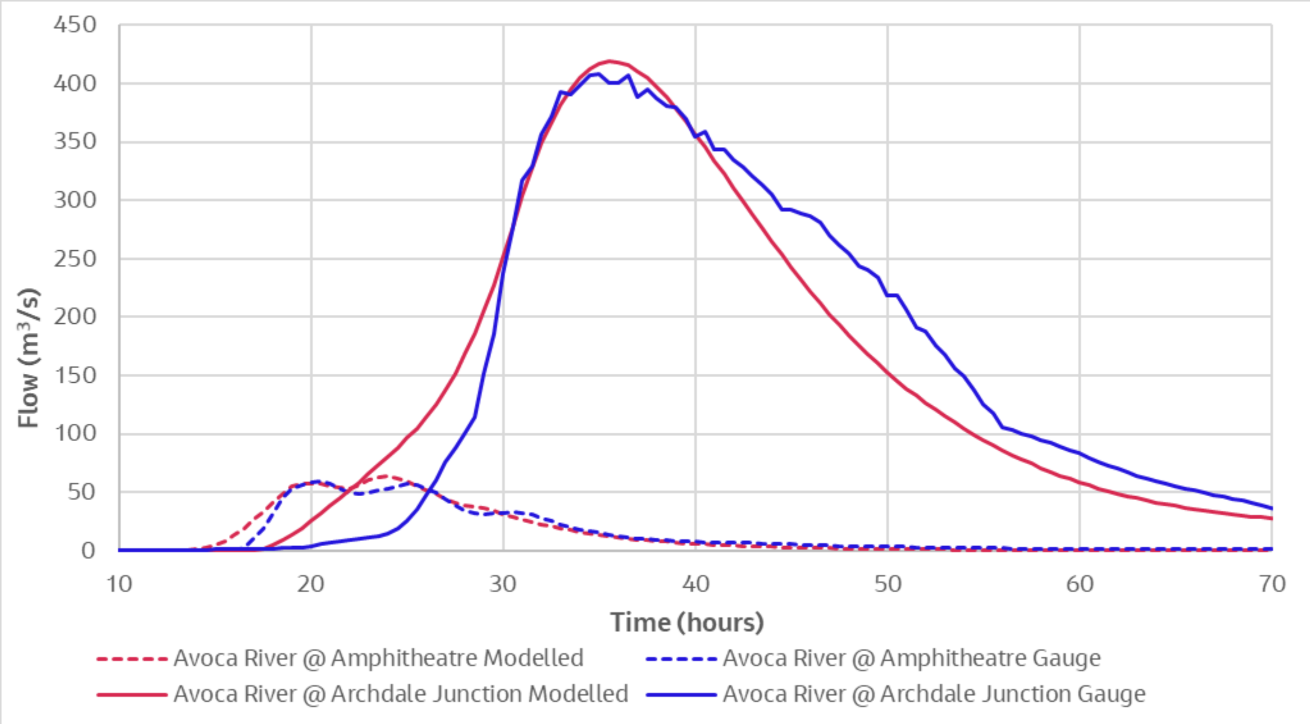


Figure 2.10: September 2010 calibration event hydrograph comparison

2.5.2.2 January 2011 calibration results

To calibrate the January 2011 event, the RORB model was run with the rainfall described in Appendix A for this event. As outlined above, the rainfall was spatially distributed across the catchment and the RORB model parameters were adjusted until the best fit was obtained.

The best fit for the calibration parameters is presented in Table 2.10 and a comparison of the recorded and modelled flows at the Avoca River @ Archdale Junction stream gauge is shown in Figure 2.11. The Avoca River @ Amphitheatre stream gauge failed during the January 2011 event and has not been used for RORB model calibration.

A good fit for peak flow and volume was achieved at the Avoca River @ Archdale Junction gauge. However, the timing of the modelled hydrographs was offset with the first peak occurring 20 hours too early for the first peak and 6 hours too early for the second peak. Beven (2003) identifies that the NSE equation is sensitive to the hydrograph timing and is not a good representation of model calibration in this situation. The timing of flow inputs is assessed in the hydraulic model as presented in Section 3.3.2.

While the routing parameter 'm' was varied, that best fit was achieved with the recommended value of 0.8 in the RORB User Manual (Laurenson, et al. 2007).

Table 2.10: January 2011 calibration event results

Gauge	K_c	m	IL (mm)	CL (mm)	Peak Flow Gauge (m^3/s)	Peak Flow Model (m^3/s)	Peak Flow Diff.	Volume Gauge (m^3)	Volume Model (m^3)	Volume Diff.	NSE
Avoca River @ Archdale Junction	39.0	0.80	26	0.85	772	755	-2.3%	9.68×10^7	9.72×10^7	0.4%	0.66

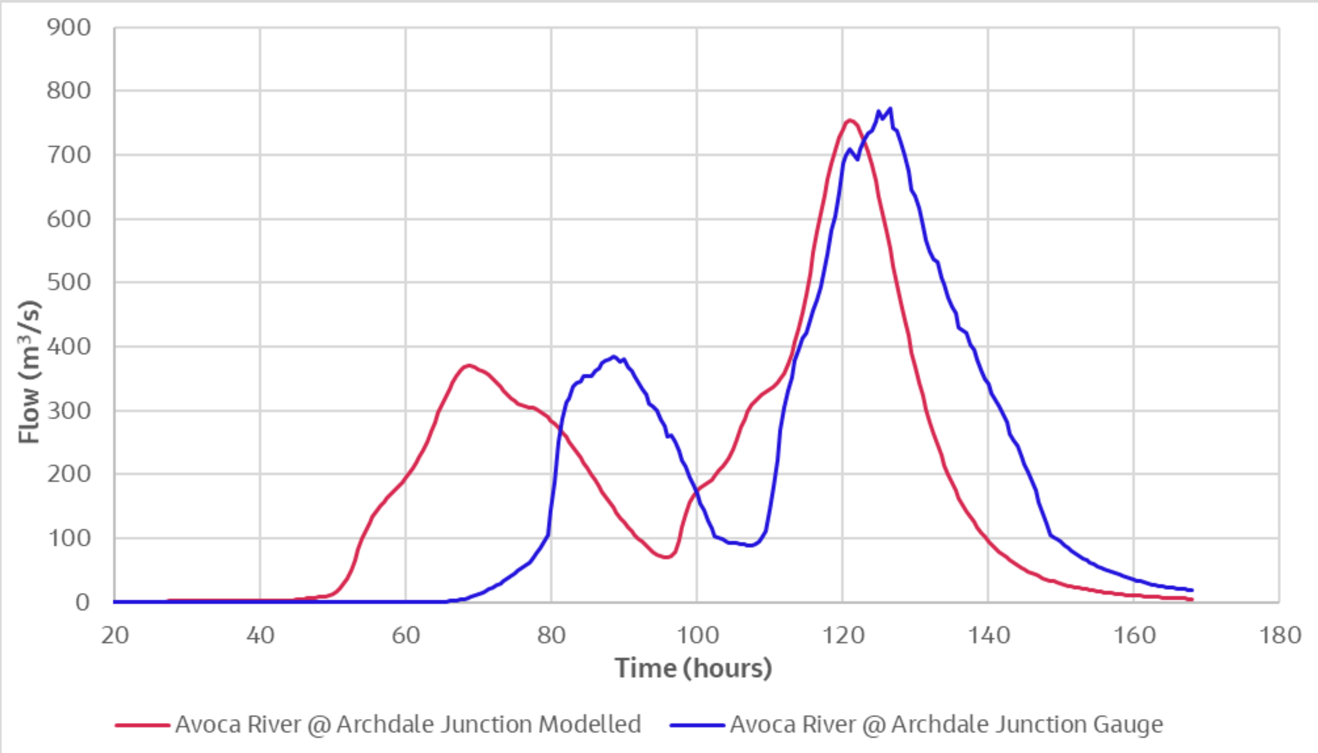


Figure 2.11: January 2011 calibration event hydrograph comparison

2.5.2.3 September 2016 calibration results

To calibrate the September 2016 event, the RORB model was run with the rainfall described in Appendix A for this event. As outlined above, the rainfall was spatially distributed across the catchment and the RORB model parameters were adjusted until the best fit was obtained.

The best fit for the calibration parameters is presented in Table 2.11 and a comparison of the recorded and modelled flows at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges is shown in Figure 2.12.

A good fit based on the NSE was achieved at Avoca River @ Amphitheatre gauge with the peak flows and volumes closely matching those recorded.

A good fit for peak flow and volume was achieved at the Avoca River @ Archdale Junction gauge. However, the timing of the modelled hydrograph was offset by approximately 7 hours too early. Beven (2003) identifies that the NSE equation is sensitive to the hydrograph and is not a good representation of model calibration in this situation. The timing of flow inputs is assessed in the hydraulic model as presented in Section 3.3.3.

Table 2.11: September 2016 calibration event results

Gauge	K_c	m	IL (mm)	CL (mm)	Peak Flow Gauge (m^3/s)	Peak Flow Model (m^3/s)	Peak Flow Diff.	Volume Gauge (m^3)	Volume Model (m^3)	Volume Diff.	NSE
Avoca River @ Amphitheatre	17.0	0.80	13	1.58	63	63	0.1%	3.95×10^6	3.96×10^6	0.3%	0.89
Avoca River @ Archdale Junction	37.0	0.78	42	0.19	389	380	-2.4%	3.03×10^7	3.03×10^7	0.0%	0.57

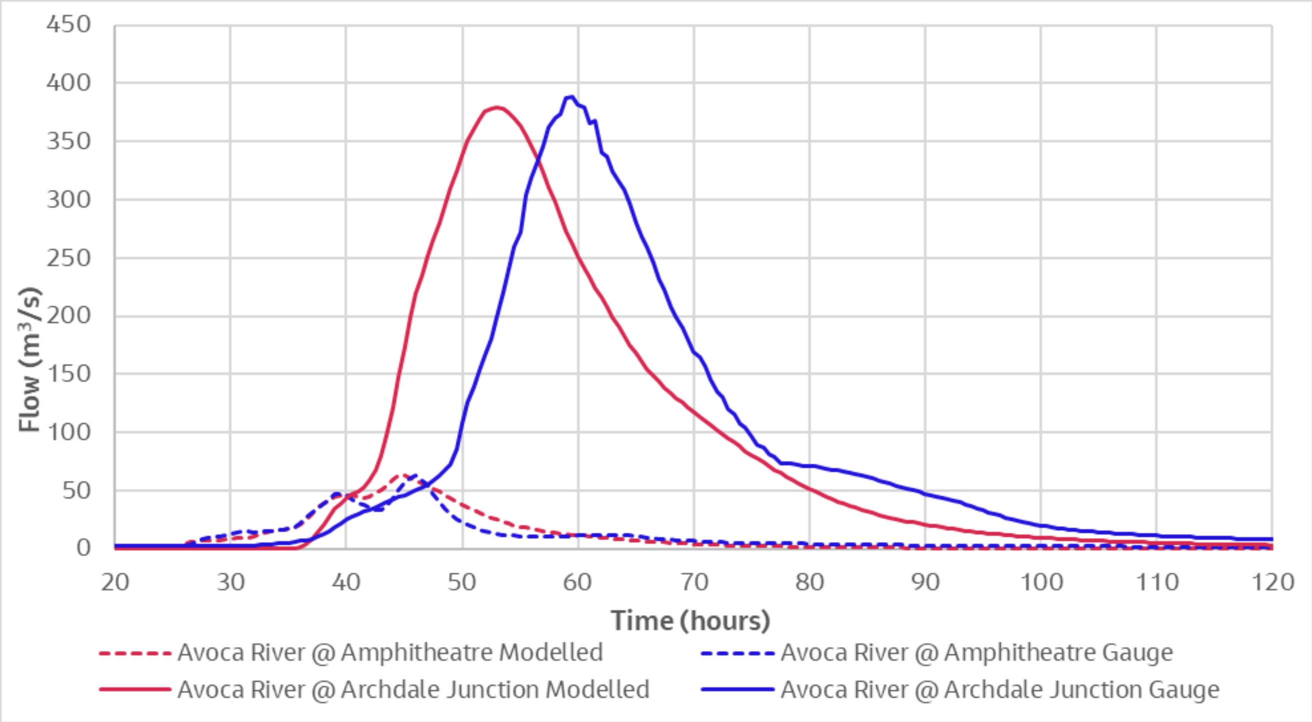


Figure 2.12: September 2016 calibration event hydrograph comparison

2.5.3 Validation results

The sections below present the results of the August 1992 and September 1996 RORB validation modelling Using the adopted RORB 'K_c' values of 15 and 39.63 at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction respectively and 'm' value of 0.8 as presented in Table 2.14.

2.5.3.1 August 1992 validation results

To validate the August 1992 event, the RORB model was run with the rainfall described in Appendix A and the calibrated K_c for this event. As outlined above, the rainfall was spatially distributed across the catchment and the loss parameters were adjusted until the best fit was obtained.

The best fit for the calibration parameters is presented in Table 2.11 and a comparison of the recorded and modelled flows at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges is shown in Figure 2.13.

Passable fits based on the NSE were achieved at Avoca River @ Amphitheatre and Avoca River @ Archdale Junction gauges. However, the model was not able represent the peak flows, with modelled flows approximately 50% lower than those recorded. As shown in Table 2.7, the August 1992 flood event was of similar magnitude to the September 2010 and September 2016 events, however the average total rainfall across the catchment of 41.4 mm is half of that recorded in the September 2010 and September 2016. The lower total rainfall depths and rapid rise of the stream gauges indicate that there may have been an intense rainfall burst that was not picked up in the sub-daily rainfall gauges, noting that of the three sub-daily rainfall gauges available for this event, Natte Yallock was the only one located in the catchment.

Table 2.12: August 1992 validation event results

Gauge	IL (mm)	CL (mm)	Peak Flow Gauge (m^3/s)	Peak Flow Model (m^3/s)	Peak Flow Diff.	Volume Gauge (m^3)	Volume Model (m^3)	Volume Diff.	NSE
Avoca River @ Amphitheatre	0	0.54	51	25	-51.6%	1.63×10^6	1.55×10^6	-4.9%	0.36
Avoca River @ Archdale Junction	7	1.15	275	164	-40.3%	1.46×10^7	1.36×10^7	-6.8%	0.57

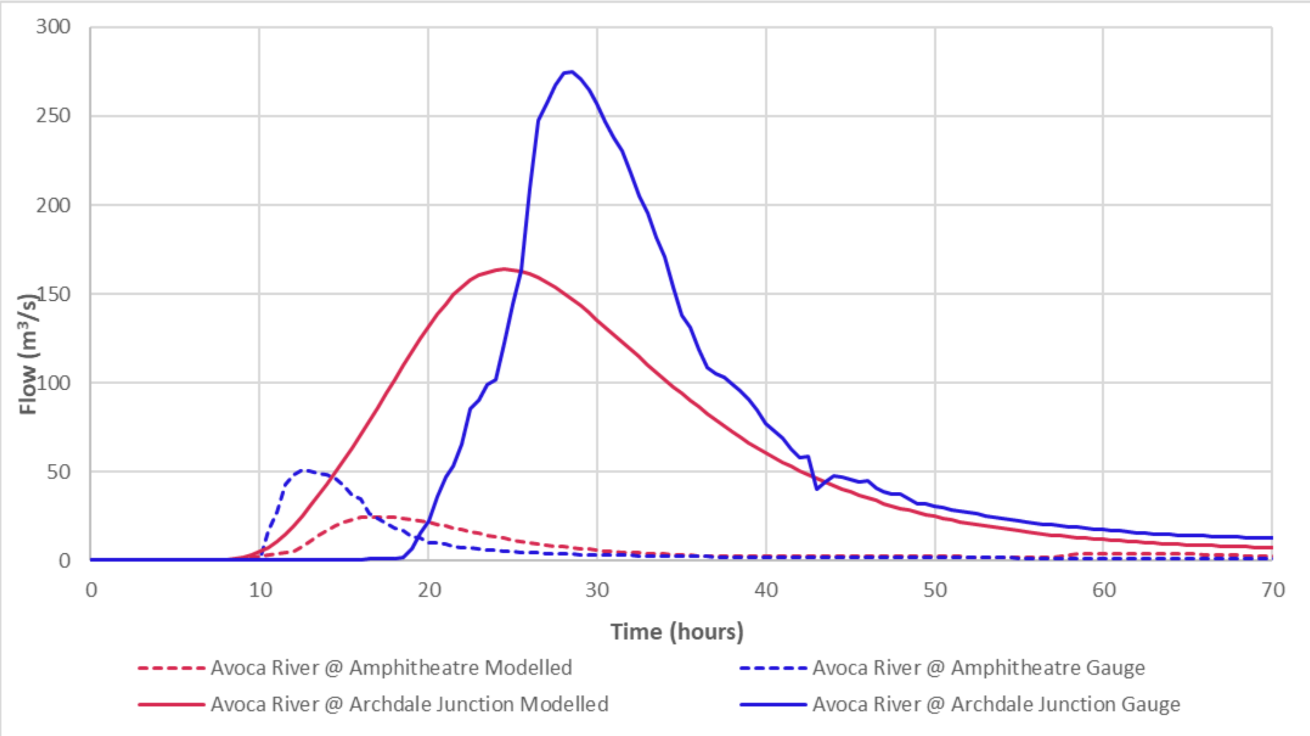


Figure 2.13: August 1992 validation event hydrograph comparison

2.5.3.2 September 1996 validation results

To validate the September 1996 event, the RORB model was run with the rainfall described in Appendix A and the calibrated K_c for this event with an m value of 0.8. As outlined above, the rainfall was spatially distributed across the catchment and the RORB model parameters were adjusted until the best fit was obtained.

The best fit for the calibration parameters is presented in Table 2.13 and a comparison of the recorded and modelled flows at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges is shown in Figure 2.14.

A passable fit based on the NSE was achieved at Avoca River @ Amphitheatre and a good fit was achieved the Avoca River @ Archdale Junction gauges. However, the model was not able represent the peak flows, with modelled flows 10.6% lower than those recorded at the Avoca River @ Amphitheatre gauge and 21.5% lower than those recorded at the Avoca River @ Archdale Junction. Whilst not as pronounced as the August 1992 event (Section 2.5.3) the rapid rise of the stream gauges was not able to be achieved indicating that there may have been an intense rainfall burst that was not picked up in the sub-daily rainfall gauges, noting that of the three sub-daily rainfall gauges available for this event, Natte Yallock was the only one located in the catchment.

Table 2.13: September 1996 validation event results

Gauge	IL (mm)	CL (mm)	Peak Flow Gauge (m^3/s)	Peak Flow Model (m^3/s)	Peak Flow Diff.	Volume Gauge (m^3)	Volume Model (m^3)	Volume Diff.	NSE
Avoca River @ Amphitheatre	2	0.79	220	20	-10.6	2.0×10^6	2.00×10^6	0.0%	0.58
Avoca River @ Archdale Junction	20	0.00	209	164	-21.5%	2.49×10^7	2.48×10^7	-0.4%	0.79

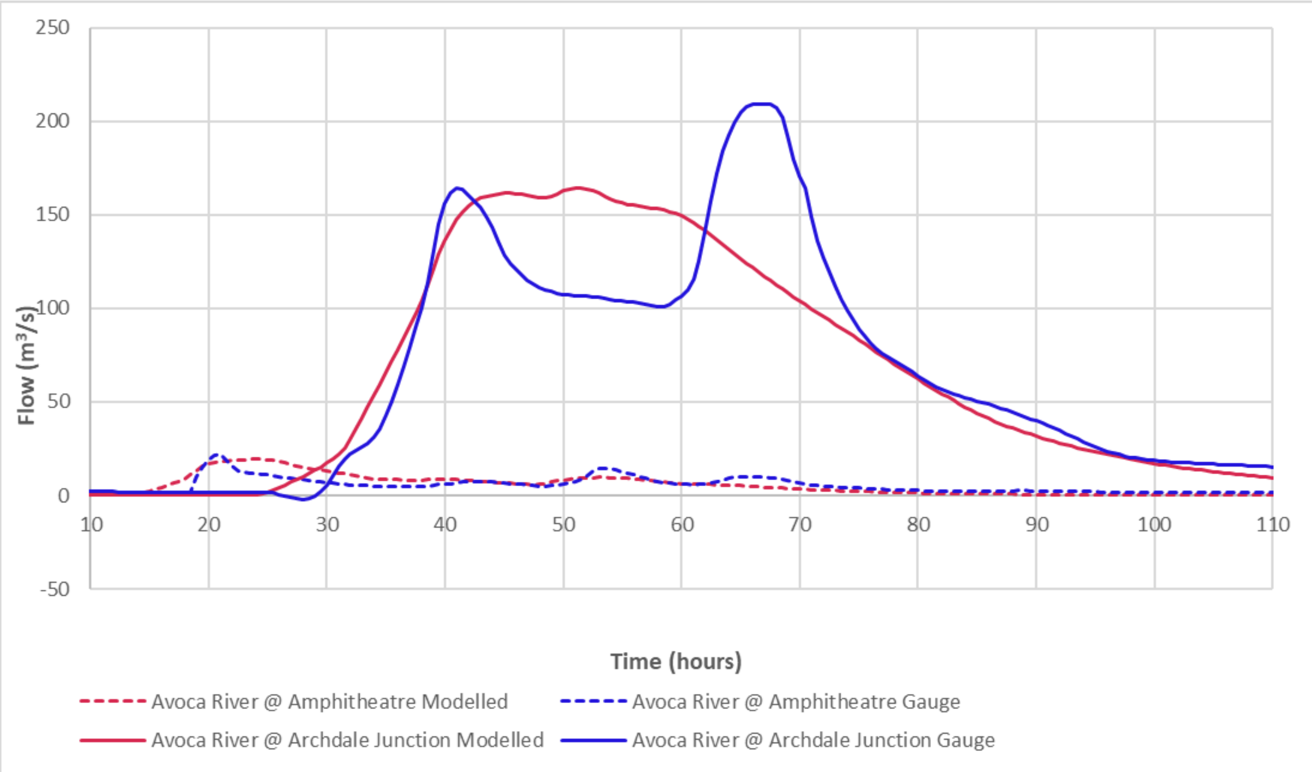


Figure 2.14: September 1996 validation event hydrograph comparison

2.5.4 Calibration and validation event summary

The September 2010, January 2011 and September 2016 events were used to calibrate the RORB model.

The resulting parameter sets were taken as an average of the calibrated parameters for the September 2010 and September 2016 events and are shown in Table 2.14. Given the uncertainty in the January 2011 event the calibrated K_c value was excluded from the average.

Table 2.14: Adopted RORB calibration parameters

Parameter	Avoca River @ Amphitheatre	Avoca River @ Archdale Junction
K_c	15.0	39.6
m	0.80	0.80

The August 1992 and September 2016 events were then used to validate the RORB model and parameters chosen through calibration.

Whilst in general the results of the calibration and validation indicate that overall the RORB model is representing the rainfall-runoff characteristics of the catchment 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.

2.6 Design event modelling

Design event modelling has been undertaken for the 20%, 10%, 5%, 2% and 1% AEP events along with Probable Maximum Precipitation (PMP) to provide inflows into the hydraulic model. 10% and 1% AEP events including an allowance for climate change under the RCP4.5 and RCP8.5 scenarios have also been modelled.

The RORB model parameters for the Upper Avoca are summarised in Table 2.15.

Table 2.15: RORB model parameters

Model Parameter	Interstation Area	Value
K_c	Avoca River @ Amphitheatre	15.0
	Avoca River @ Archdale Junction	39.6
	Catchment Outlet	20.6[1]
m	Global	0.8
Initial Loss	-	Refer to Section 2.6.4
Continuing Loss	-	Refer to Section 2.6.4

[1.] The K_c for the catchment outlet interstation area was determined using the $K_c/D_{ave.}$ ratio from the calibrated K_c value for the Avoca River @ Archdale Junction interstation area.

2.6.1 Design rainfall

Intensity-Frequency-Duration (IFD) rainfall data was sourced from the Bureau of Meteorology's Design Rainfall Data System (2016) (www.bom.gov.au/water/designRainfalls/revised-ifd/). Catchment average rainfall was determined across the catchment area using the gridded IFD data. The resulting catchment average rainfall depths are presented in Table 2.16.

It is recommended in ARR 2019 that for catchments with an area greater than 20 km^2 that rainfall be spatially varied across the catchment. Rainfall depths have been spatially varied using RORB's inbuilt function based on gridded IFD data. The spatial distribution of the 1% AEP 24 hour duration storm event is shown in Figure 2.15.

Table 2.16: Catchment average IFD rainfall depths

Duration	Total Depth (mm)						
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
1 hr	21.0	25.6	30.5	37.7	43.9	48.8	55.9
1.5 hr	24.0	29.1	34.6	42.7	49.5	55.2	63.2
2 hr	26.4	32.0	37.9	46.6	53.9	60.0	68.7
3 hr	30.3	36.6	43.2	52.8	60.8	67.6	77.3
4.5 hr	35.1	42.2	49.6	60.1	68.8	76.3	87.2
6 hr	39.1	46.8	54.8	66.1	75.3	83.5	95.3
9 hr	45.6	54.5	63.5	76	86.1	95.4	109
12 hr	50.9	60.6	70.6	84.2	95.0	105	120
18 hr	59	70.3	81.8	97.2	109	121	139
24 hr	65.1	77.7	90.4	108	121	135	154
36 hr	73.7	88.3	103	123	139	154	177
48 hr	79.6	95.6	112	134	152	170	196
72 hr	86.9	105	123	149	170	193	225
96 hr	91.3	110	130	158	181	207	244
120 hr	94.3	114	134	163	187	215	254
144 hr	96.6	116	136	166	191	218	259
168 hr	98.5	118	138	168	192	220	260

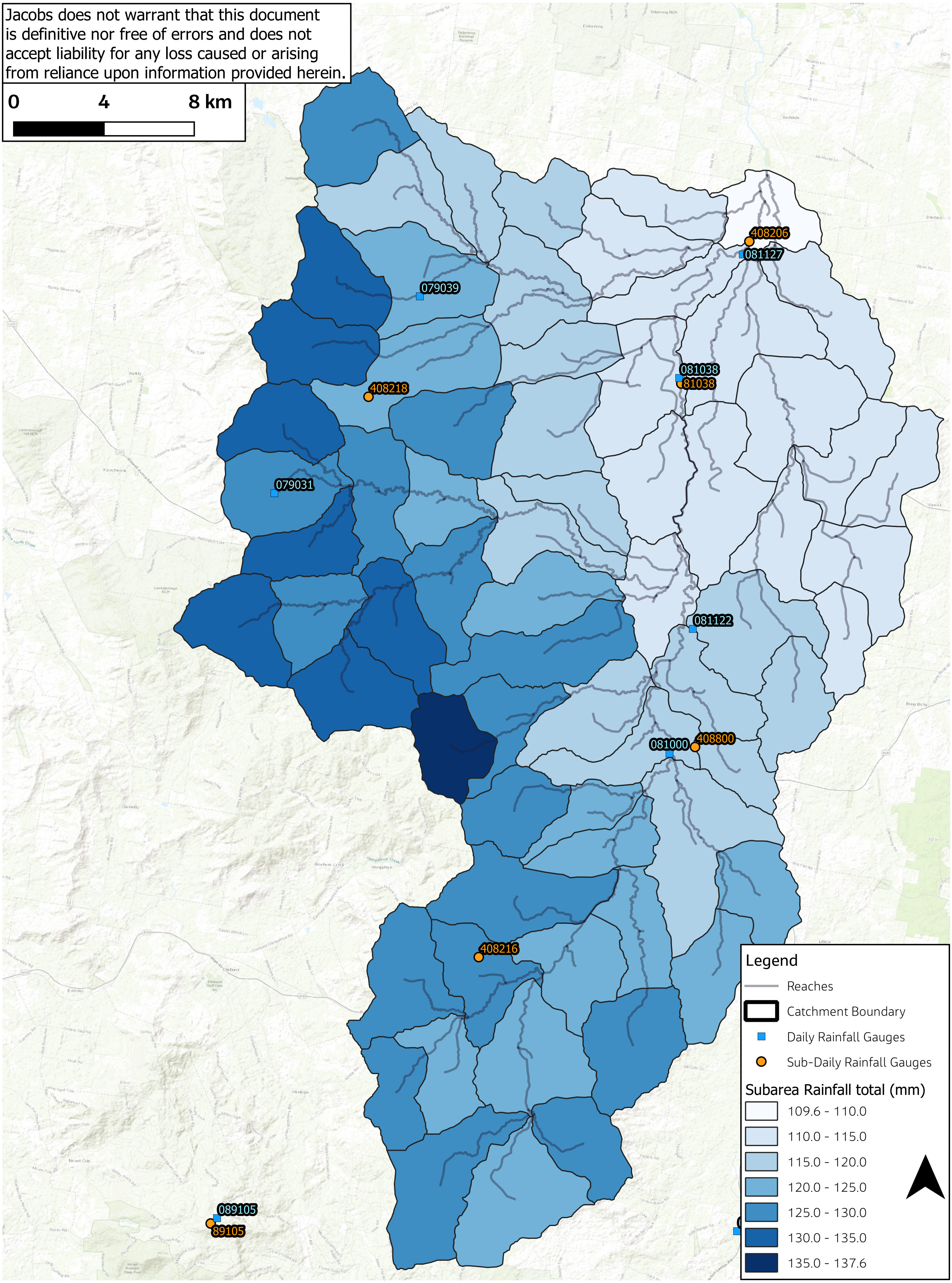


Figure 2.15: Spatial Distribution of 1% AEP 24 hour total rainfall

Jacobs

2.6.1.1 Probable maximum precipitation

The PMP was derived using the Generalised Short-Duration Method (GSDM) (BoM 2003) for storm duration 3 hours and shorter and the Generalised Southeast Australia Method (GSAM) (BoM 2006) for events longer than 24 hours. Table 2.17 provides a summary of the final PMP estimate of rainfall depth across the catchment. The PMP storms modelled in RORB were spatially and temporally distributed in accordance with the GSDM and GSAM methods.

Table 2.17: PMP rainfall depth estimates

	1 hr	2 hr	3 hr	12 hr	24 hr	36 hr	48 hr	72 hr
Total Rainfall Depth (mm)	130	180	230	400[1]	520	590	640	670

[1.] The 12 hour storm duration total rainfall depth is interpolated between the GSDM and GSAM PMP estimates as per the instructions provided in BoM (2006).

2.6.1.2 Climate change

The data for ARR 2019 Representative Concentration Pathway (RCP) 4.5 and 8.5 2090 interim climate factors was extrapolated to 2100. The resulting increases in rainfall intensity were 9.6% and 23.2% for the RCP 4.5 and RCP 8.5 climate scenarios respectively at 2100. The resulting catchment average rainfall depths are presented in Table 2.18.

Table 2.18: Climate change catchment average IFD rainfall depths

Duration	10% AEP Total Depth (mm)		1% AEP Total Depth (mm)	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1 hr	28.1	31.6	48.1	54
1.5 hr	31.9	35.9	54.3	61
2 hr	35	39.4	59.1	66.4
3 hr	40.1	45.1	66.6	74.9
4.5 hr	46.2	52	75.4	84.7
6 hr	51.3	57.7	82.5	92.8
9 hr	59.7	67.1	94.4	106
12 hr	66.5	74.7	104	117
18 hr	77.1	86.6	120	135
24 hr	85.1	95.7	133	149
36 hr	96.8	109	152	171
48 hr	105	118	167	188
72 hr	115	129	187	210
96 hr	121	136	198	223
120 hr	125	140	205	231
144 hr	127	143	209	235
168 hr	129	145	211	237

2.6.2 Temporal patterns

Aerial temporal patterns for the Murray Basin region were sourced from the DataHub (Appendix B). Embedded rainfall bursts have been filtered using the inbuilt function in RORB.

The PMP temporal patterns were derived using the Generalised Short-Duration Method (GSDM) (BoM 2003) for storm duration 3 hours and shorter and the Generalised Southeast Australia Method (GSAM) (BoM 2006) for storm duration 24 hours and longer. The 12 hour PMP was assessed using both the GSDM and GSAM temporal patterns with the temporal pattern resulting in the critical flows adopted.

2.6.3 Areal reduction factors

Areal reduction factors for the southern temporal zone were used.

2.6.4 Storm losses

Initial and continuing losses have been defined through reconciling Monte Carlo flood frequency analysis results to the FFA results as described in Section 2.6.5. The resulting design event initial and continuing losses are presented in Table 2.19. These initial losses are factored by the Monte Carlo flood frequency analysis initial loss factors presented in Table 2.20.

Table 2.19: Design event storm losses

	Avoca River @ Amphitheatre	Avoca River @ Archdale Junction	Catchment Outlet
Initial Losses (mm)	20	25	25
Continuing Losses (mm/hr)	1.2	0.6	0.6

2.6.5 Design flows and critical events

Design flows have been defined by validating Monte Carlo flood frequency analysis results to the FFA results. The validation was achieved by varying the initial and continuing losses. Initially the regional initial loss obtained from the DataHub (Appendix B) of 27 mm and continuing loss of 4.4 mm/hr were used, these values were then varied until a good fit with the FFAs were achieved. Weighting was given to validating the Monte Carlo flood frequency analysis results to the FFA results at more frequent events (20%, 10% and 5% AEPs) where the uncertainty bounds are smaller as a result of the length of available gauge records.

The validated Monte Carlo flood frequency analysis peak flows to the FFA results are shown in Figure 2.16 for the Avoca River @ Amphitheatre gauge and Figure 2.17 for the Avoca River @ Archdale Junction gauge.

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 2.20.

The 12-hour PMP storm duration using the 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 2.20).

The AEP event design RORB hydrographs at the Avoca River @ Amphitheatre gauge, Avoca Township and Avoca River @ Archdale junction gauge are shown in Figure 2.18, Figure 2.19 and Figure 2.20 respectively. The PMP event hydrographs are presented in Figure 2.21. A comparison of the 10% and 1% AEP climate change hydrographs are shown in Figure 2.22 and Figure 2.23 respectively.

Please note that RORB hydrographs do not represent the entire flow across the floodplain because cross sub-catchment flows are not represented in the RORB model. Please refer to Section 5.7 for floodplain flow hydrographs.

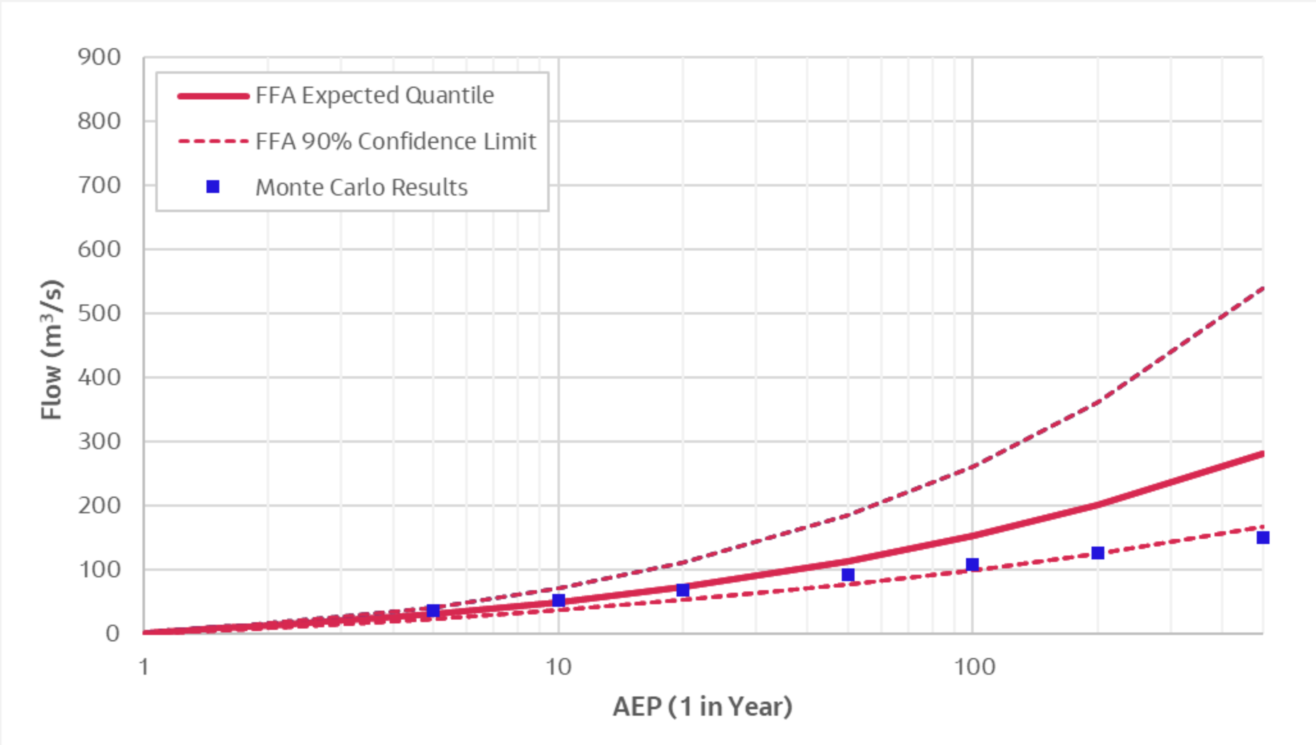


Figure 2.16: Avoca River @ Amphitheatre Monte Carlo flood frequency analysis flow validation

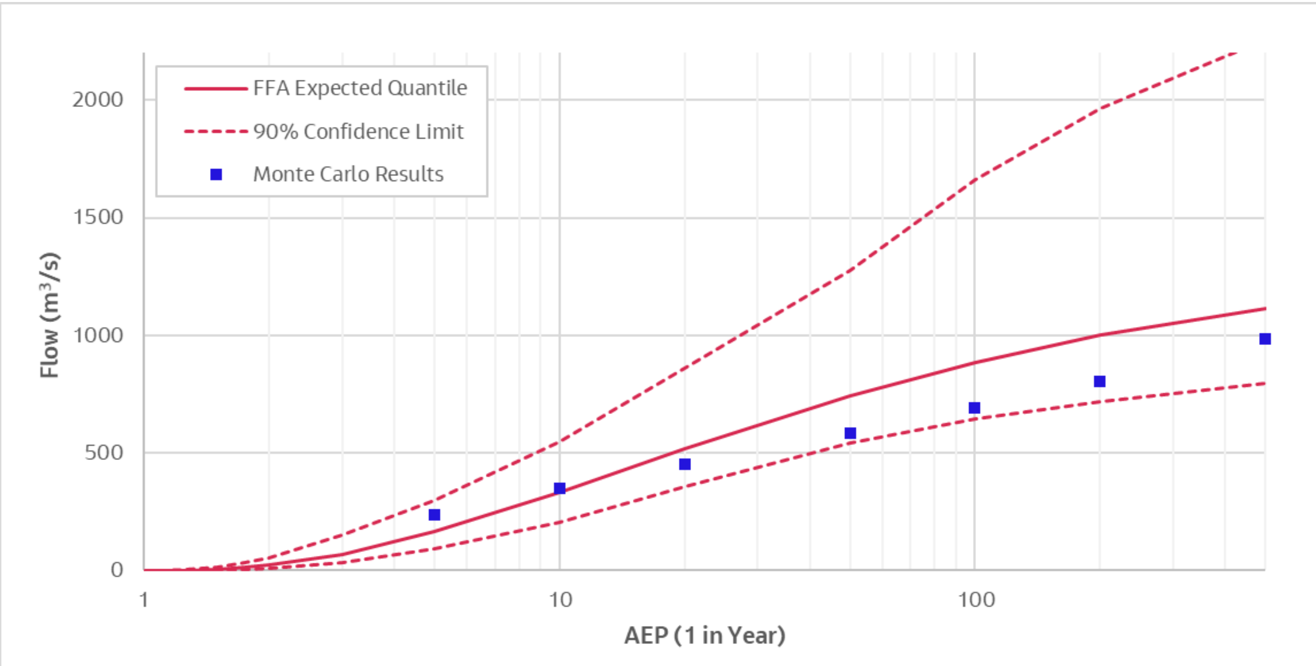


Figure 2.17: Avoca River @ Archdale Junction Monte Carlo flood frequency analysis flow validation

Table 2.20: 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)			Adopted Design Event Parameters		
	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	Duration	Areal Temporal Pattern	Initial Loss Factor
20%	32	37	**36**	144	**147**	164	239	**228**	24 h	7	0.91
10%	50	52	**56**	204	**201**	334	348	**336**	24 h	2	0.91
5%	74	68	**64**	253	**248**	519	451	**440**	24 h	6	0.72
2%	114	94	**90**	334	**328**	744	584	**553**	24 h	2	1.09
1%	154	109	**109**	399	**401**	886	693	**701**	24 h	2	0.83
0.5%	202	127	**128**	463	**467**	1001	802	**858**	24 h	2	0.40
0.2%	282	150	**146**	545	**528**	1116	985	**957**	24 h	2	0.88
	Adopted Design Event			Adopted Design Event		Adopted Design Event			Duration	Temporal Pattern	
PMP	**796**			**2901**		**5206**			12 h	GSAM	

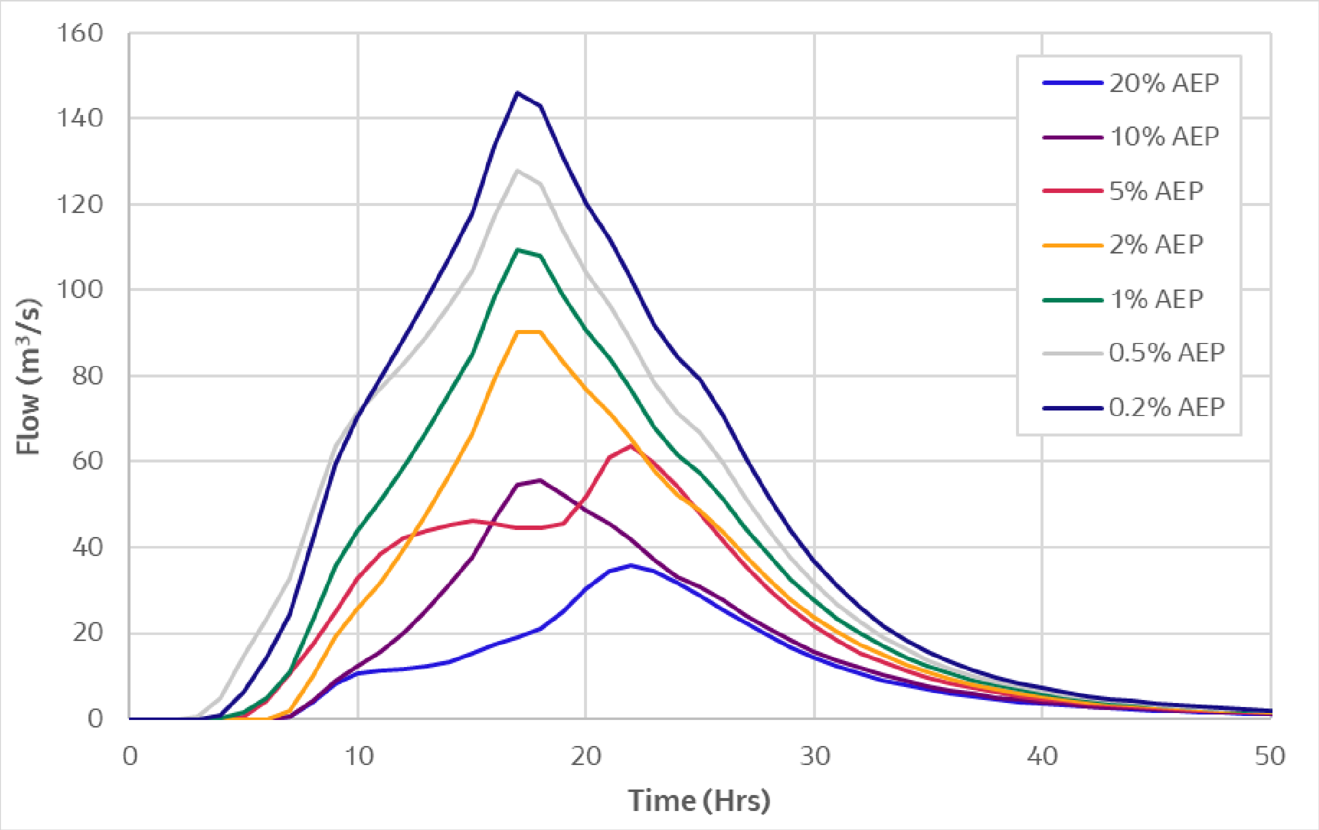


Figure 2.18: Avoca River @ Amphitheatre RORB design event hydrographs

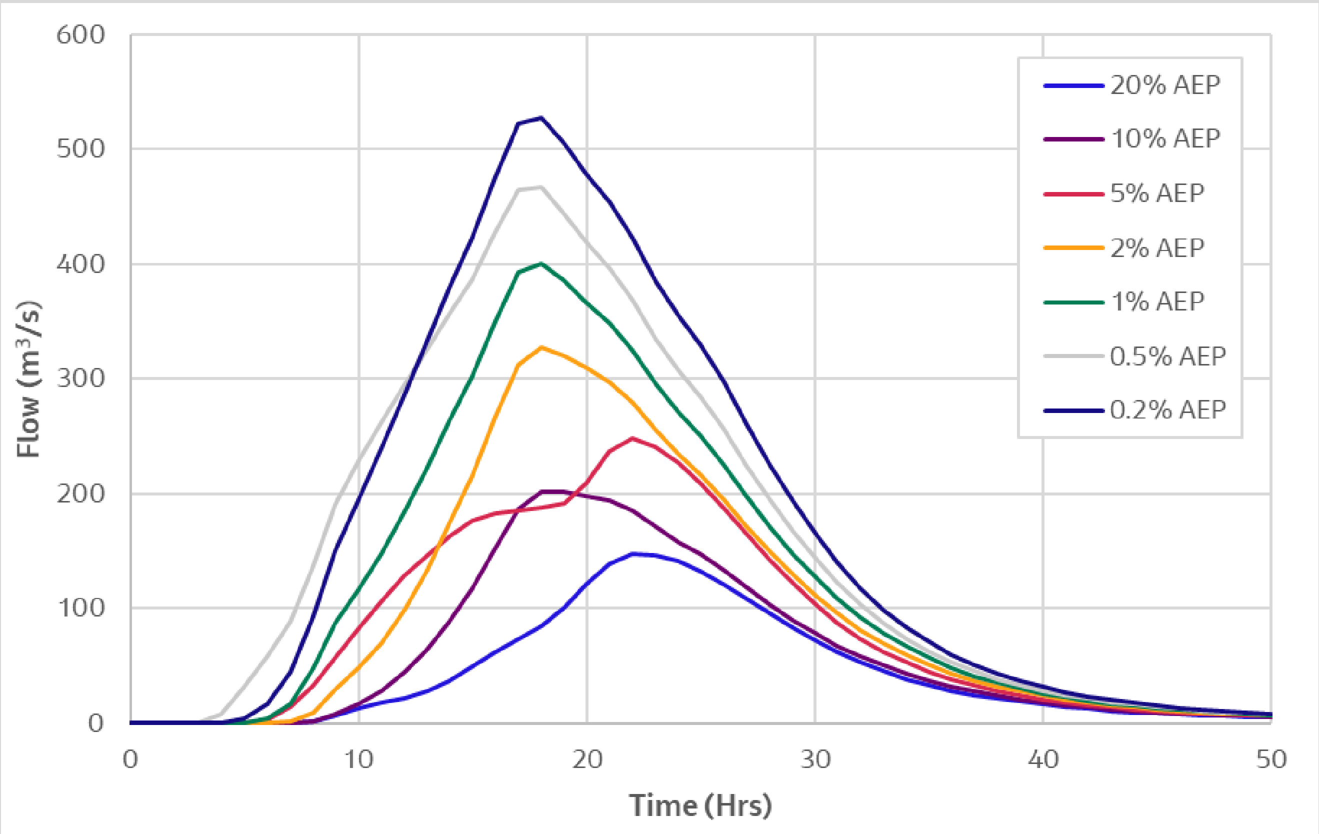


Figure 2.19: Avoca Township RORB design event hydrographs

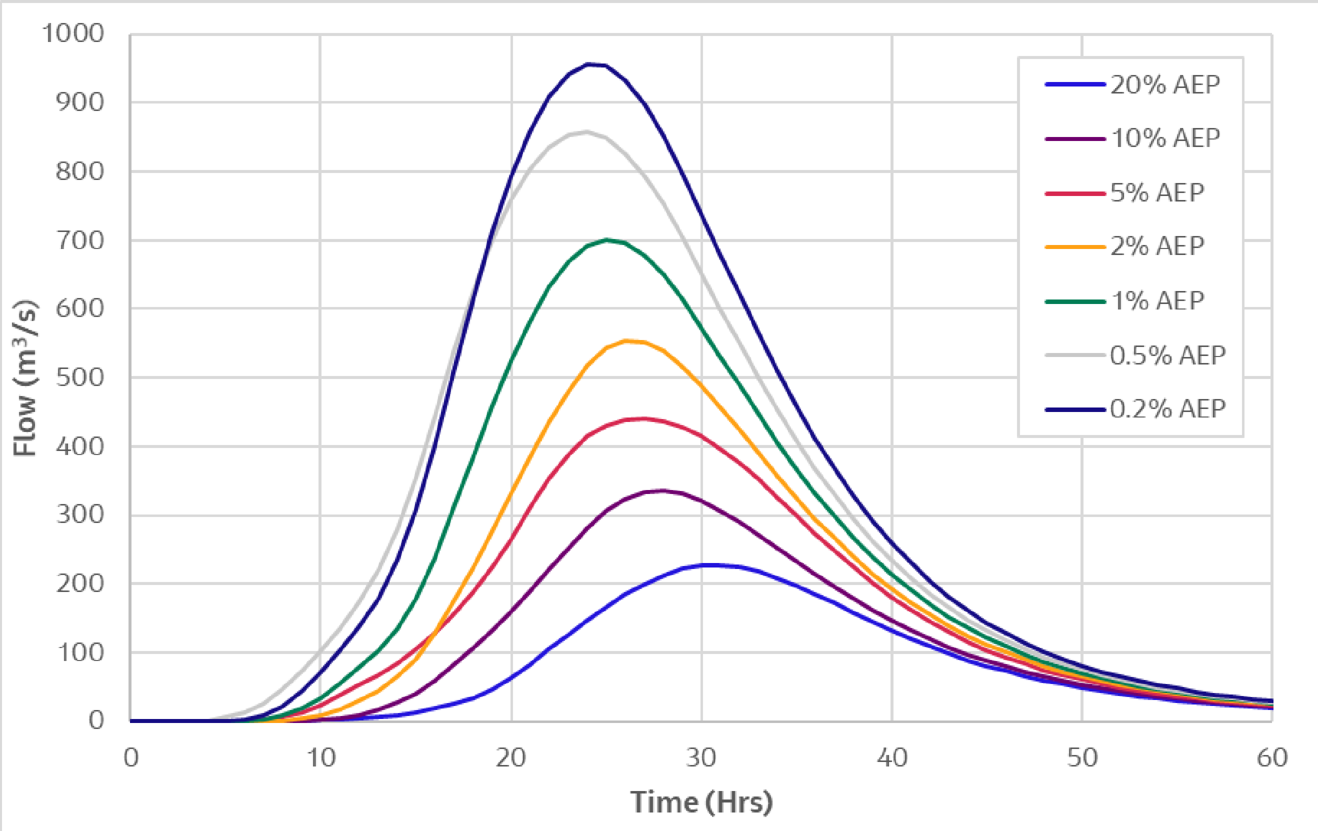


Figure 2.20: Avoca River @ Archdale Junction RORB design event hydrographs

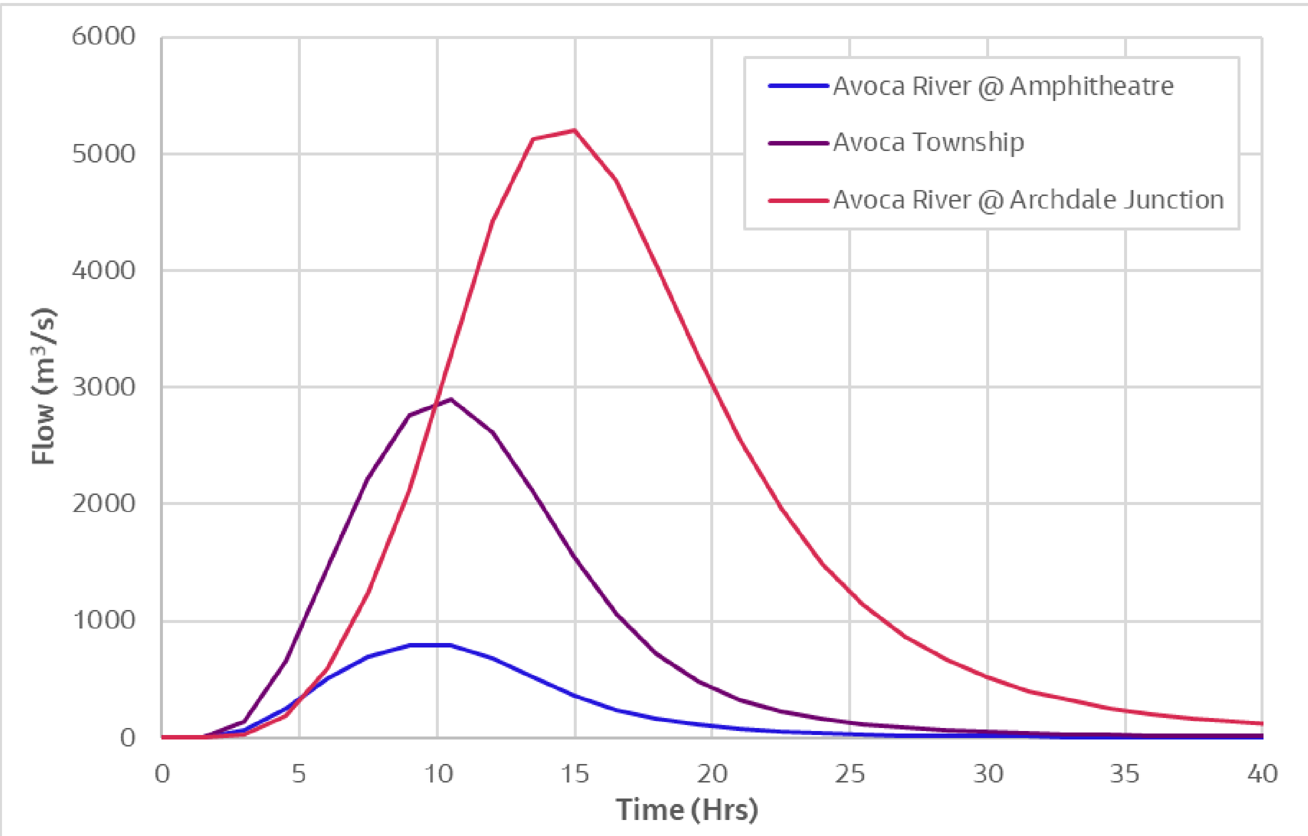


Figure 2.21: PMP RORB design event hydrographs

2.6.5.1 Climate change design flows

The 10% and 1% AEP event RORB peak flows for the 2100 RCP 4.5 and RCP 8.5 climate change scenarios are presented in Table 2.21. Hydrographs at the Avoca River @ Amphitheatre gauge, Avoca Township and Avoca River @ Archdale junction gauge for the 10% AEP and 1% AEP events are shown in Figure 2.22 and Figure 2.23 respectively.

Table 2.21: Climate change RORB peak flows

Location	10% AEP Peak Flow (m^3/s)			1% AEP Peak Flow (m^3/s)		
	2020 (Current)	2100 RCP 4.5	2100 RCP 8.5	2020 (Current)	2100 RCP 4.5	2100 RCP 8.5
Avoca River @ Amphitheatre	56	65	78	109	124	146
Avoca Township	201	237	286	401	453	525
Avoca River @ Archdale Junction	336	396	484	701	800	939

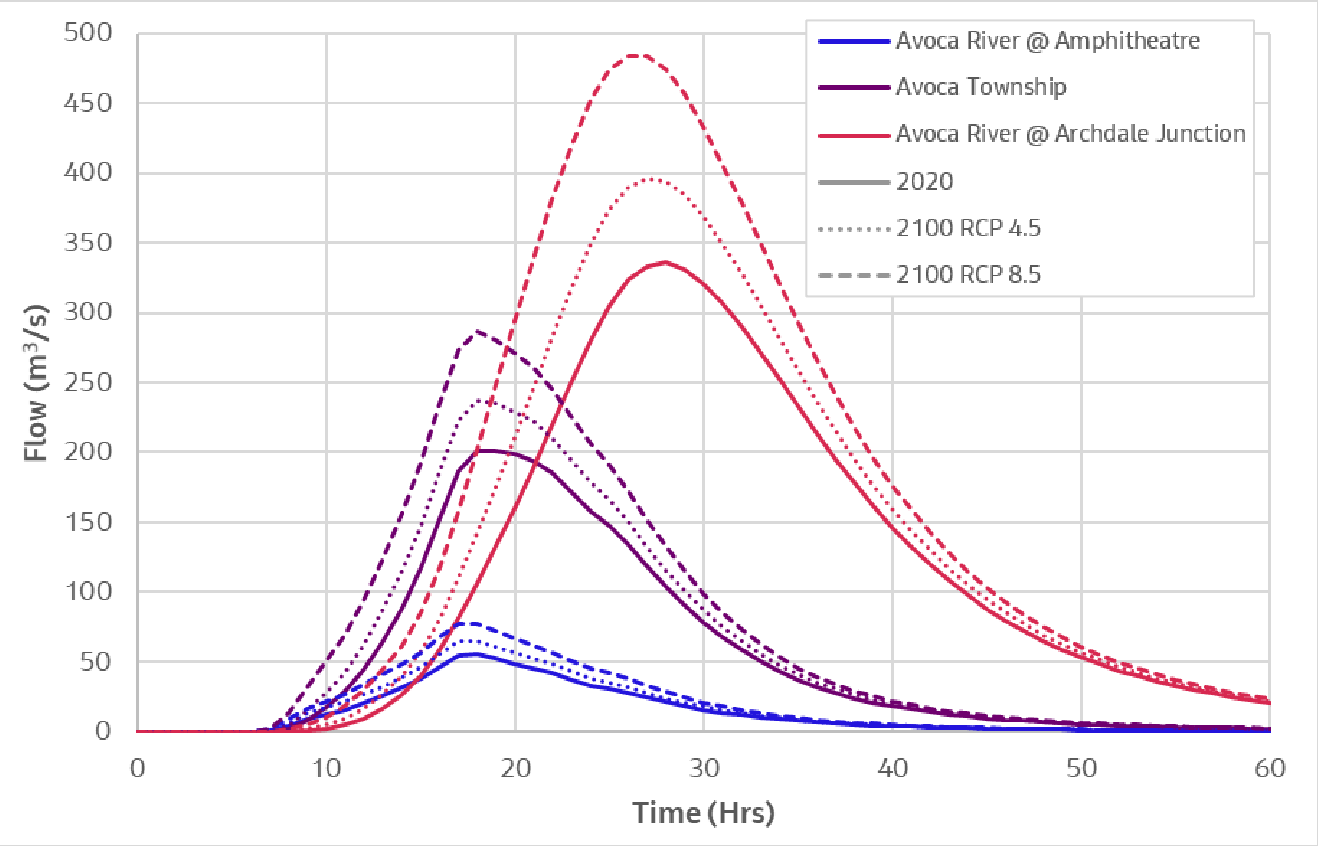


Figure 2.22: 10% AEP climate change RORB design event hydrographs

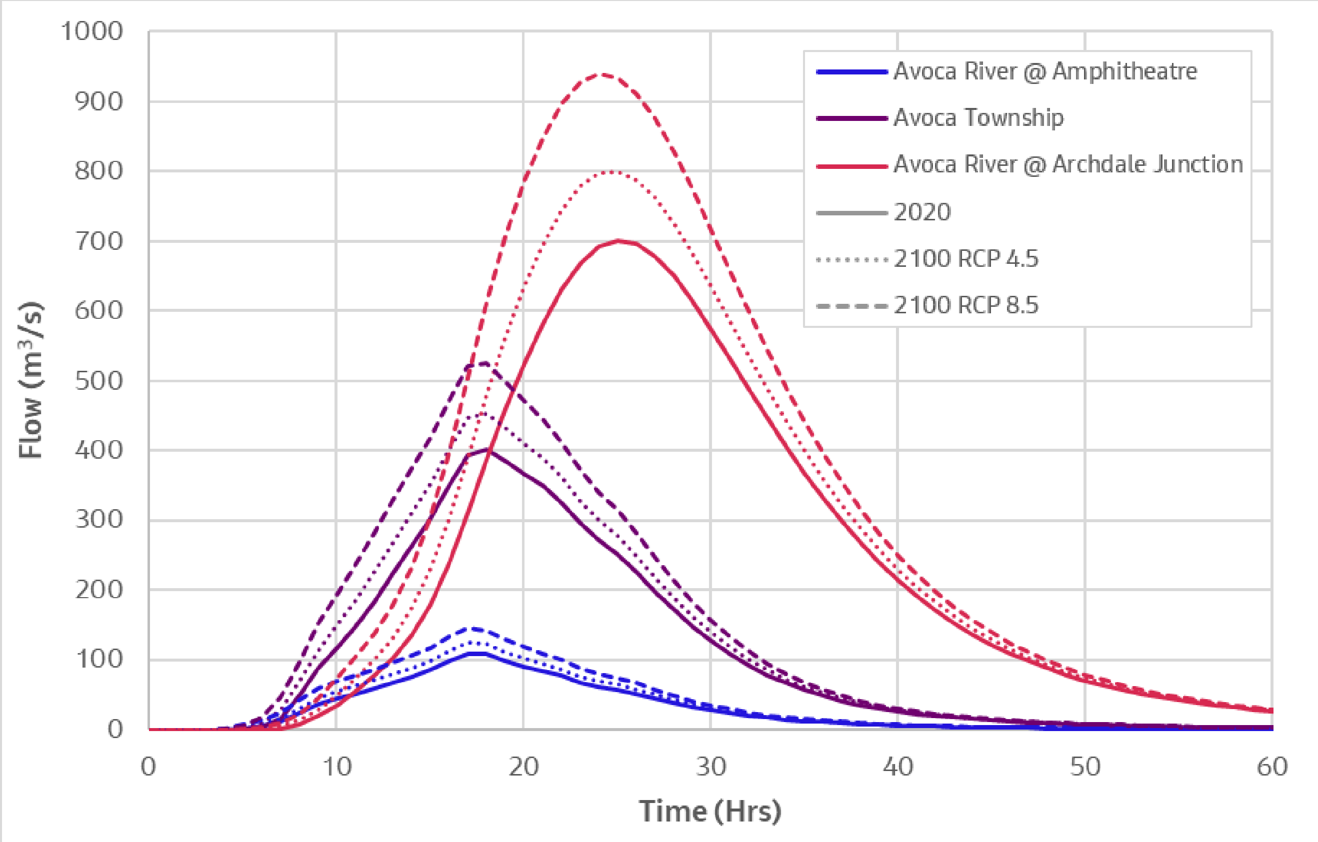


Figure 2.23: 1% AEP climate change RORB design event hydrographs

2.7 Sensitivity analysis

To better understand the level uncertainty associated with the adopted hydrologic modelling parameters, sensitivity analysis has been undertaken on the following parameters:

- Kc routing parameter
- Initial and continuing losses
- Spatial rainfall variation
- Temporal rainfall variation

A detailed description of each sensitivity analysis and the results is provided in the following sections.

2.7.1 K_c routing parameter sensitivity analysis results

To assess the uncertainty associated with the K_c routing parameters, the adopted K_c (Table 2.15) have been varied by $^{+}/_{-}$ 20%. The resulting sensitivity analysis K_c values are presented in Table 2.22.

The sensitivity analysis K_c values were modelled in the RORB using the critical 1% AEP event and the peak flows are presented in Table 2.22 and Figure 2.24. The results of the sensitivity analysis show that the RORB flows are sensitive to the adopted K_c parameter in peak flow where changes of approximately $^{+}/_{-}$ 10% and are observed at each location. At the Avoca River @ Archdale Junction gauge there is also an observable change in hydrograph timing of approximately 3 hours. However, the majority flow routing occurs in the hydraulic model as it covers a large proportion of the catchment area.

Table 2.22: Sensitivity analysis K_c values and 1% AEP peak flows

Location	K_c value			1% AEP peak flow (m^3/s)		
	Adopted	+ 20%	- 20%	Adopted	+ 20%	- 20%
Avoca River @ Amphitheatre	15.0	18.0	12.0	109	99	121
Avoca Township	NA	NA	NA	401	356	443
Avoca River @ Archdale Junction	39.6	47.5	31.7	701	612	802
Catchment Outlet	20.6	24.7	16.5	NA	NA	NA

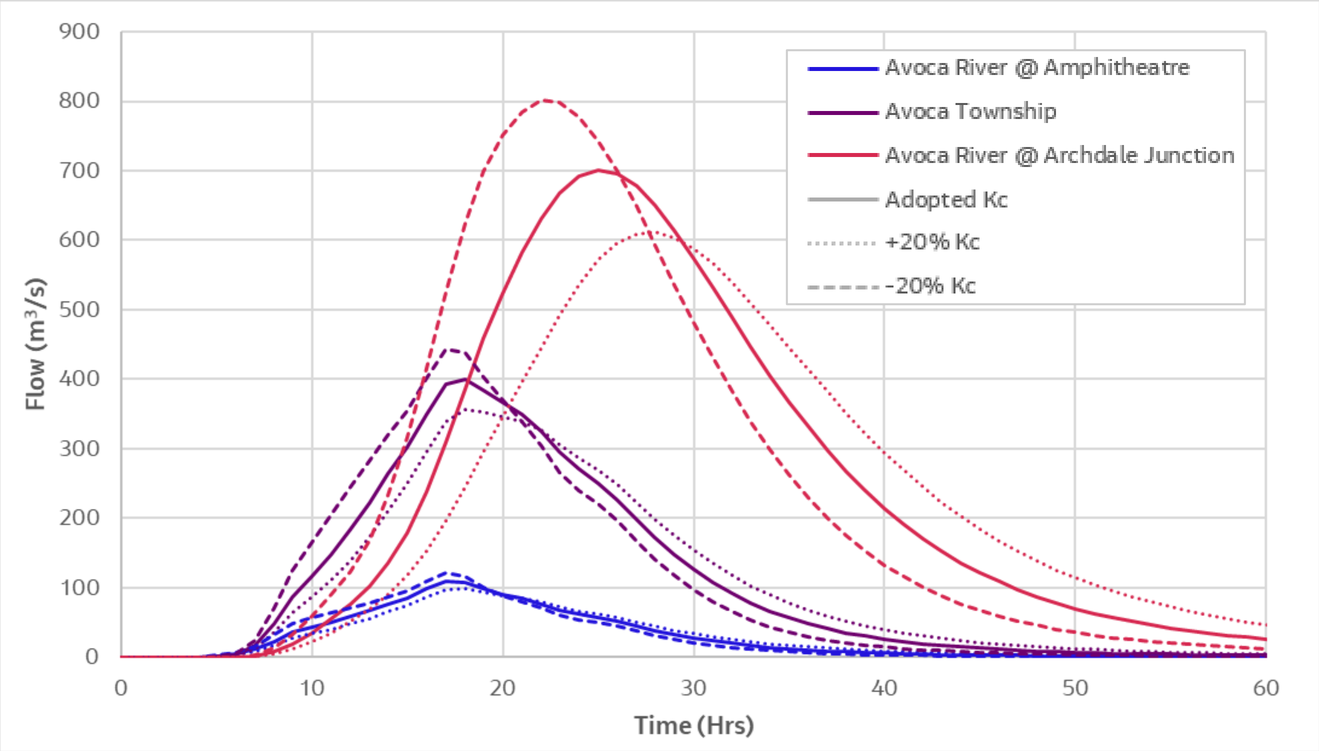


Figure 2.24: K_c sensitivity analysis 1% AEP hydrograph comparisons

2.7.2 Initial and continuing losses sensitivity analysis results

To assess the uncertainty associated with the initial and continuing losses, the adopted losses (Table 2.19) as derived by the Monte Carlo flood frequency analysis validation have been compared to the rural regional initial loss obtained from the DataHub of 27 mm and continuing loss of 4.4 mm/hr in the RORB model using the critical 1% AEP event.

A comparison of the adopted peak flows to those derived using regional loss values is provided in Table 2.23 and Figure 2.25. These results indicate that the regional continuing loss value of 4.4 mm/hr may be significantly overestimating continuing loss values in the catchment during periods of flood. Noting that the regional loss parameters presented in ARR 2019 have a degree of uncertainty and local data is preferred, the difference could be equated to significant flood events in the Upper Avoca River catchment been highly influenced by antecedent conditions, not just the magnitude of rainfall.

Table 2.23: Regional loss values 1% AEP peak flow comparison

Location	Adopted 1% AEP peak flow (m^3/s)	Regional loss values 1% AEP peak flow (m^3/s)
Avoca River @ Amphitheatre	109	44
Avoca Township	401	133
Avoca River @ Archdale Junction	701	188

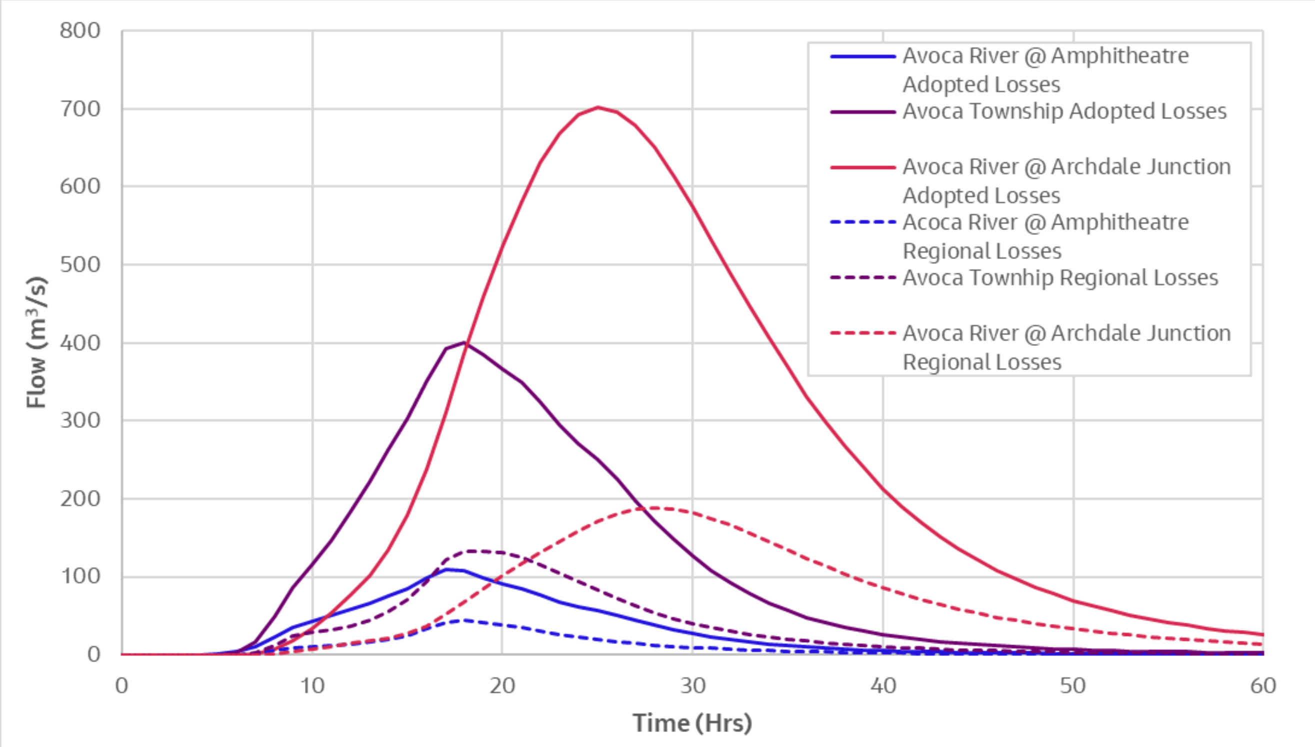


Figure 2.25: Regional loss sensitivity analysis 1% AEP hydrograph comparisons

2.7.3 Spatial rainfall variation results sensitivity analysis results

As the Upper Avoca River catchment area is great 20 km^2 the design rainfall was spatially varied across the catchment. To assess the uncertainty associated with spatial variation of rainfall across the catchment, a modelling scenario where constant rainfall across the catchment has been modelled in the RORB model using the critical 1% AEP event.

A comparison of the adopted peak flows to those derived using uniform spatial pattern is provided in Table 2.24 and Figure 2.26. These results indicate that in the upper catchment (Avoca River @ Amphitheatre) are more sensitive to spatial rainfall variations with a 13% reduction in peak flow in comparison to the lower catchment with a 6% reduction in peak flow at Avoca River @ Archdale Junction. This is consistent with the gridded IFD data (Figure 2.15) which shows higher rainfall in the hilly areas of the upper catchment. This analysis highlights the influence that the available coverage and quality of rainfall data across a catchment can have on the results of model calibration and validation.

Table 2.24: Uniform spatial pattern 1% AEP peak flow comparison

Location	Adopted 1% AEP peak flow (m^3/s)	Uniform spatial pattern 1% AEP peak flow (m^3/s)
Avoca River @ Amphitheatre	109	95
Avoca Township	401	363
Avoca River @ Archdale Junction	701	661

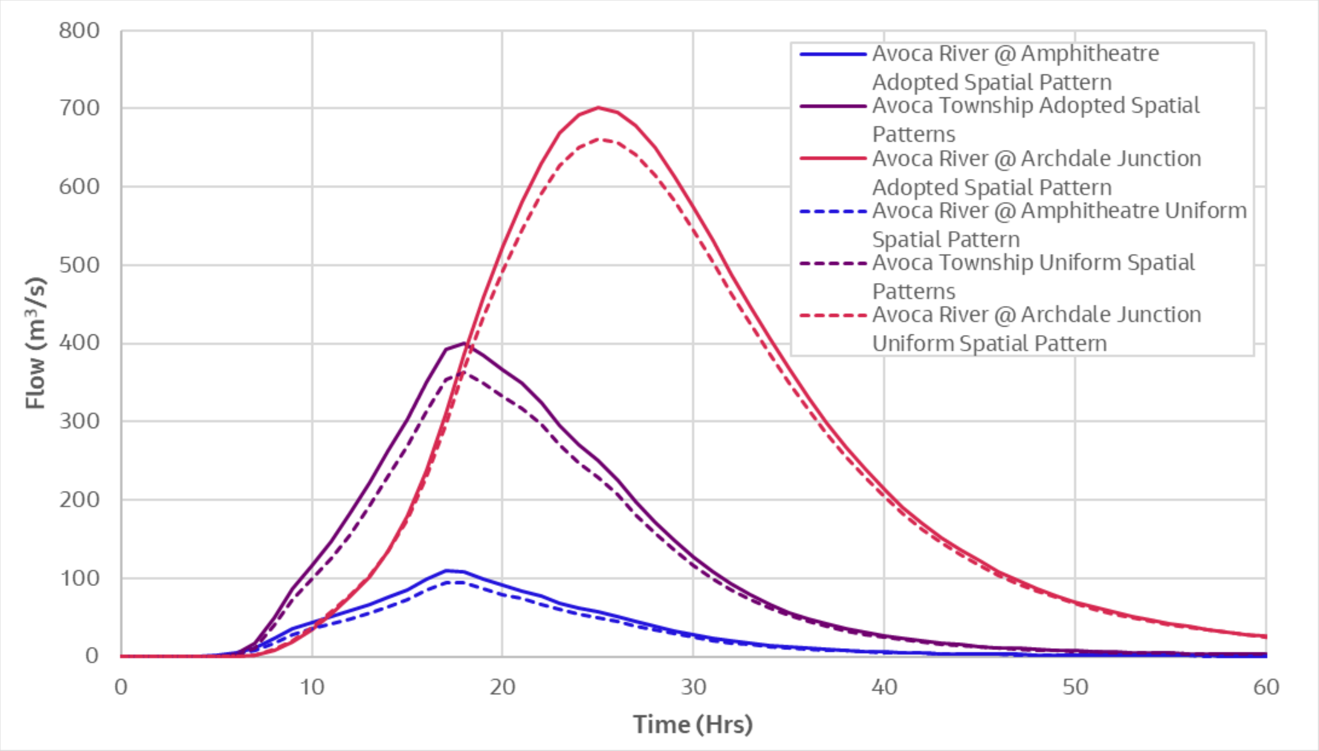


Figure 2.26: Uniform spatial pattern sensitivity analysis 1% AEP hydrograph comparisons

2.7.4 Temporal rainfall variations results sensitivity analysis results

For the adopted % AEP 24-hour event, aerial temporal pattern 2 was assessed as representing the critical peak flows from the Monte Carlo flood frequency analysis. Figure 2.27 and Figure 2.28 show a comparison of the hydrographs at Avoca River @ Amphitheatre and Avoca River @ Archdale Junction respectively for each of the 10-design aerial temporal patterns. The analysis shows that there are variance in peak flows of approximately $^+/_-$ 20% at Avoca River @ Amphitheatre, reduced to $^+/_-$ 10% at Avoca River @ Archdale Junction.

Figure 2.27 shows that at Avoca River @ Amphitheatre there is about 10-hour variance in peak flow timing between a front-loaded storm (temporal pattern 4) and a rear-loaded storm (temporal pattern 3). This is reduced to about seven hours at Avoca River @ Archdale Junction (Figure 2.28) as result flow routing through the catchment influencing the flood peak timing.

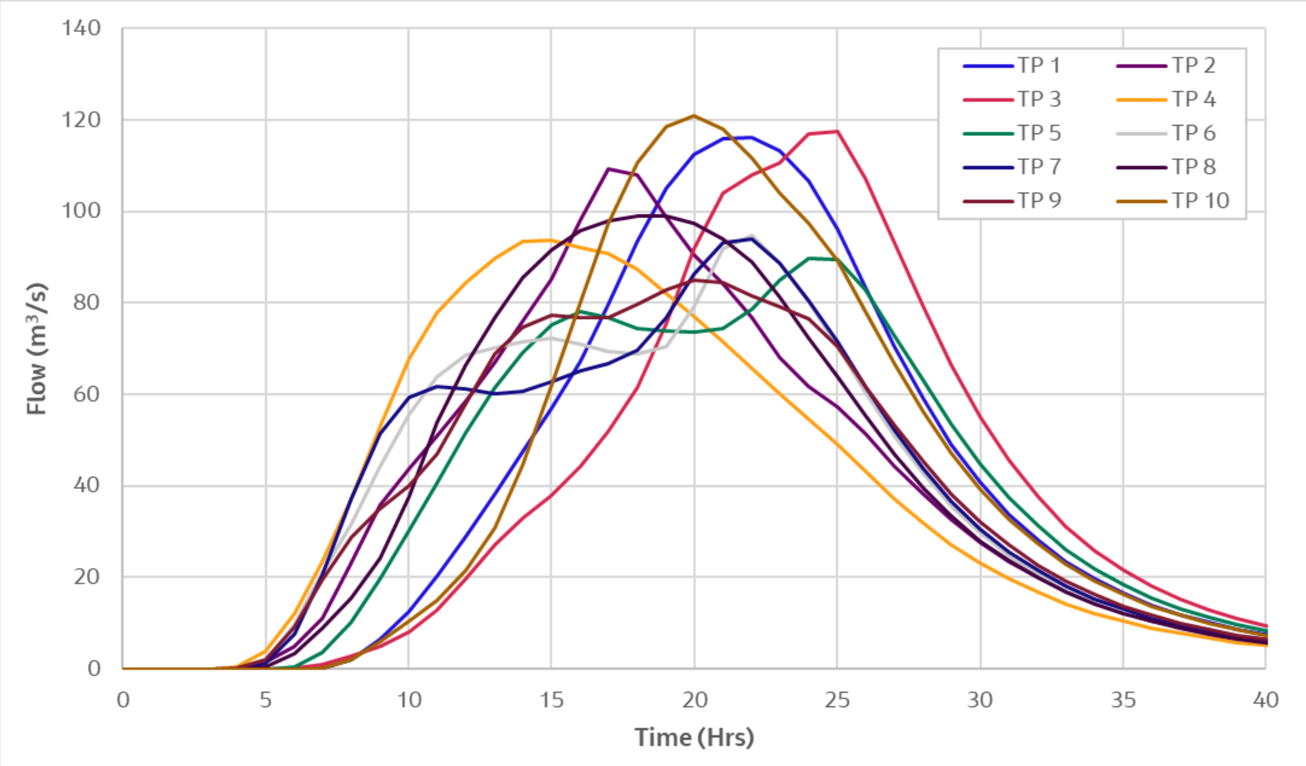


Figure 2.27: Temporal pattern sensitivity analysis Avoca River @ Amphitheatre 1% AEP hydrograph comparisons

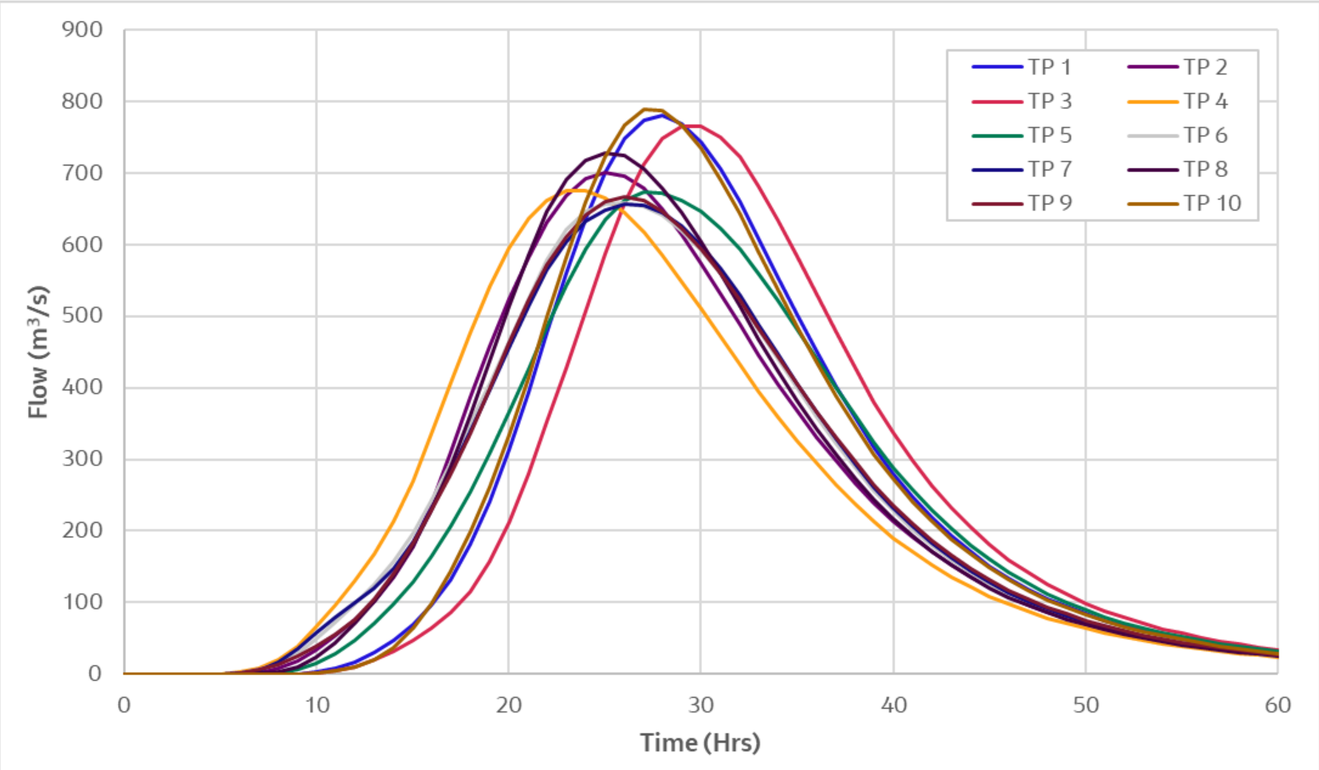


Figure 2.28: Temporal pattern sensitivity analysis Avoca River @ Archdale Junction 1% AEP hydrograph comparisons

3. Hydraulic modelling

Adopted storm events were applied to a TUFLOW model to simulate the catchment's response to flooding. TUFLOW is a modelling package supporting both 1D and 2D elements, allowing individual structures (e.g. bridges and culverts) to be represented within the greater floodplain.

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 coverage and layout of each model is shown in Figure 3.1. The main characteristics of the models can be summarised as:

- **Regional model –** 10 m grid size model covering the entire Investigation area 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.

3.1 TUFLOW version

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

3.2 Model development

3.2.1 Grid size and orientation

The grid size adopted was 10 m for the 'regional', large scale model, and 2 m for the three town models. The 2 m grid allows for the recommended 4-5 grid cells across major waterways. To achieve this outside of the towns, the regional model uses a 1D channel network to represent key watercourses.

Each model is tilted in orientation to generally align with the Avoca River and the Avoca-Bealiba Road.

3.2.2 Topography

Due to limited coverage across the study area, three DEM datasets were used to inform the ground of the TUFLOW model, these included:

- **2009-10 Victorian State-Wide Floodplains LiDAR Project:** Captured on 30 April 2011
- **2009-10 ISC Rivers LiDAR:** Captured on 10 October 2010
- **VicMap Elevation DTM 10m:** 10 m grid with a stated accuracy of +/- 5 m.

A description of these datasets, their coverage and verification of vertical accuracy is provided in the Data Review Report.

Review of the LiDAR datasets shows that the 2009-10 ISC Rivers LiDAR provides better definition of the waterways, mainly the Avoca River channel and has been overlayed on top of the 2009-10 Victorian State-Wide Floodplains LiDAR Project dataset.

The 10 m DTM, with full coverage of the catchment, was used 'beneath' the two sets of LiDAR, to infill a section of missing LiDAR coverage north-east of Natte Yallock.

Where required, significant hydraulic features such as road embankments and bunds were re-enforced using in-built functions in TUFLOW.

3.2.3 Model roughness

Each cell of the 2D model is assigned a roughness parameter for hydraulic calculations. Land use, planning layers and aerial imagery were used to determine these values across the model. Outside of the town areas, the catchment is largely pasture or crops, with some rural housing and patches of forest. Roads, waterbodies and the railway were also assigned individual roughness values. Adopted Manning's 'n' roughness values are summarised in Table 3.1 and the coverage mapped in Figure 3.2.

Table 3.1: Adopted Manning's 'n' values

Description	Manning's 'n'
Farming, fields, grass (typical floodplain)	0.04
Roads (sealed)	0.02
Roads (unsealed)	0.03
Rural residential	0.20
Urban residential	0.30
Industrial	0.30
Moderate vegetation	0.06
Thick vegetation	0.07
Waterways (minimal vegetation)	0.035
Waterways (moderate vegetation)	0.06
Railways	0.05
Lakes	0.02
Cropped fields	0.05

3.2.4 1D open channel

In the regional model, the major watercourses in the Investigation area including the Avoca River, Amphitheatre Creek, No. 2 Creek and Rutherford Creek were represented by an embedded 1D network as shown in Figure 3.1.

In total approximately 85 km of 1D river channel was embedded within the hydraulic model. The bathymetry of the river was defined by extracting cross-sections at regular intervals from the 2009-10 ISC Rivers LiDAR. Surveyed cross-sections were also included in the 1D river network upstream and downstream of significant hydraulic structures including bridges and weirs.

The rivers were modelled as a steep channel (S type in TUFLOW). This channel type is the preferred channel type as it incorporates all flood regimes including super-critical flow.

The 1D networks were dynamically linked to the 2D model domain providing a free exchange of water between the 1D channel and the adjacent floodplain when banks levels are exceeded.

3.2.5 Hydraulic structures

Survey of structures within the catchment was undertaken in December 2019 – January 2020. Results of this, in combination with council records, VicRoads drawings, and site inspection, were used to inform the representation of culverts, bridges and weirs as detailed in Jacobs (2020a).

Bridges were represented as layered flow constrictions in the 2D models, and as TUFLOW ‘B’ bridge types in 1D. Form loss coefficients were derived from AustRoads (2018) and for the layered flow constrictions were applied using a form loss of 1.56 has been applied to Layer 2 representing the bridge deck.

3.2.6 Boundary conditions

Inflows from the RORB model were applied as external QT (flow-time) boundaries for areas of the catchment outside (upstream) of the TUFLOW model. The routed flows from the RORB model were applied. Internal inflows were applied as SA (source-area) boundaries. Where appropriate, if a clearly defined flow path (waterways) is present in a sub-catchment, streamlines were used to apply flow directly to the waterways first. As appropriate based on the length of flow routing in the hydraulic model, both ‘routed’ and ‘excess rainfall’ hydrographs were applied. These boundaries are shown on Figure 3.1.

The Avoca River 1D channel downstream boundary is modelled as a head versus flow boundary (rating curve) applied to the 1D river network. The rating curve was derived using the Manning’s equation with a cross-section of the entire floodplain downstream of the 2D model boundary and the appropriate Manning’s n value. The sensitivity of the flood model to downstream boundary setup is analysed in 3.4.3.

For downstream boundaries (outflow) on the floodplain, automatically generated HQ (height-flow) boundaries were used at the downstream extents of the models. These are located downstream of the area of interest to minimise the influence of the boundary.

At the upstream interface between the fine-mesh models and the larger regional model, flows from the regional model were applied directly as QT boundaries.

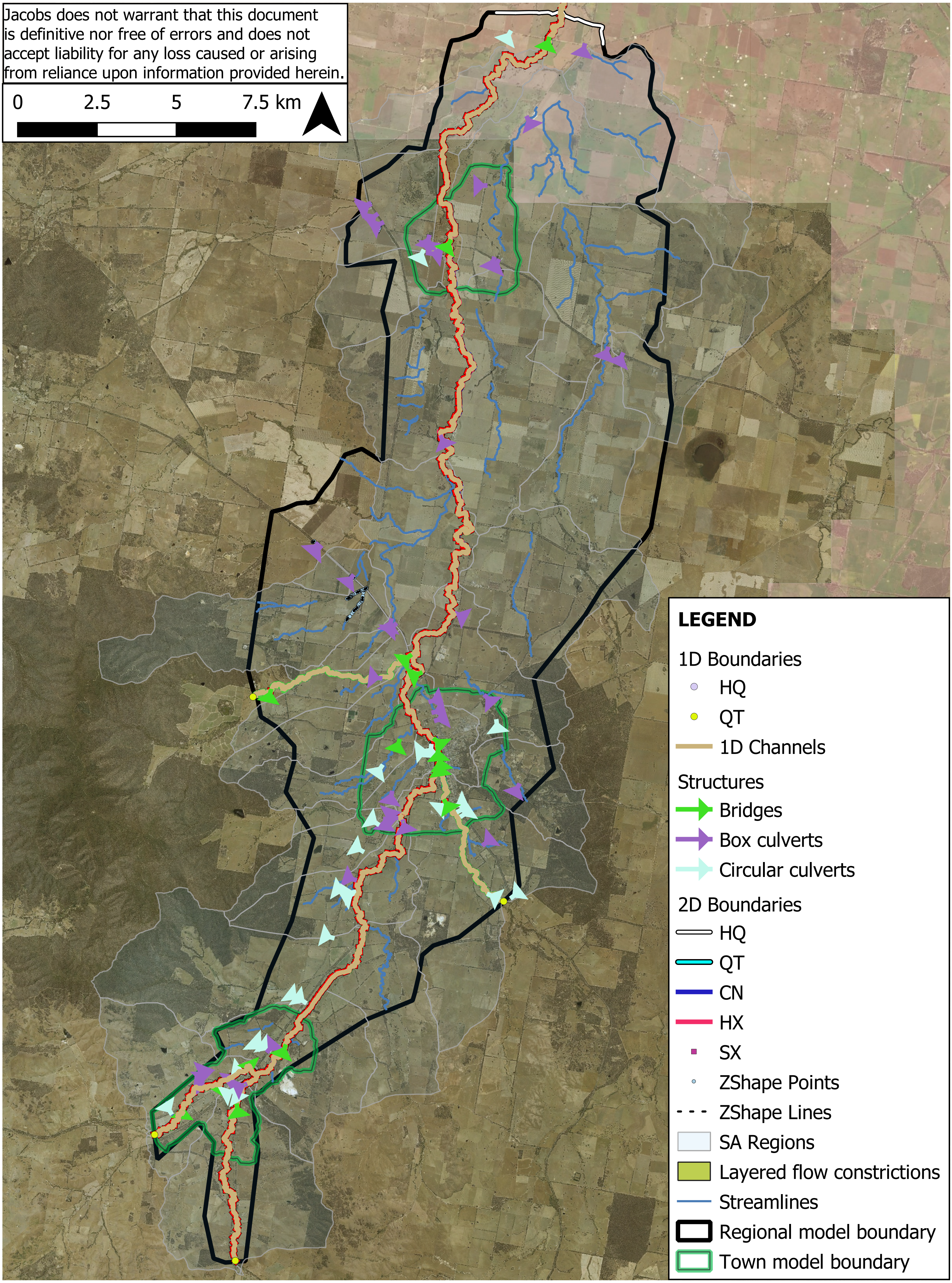


Figure 3.1: TUFLOW Model Layout

Jacobs

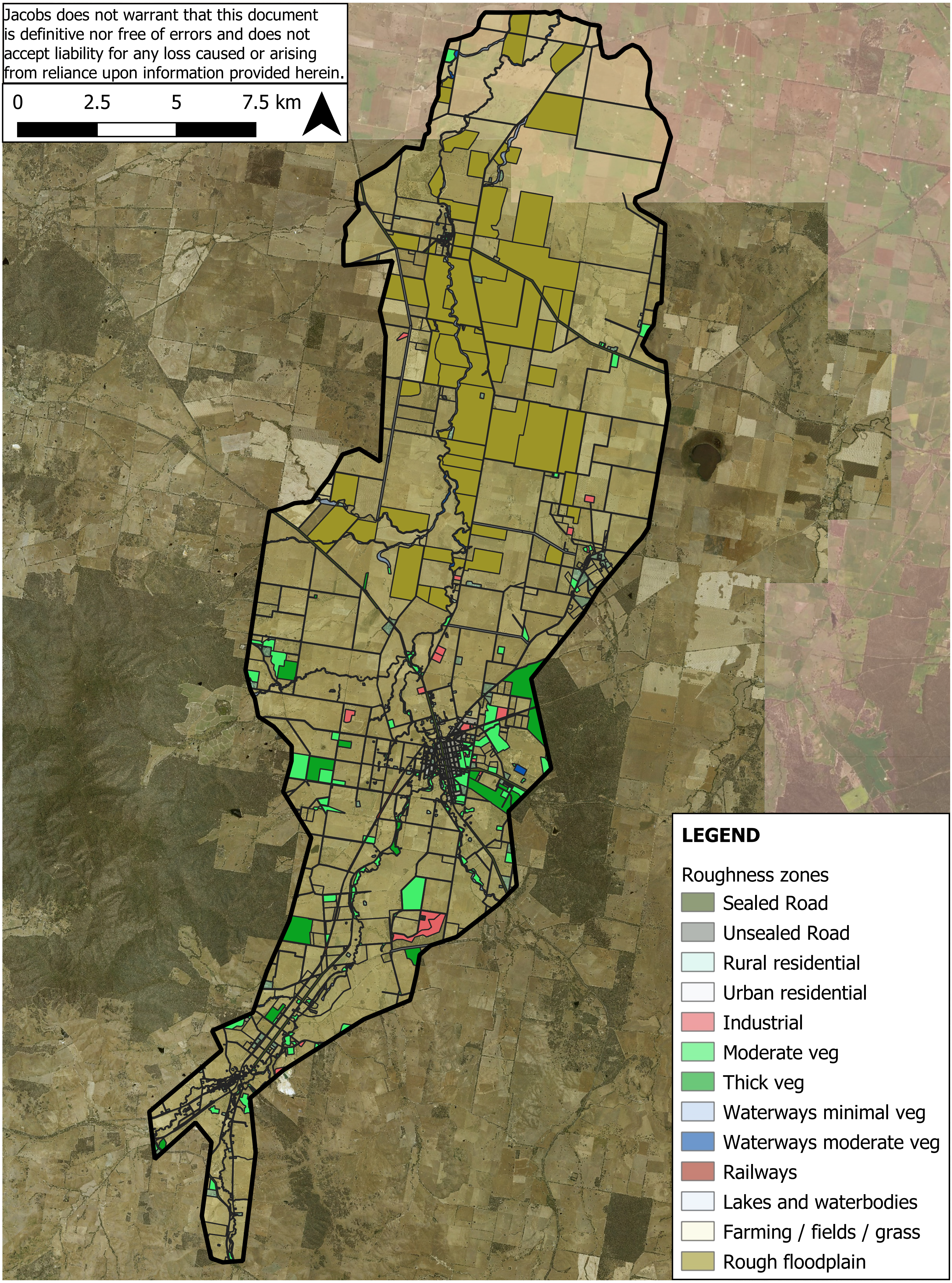


Figure 3.2: Manning's roughness zones

Jacobs

3.3 Calibration and validation

To calibrate the TUFLOW hydraulic model, catchment inflows from the calibrated RORB model (see Section 2.5) 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 Project Reference Group (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.

3.3.1 September 2010 calibration event results

A comparison of the recorded and modelled water levels at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges for the September 2010 calibration event are shown in Figure 3.3 and Figure 3.4 respectively. Photos and historic aerial imagery show that during the September 2010 flood event the fence along the southern boundary of the Avoca Public Park was of a steel sheeting type and has been modelled represented in the model using a breakline.

The modelled peak water level is 123 mm higher than that recorded at the Avoca River @ Amphitheatre gauge and 16 mm higher at the Avoca River @ Archdale Junction gauge. At the Avoca River @ Archdale Junction gauge, the modelled flood levels fall quicker than recorded. This a result of the inability for the RORB model to represent the slow falling limbs on the flood hydrographs as described in Section 2.5.2.1.

There are nine surveyed flood level marks across the catchment available for the September 2010 event. These are shown in Figure 3.5 with flood extent from the town model and include eight marks in Avoca, and one in Natte Yallock. Peak flood levels from the regional and town flood models were compared to the flood marks.

In Avoca at the flood pole on the east side of the Avoca River the town flood models underestimate flood levels by up to 281 mm while upstream of the Pyrenees Highway a close fit to the recorded flood levels within 69 mm was achieved. The four flood level marks located along the fence line of the Avoca Public Park are over estimated by between 205 mm and 295 mm. It should be noted that there is a large discrepancy in the flood marks surveyed at the Avoca Public Park been approximately 400 mm lower than those on east side of the Avoca River. Following review of the available flood photography, site visits and the flood modelling this difference was not able to be rationalised.

In Natte Yallock the town model overestimates flood levels by 99 mm and is considered a good fit.

Limited flood photography was available for the September 2010 calibration event so a comparison of extent to photography was able to be completed.

The modelled September 2010 flood extent and depths for the whole catchment are mapped in Figure 3.6.

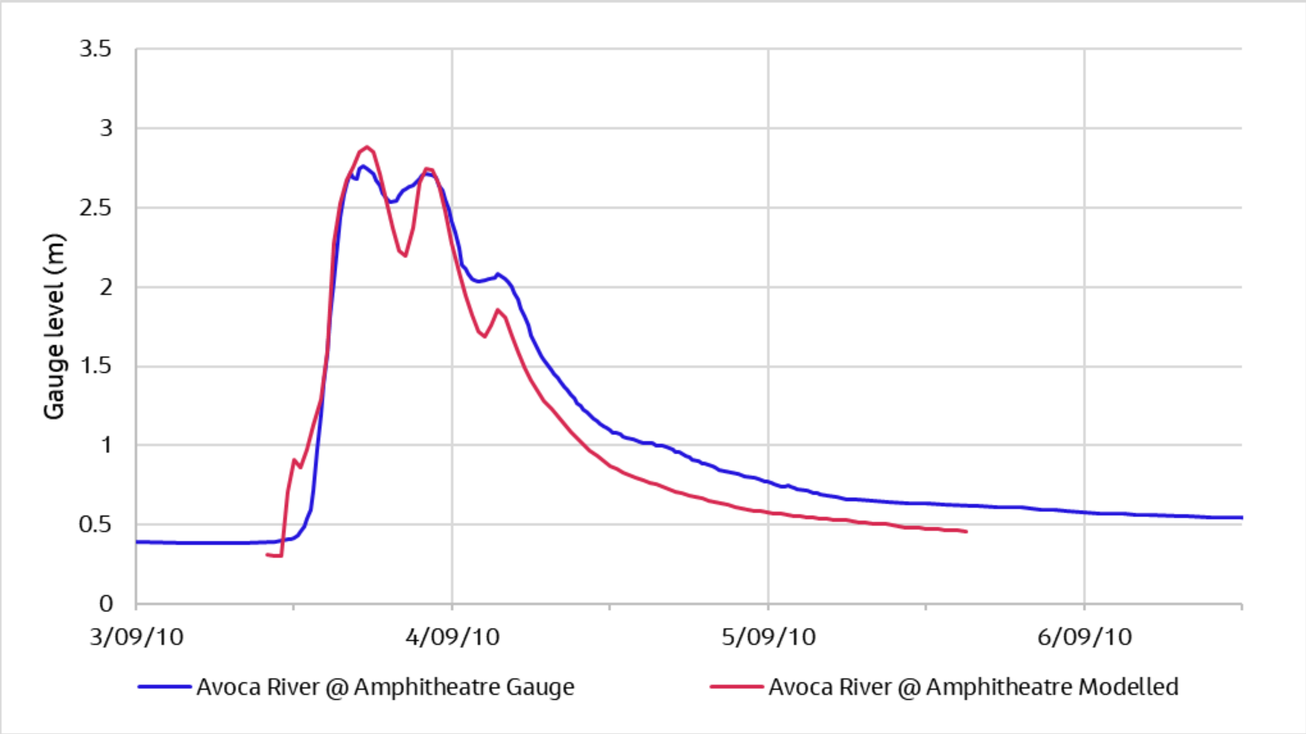


Figure 3.3: Avoca River @ Amphitheatre September 2010 calibration event gauge level comparison

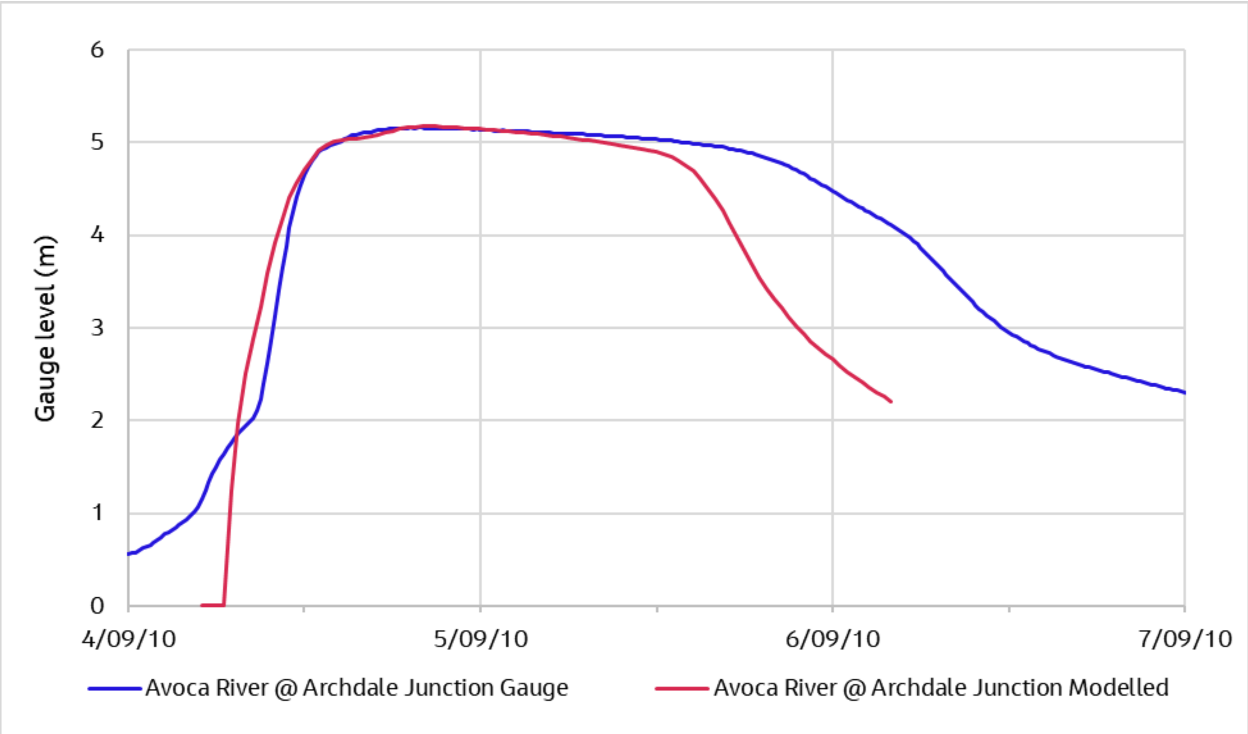
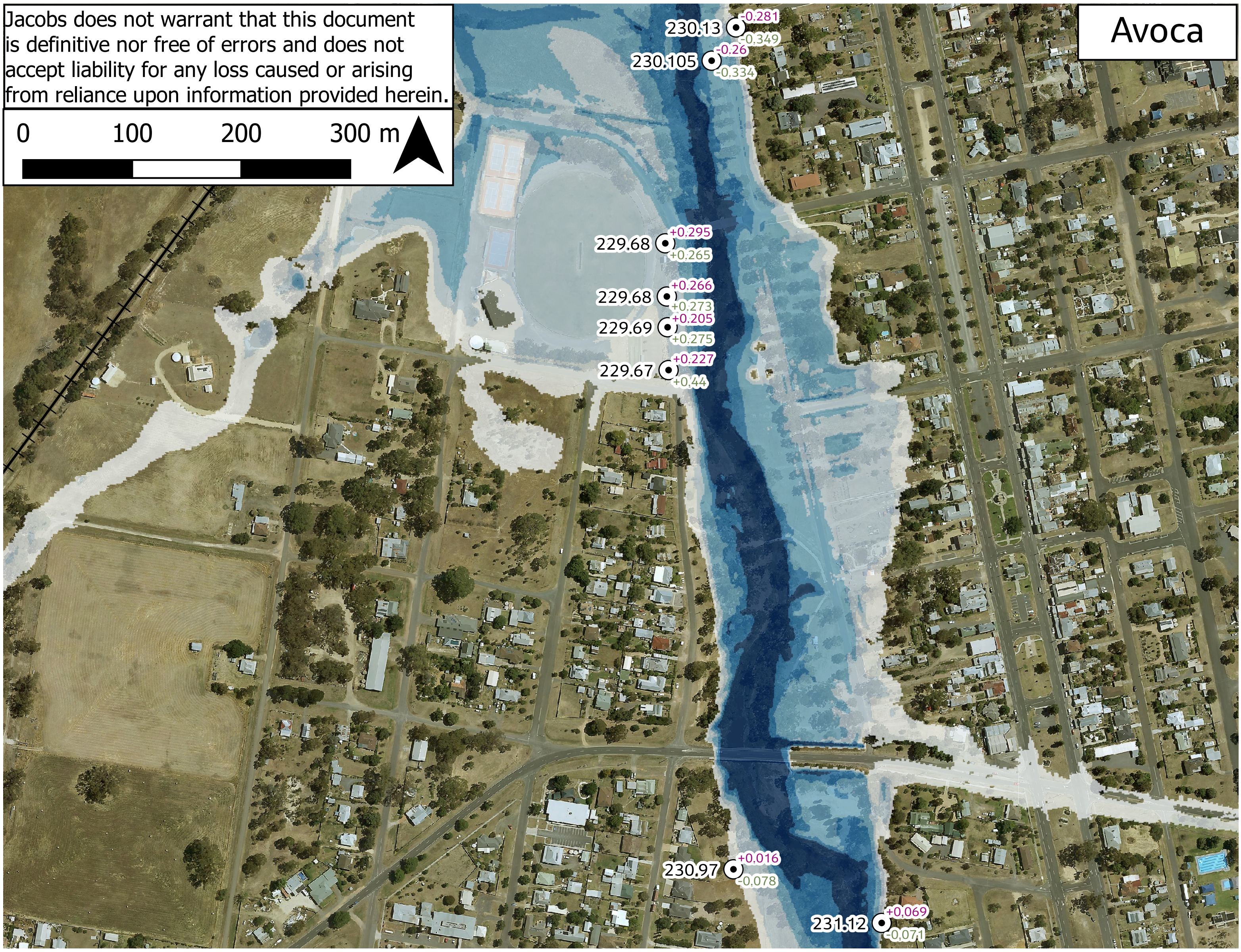


Figure 3.4: Avoca River @ Archdale Junction September 2010 calibration event gauge level comparison



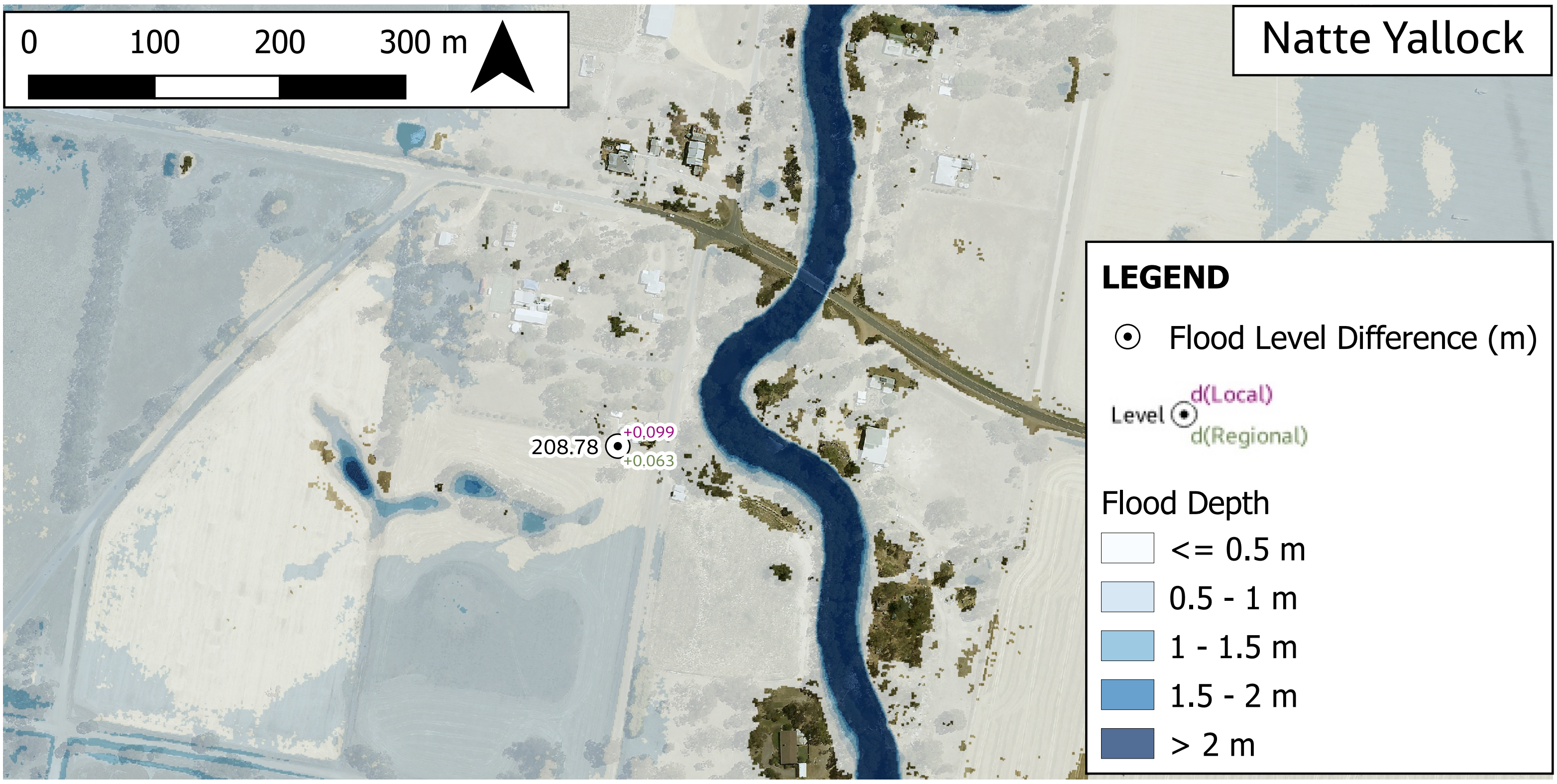


Figure 3.5: September 2010 calibration event flood mark comparisons

Jacobs

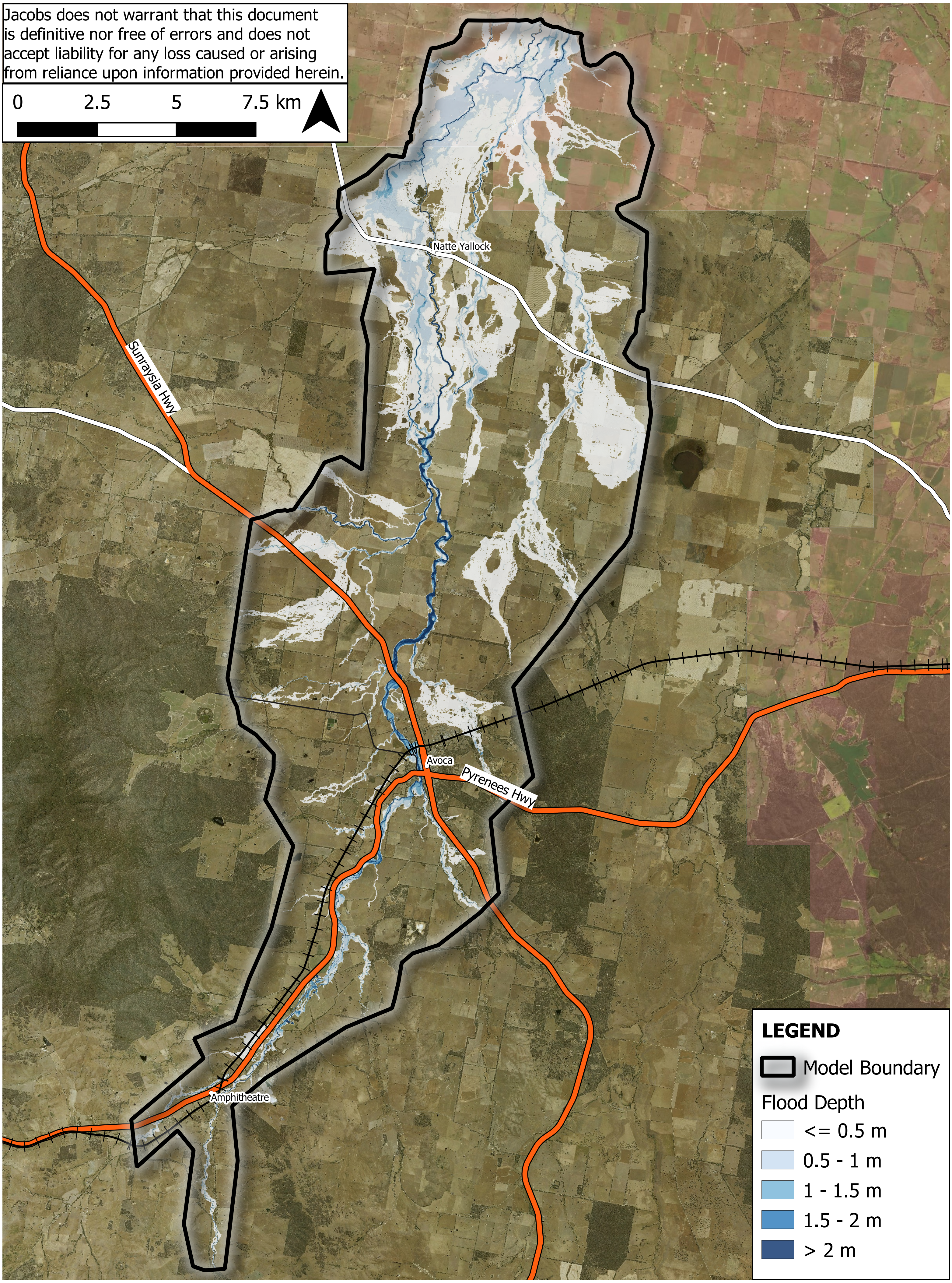


Figure 3.6: September 2010 calibration event flood depth map

Jacobs

3.3.2 January 2011 calibration event results

The January 2011 flood event is the largest in recorded history resulting in the failure of the Avoca River @ Amphitheatre stream gauge, so it has been excluded from the calibration process. A comparison of the recorded and modelled water levels at the Avoca River @ Archdale Junction stream gauge is shown in Figure 3.7. Photos and historic aerial imagery show that during the January 2011 flood event the fence along the southern boundary of the Avoca Public Park was of a steel sheeting type and has been modelled represented in the model using a breakline.

The modelled peak water level is 10 mm lower than that recorded at the Avoca River @ Archdale Junction gauge which is considered a very good fit.

There are seven surveyed flood level marks, all of which are in Avoca for the January 2011 event. These are shown in Figure 3.8 with flood extent from the town model. Peak flood levels from the regional and town flood models were compared to the flood marks. At the flood pole on the east side of the Avoca River the town flood model underestimates flood levels by up to 324 mm while at the railway bridge the flood level is underestimated by 301 mm. A good fit was achieved at the four flood level marks located along the fence line of the Avoca Public Park with modelled flood level differences between 1 mm below and 66 mm above the surveyed levels. It should be noted that there is a large discrepancy in the flood marks surveyed at the Avoca Public Park been approximately 400 mm lower than those on east side of the Avoca River. Following review of the available flood photography, site visits and the flood modelling this difference was not able to be rationalised.

The modelled January 2011 flood extent and depths are mapped for the whole catchment in Figure 3.8.

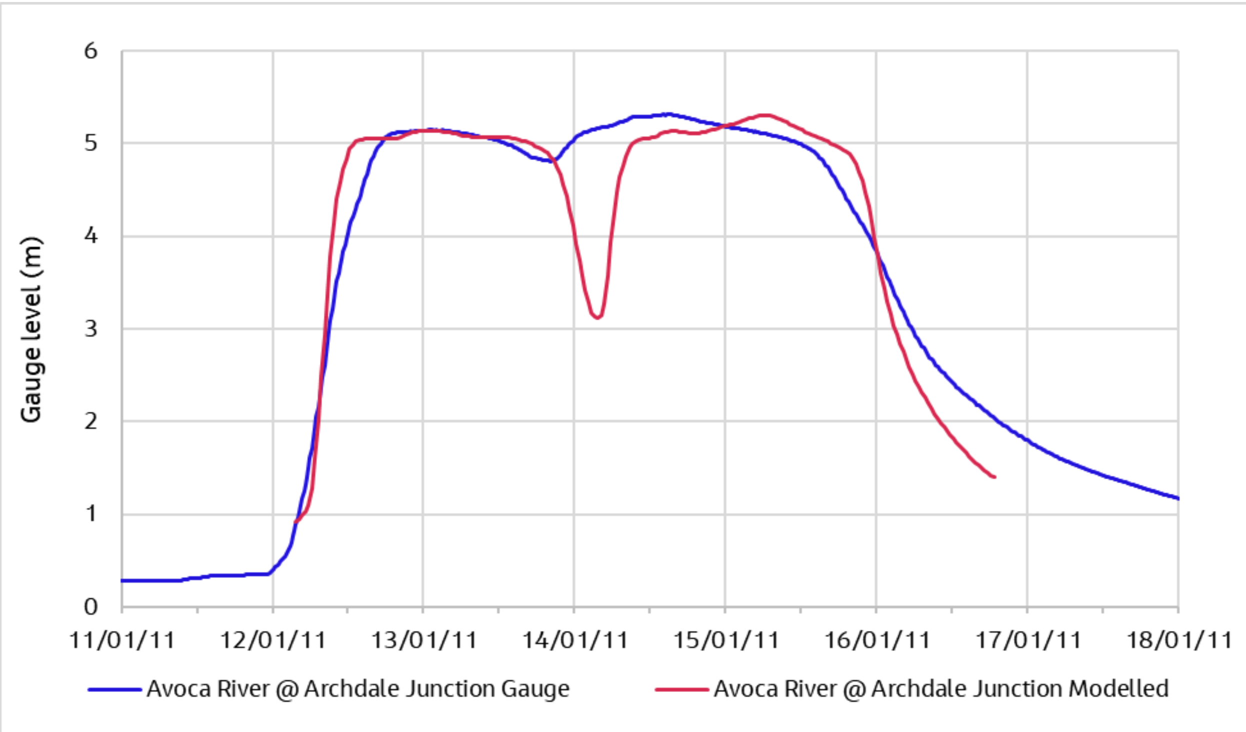


Figure 3.7: Avoca River @ Archdale Junction January 2011 calibration event gauge level comparison

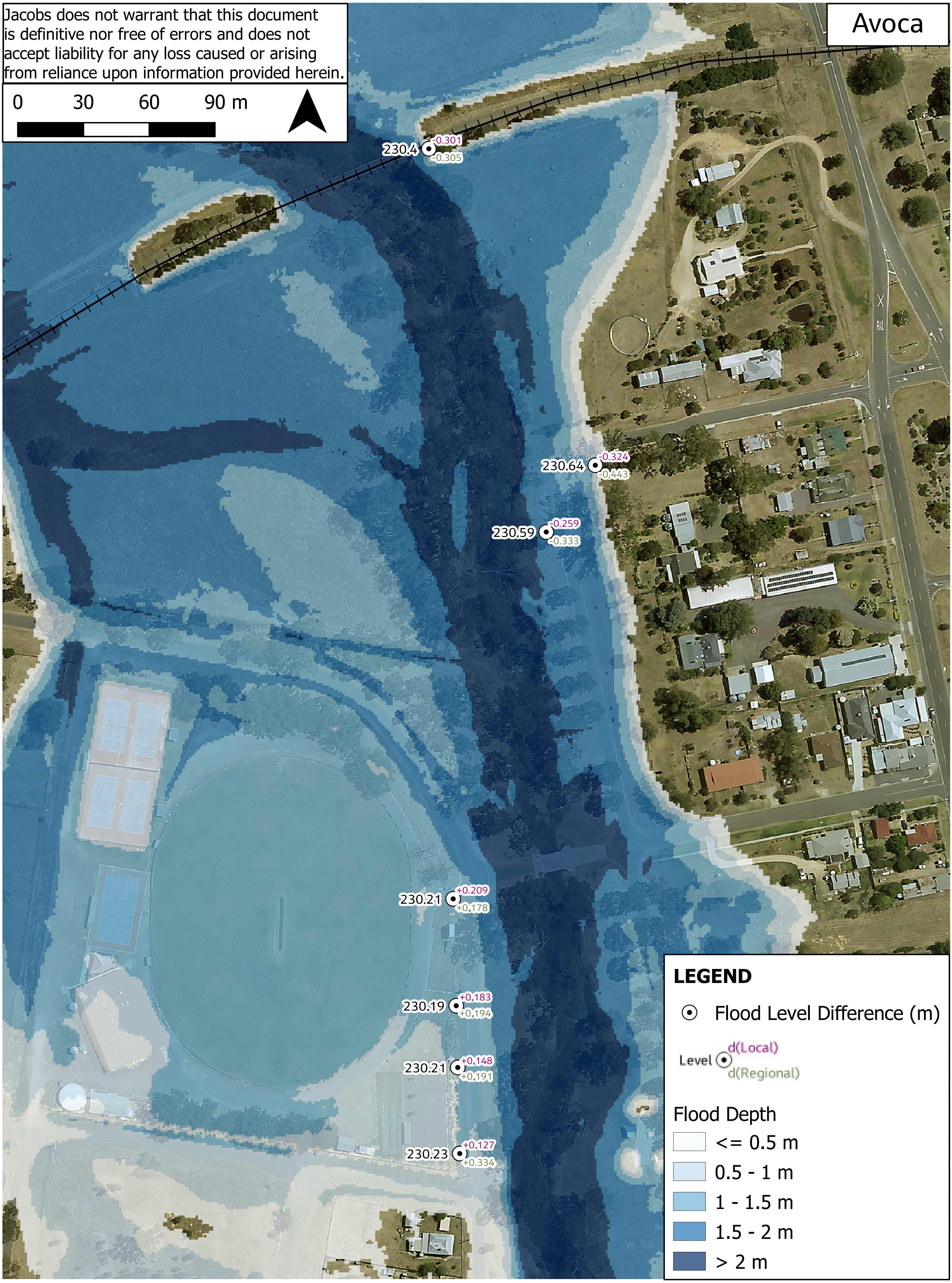


Figure 3.8: January 2011 calibration event flood mark comparisons

Jacobs

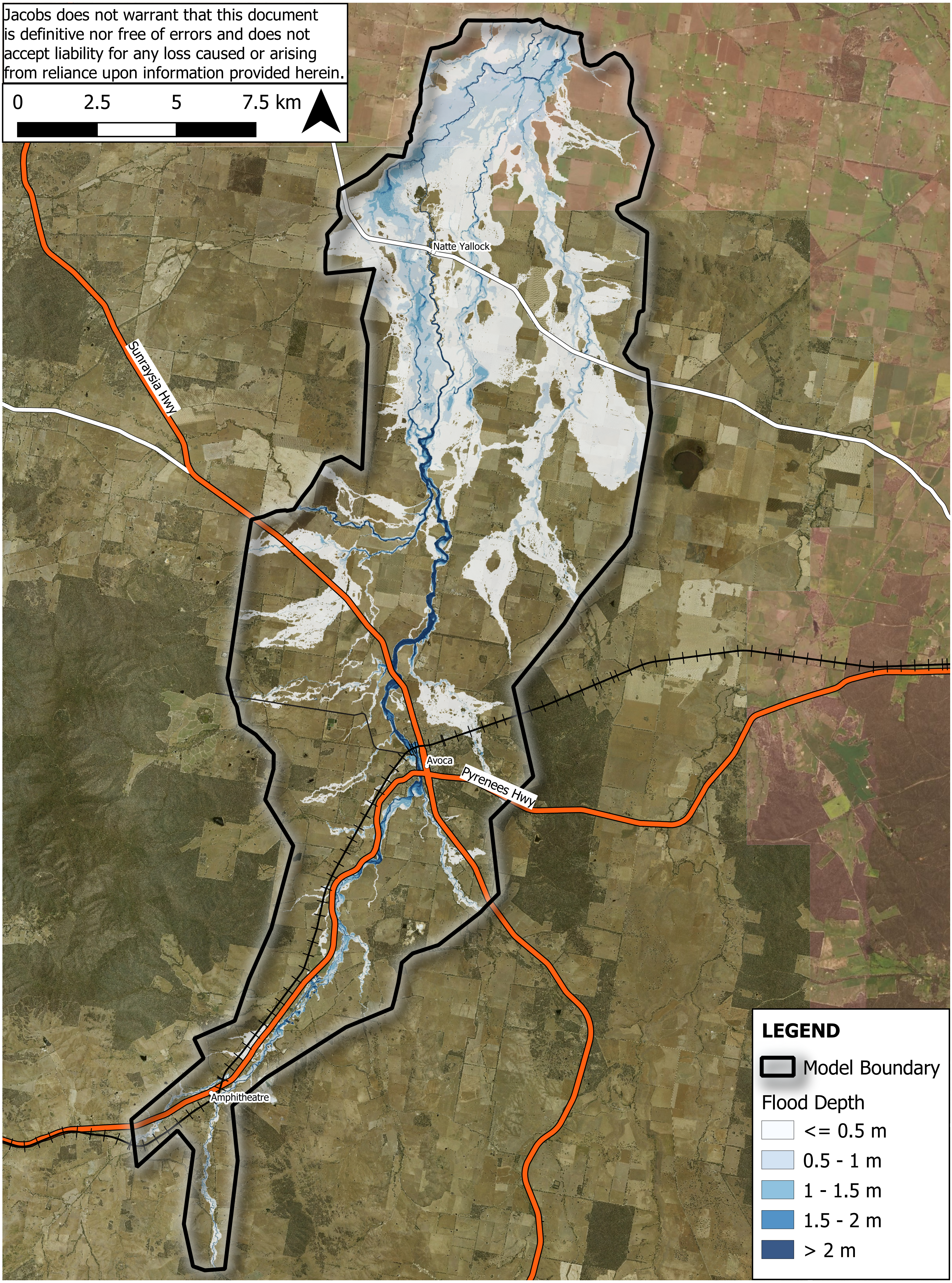
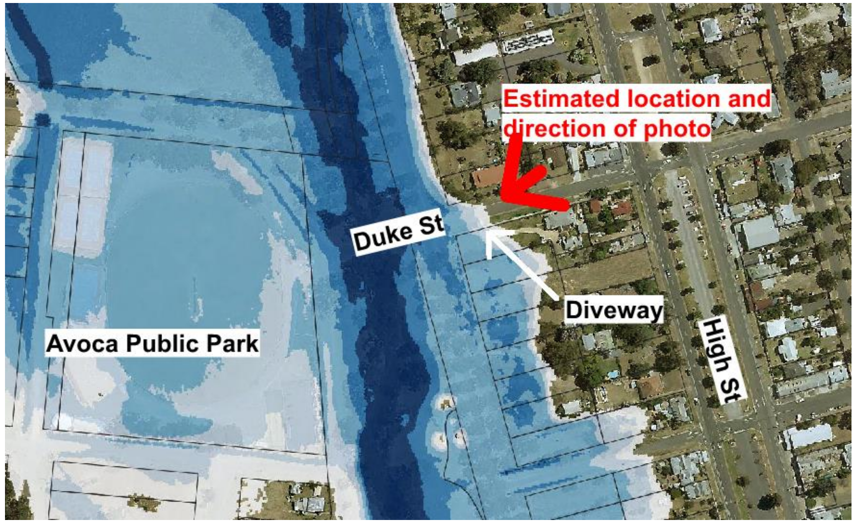
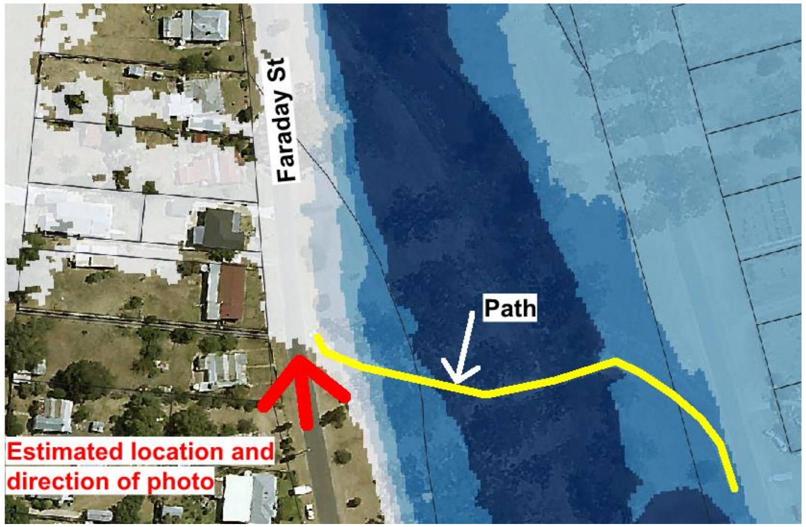
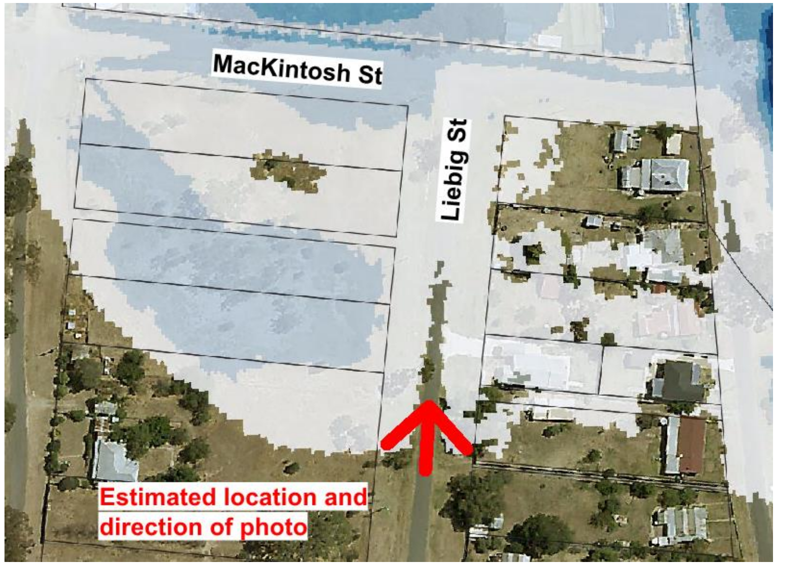


Figure 3.9: January 2011 calibration event flood depth map

Jacobs

Table 3.2: January 2011 event flood photography comparison

Comparison	Photo	Flood extent
Duke Street, Avoca looking west towards Avoca Public Park Flooding shown (photo may not represent flood peak) to extend approximately to driveway of 8 Duke St, Avoca.		
Faraday Street, Avoca adjacent to path looking north As shown by debris flooding inundates Faraday Street approximately adjacent to the path and residential properties have minor inundation in front yards.		

Comparison	Photo	Flood extent
Liebig Street, Avoca looking north towards Avoca Public Park As shown by debris flooding inundates Faraday Street approximately adjacent to the gum tree and residential properties do not appear to be inundated.		

3.3.3 September 2016 validation event results

A comparison of the recorded and modelled water levels at the Avoca River @ Amphitheatre and Avoca River @ Archdale Junction stream gauges for the September 2016 validation event are shown in Figure 3.10 and Figure 3.11 respectively. Community members were able to provide information on oat and canola crop coverage during the September 2016 event which was applied to the model as Manning's 'n' changes over the identified paddocks.

A very good fit to peak water level is achieved at the stream gauges. The modelled peak water level is 70 mm higher than that recorded at the Avoca River @ Amphitheatre gauge and 8 mm lower at the Avoca River @ Archdale Junction gauge. At the Avoca River @ Archdale Junction gauge, the modelled flood levels rise and fall quicker than those recorded. It is believed this is a function of the hydraulic model representing flow and ponded water already in the system from a previous rainfall and high flow event occurring four days earlier on 10 September.

There is one surveyed flood level mark in Avoca available for the September 2016 flood event shown in Figure 3.12 with the town model flood extent. Peak flood levels from the regional flood model were compared to the flood mark. The town model, with finer resolution of the terrain, underestimates the peak level by 42 mm which is considered a good fit.

Aerial imagery was provided by the NCCMA of flooding at Natte Yallock. However, this imagery was captured on 5 October 2016 representing a subsequent smaller flood event to the September 2016 calibration event.

The modelled September 2016 flood extent and depths are mapped for the whole catchment in Figure 3.13.

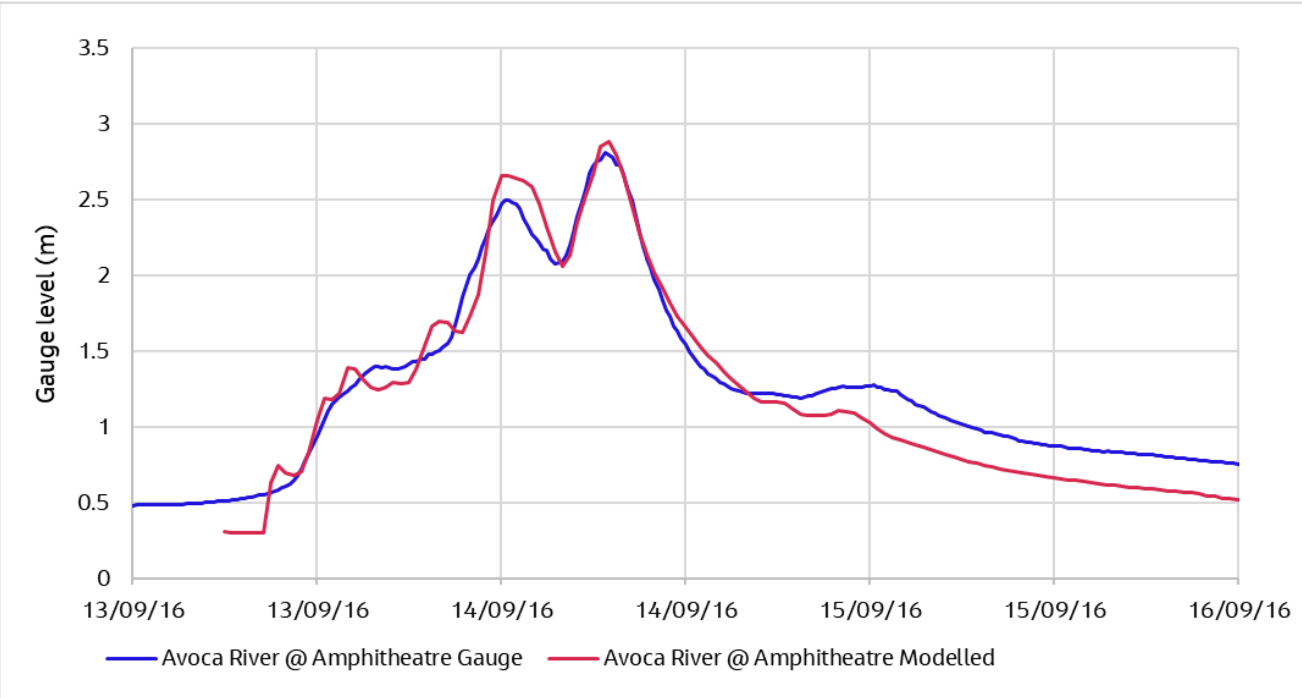


Figure 3.10: Avoca River @ Amphitheatre September 2016 validation event gauge level comparison

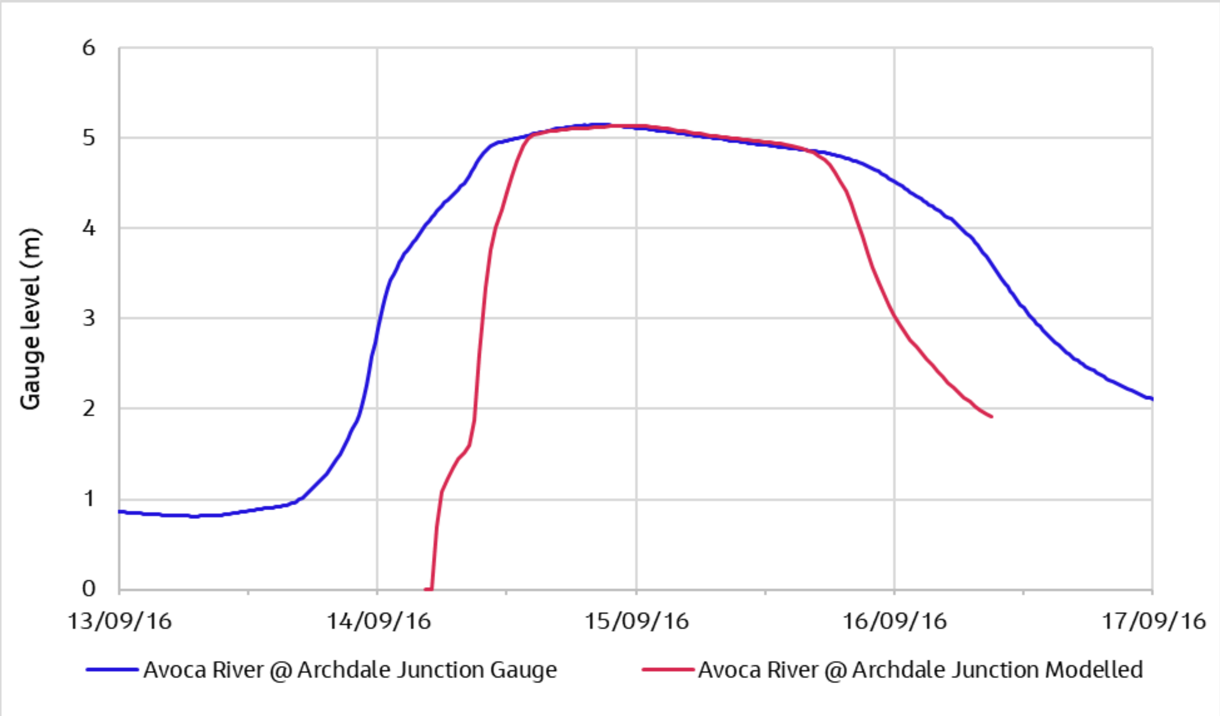


Figure 3.11: Avoca River @ Archdale Junction 2016 validation event gauge level comparison

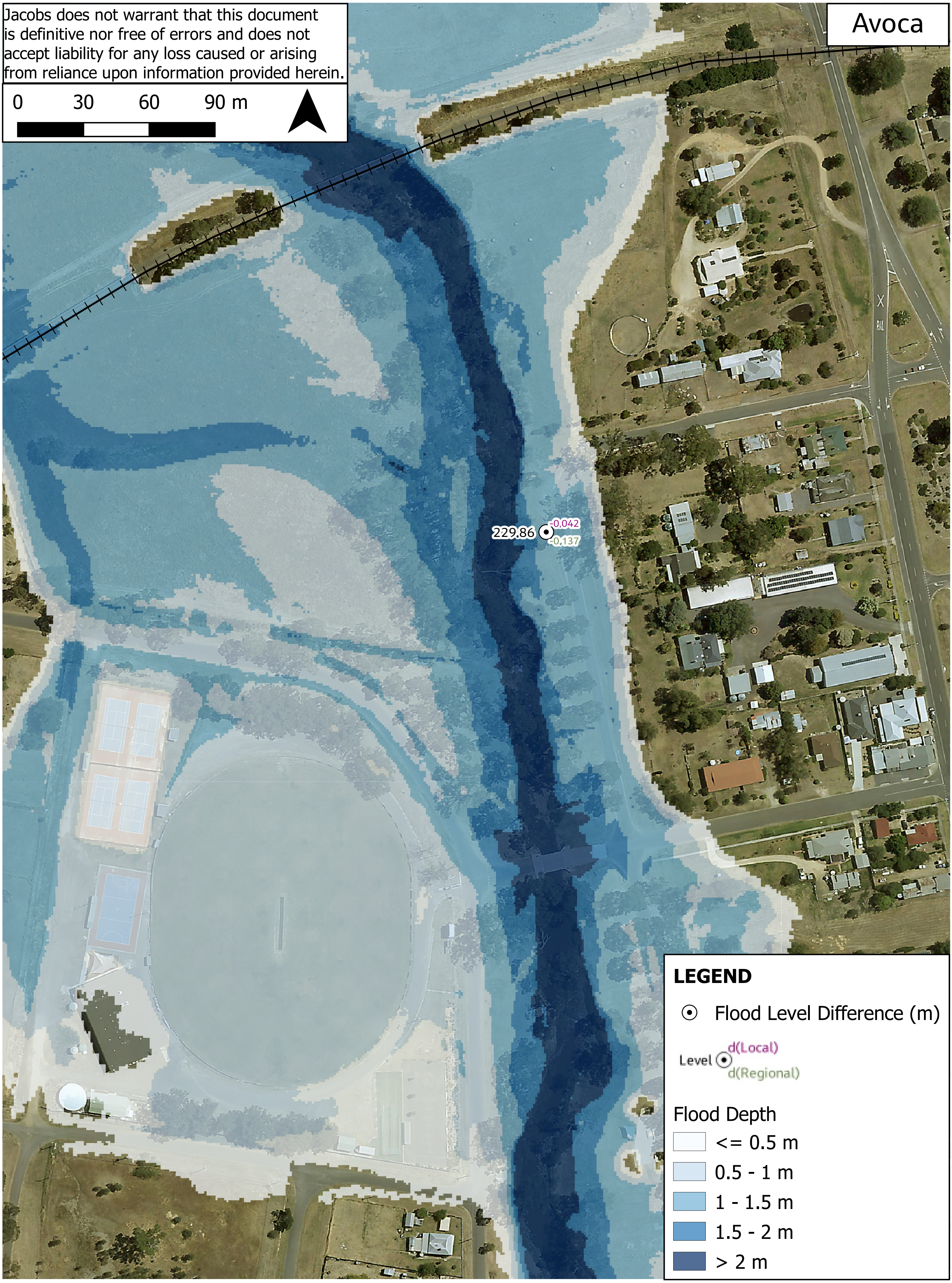


Figure 3.12: September 2016 calibration event flood mark comparisons

Jacobs

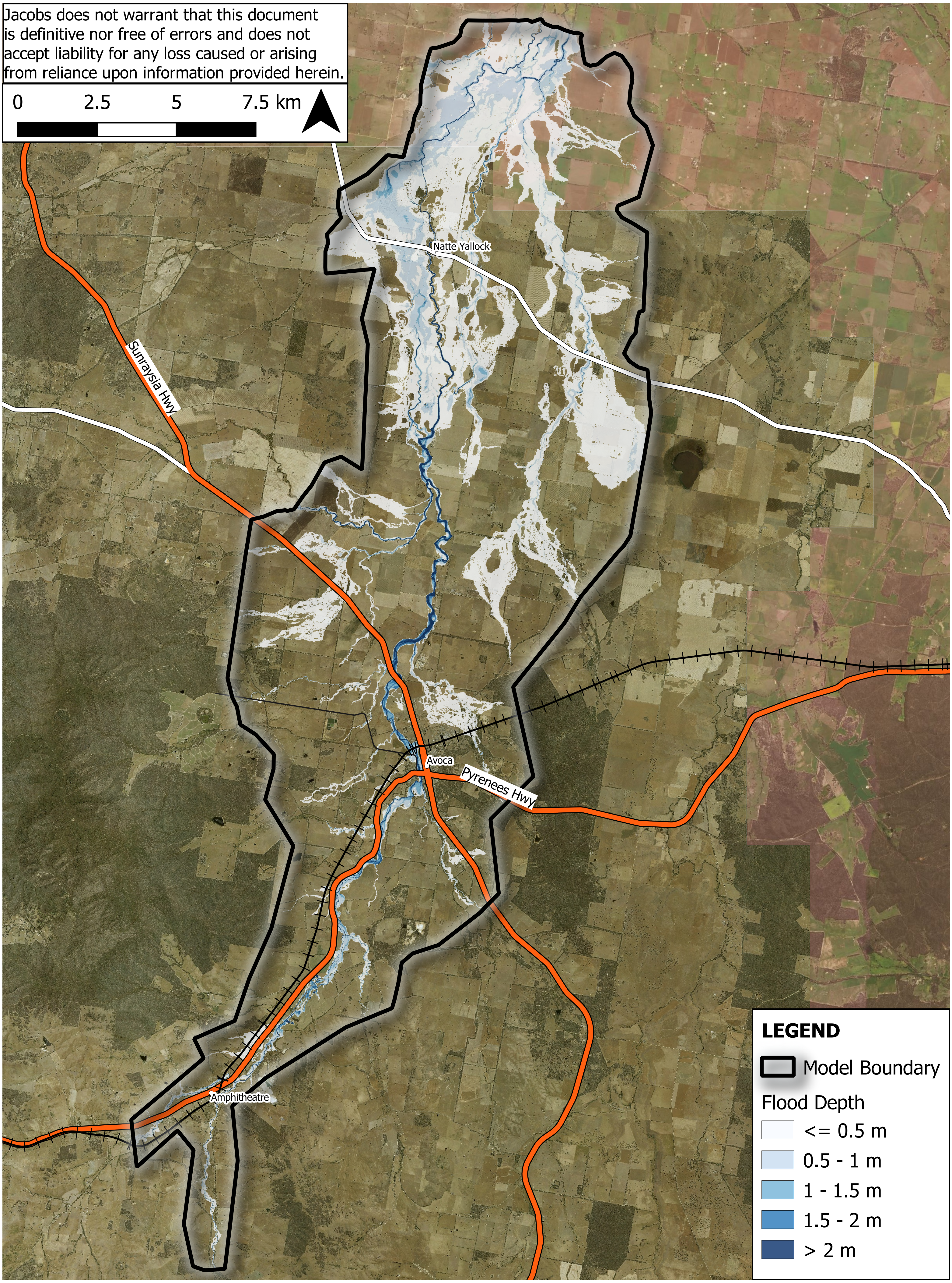


Figure 3.13: September 2016 calibration event flood depth map

Jacobs

3.3.4 Calibration and validation summary

The hydraulic model calibration and validation results identified a few key themes:

- A good fit is 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 the TUFLOW hydraulic 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.

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

3.4 Sensitivity analysis

To better understand the level of uncertainty associated with the adopted hydrologic modelling parameters, sensitivity analysis has been undertaken on the following parameters:

- Surface roughness (Manning's 'n' values)
- Structure blockage
- Downstream boundary

The model sensitivity is presented in flood level impacts maps where the difference in peak water level resulting from the adopted model parameters/setup and those of the sensitivity analysis. Areas of no change (within the confidence limits of $^{+}/_{-}$ 0.1 m) are coloured yellow. Areas where there is a decrease in flood level are in shades of green and areas where there is an increase in flood level are in shades of orange/red. Areas that were not inundated and now are referred to as "was dry now wet" and coloured blue, while areas that were inundated and are now not are referred to as "was wet now dry" and are coloured magenta.

A detailed description of each sensitivity analysis and the results is provided in the following sections.

3.4.1 Surface roughness

To assess the uncertainty associated with surface roughness, the adopted Manning's 'n' values (Table 3.1) have been varied by $^{+}/_{-}$ 20% in the TUFLOW model using the critical 1% AEP event. The resulting sensitivity analysis results are shown in Figure 3.14 for increased surface roughness and Figure 3.15 for decreased surface roughness.

The results of the sensitivity analysis show that overall across the majority of the floodplain the changes in flood level are within the mapping tolerance of $^{+}/_{-}$ 0.1 m. In the lower flood floodplain around Natte Yallock the flood levels are increased by approximately 0.05 m for the increased surface roughness scenario. As shown in Figure 3.14, this increase in peak flood levels corresponds to the creation of new flowpaths downstream of Natte Yallock as shown by the areas of "was dry now wet".

While the results of this sensitivity test show that the overall flood levels may not be sensitivity to variances in Manning's 'n' values $^{+}/_{-}$ 20%, observations provided by the community and the results September 2016 calibration event modelling indicate that flood behaviour in the lower floodplain is sensitivity to crops present during a flood event. This includes the season, location and variety of crops being grown, with thicker, taller and stronger (less likely to be flattened in a flood event) impacting on flood levels and flow paths.

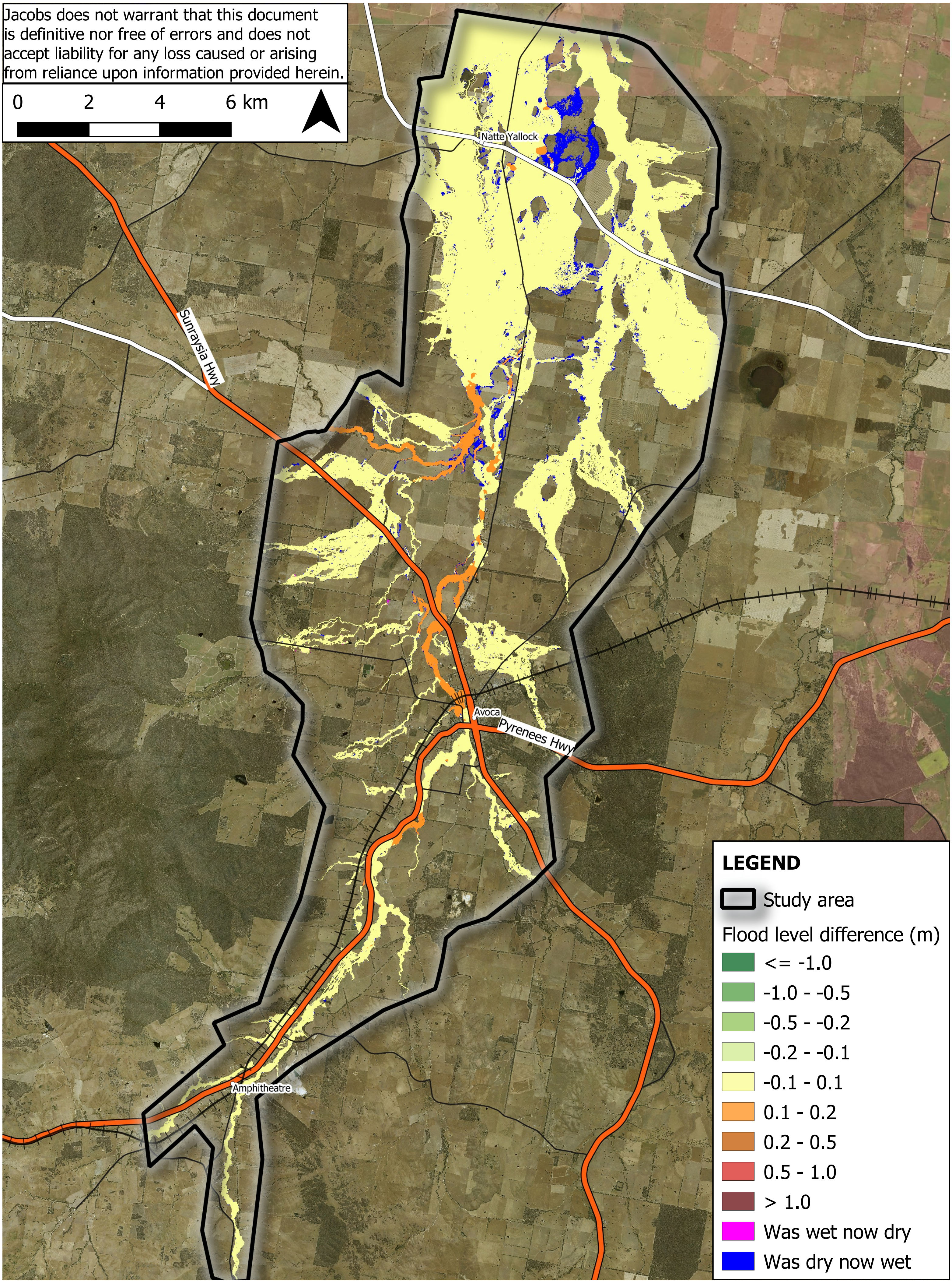


Figure 3.14: 1% AEP +20% surface roughness sensitivity flood level difference map

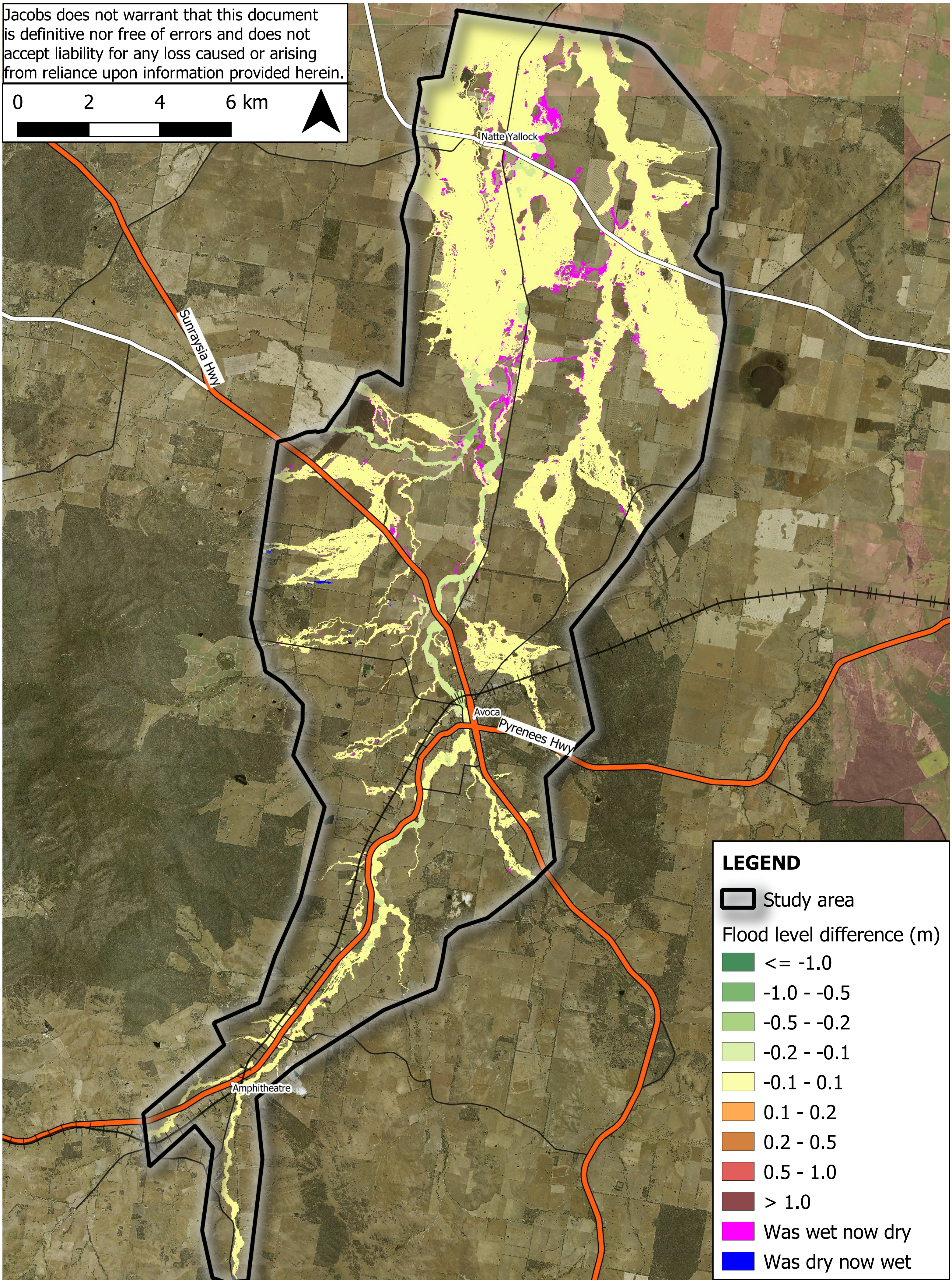


Figure 3.15: 1% AEP -20% surface roughness sensitivity flood level difference map

3.4.2 Structure blockages

The TUFLOW model was used to assess the impact of structure blockage on upstream flood levels for the key structures listed in Table 3.3 for the 1% AEP event. The blockages modelled (Table 3.3) are based on the blockage assessment methodology provided in Book 6, Chapter 6 of ARR 2019. Each blockage was modelled separately so as not to impact on the analysis of downstream structures and the resulting sensitivity analysis impact map (Figure 3.16) is a composite of all of model results.

The results show that based on ARR blockage assessment, flood levels are not sensitive to ARR 2019 blockages. However, except for the Fraser Street culverts which convey very little flow, the percent blockage was relatively small. If large obstructions occur across key structures such as large trees, shipping containers, caravans, etc much large blockages may occur that have a significant impact on local flood levels.

Table 3.3: Structure blockage sensitivity test locations

Structure	% Blocked	US peak flood level increase (m)
Amphitheatre Creek railway culverts at Humffray Street	15%	0.005
Amphitheatre Creek Pyrenees Highway bridge northern end of Amphitheatre	10%	0.06
Avoca River Fraser Street culverts in Amphitheatre	50%	0.007
Avoca River Pyrenees Highway bridge in Avoca	15%	0.015
Avoca River railway bridge in Avoca	15%	0.014
Avoca River Sunraysia Highway bridge north of Avoca	10%	0.005
Avoca River Maryborough – St Arnaud Road bridge in Natte Yallock	15%	0.005

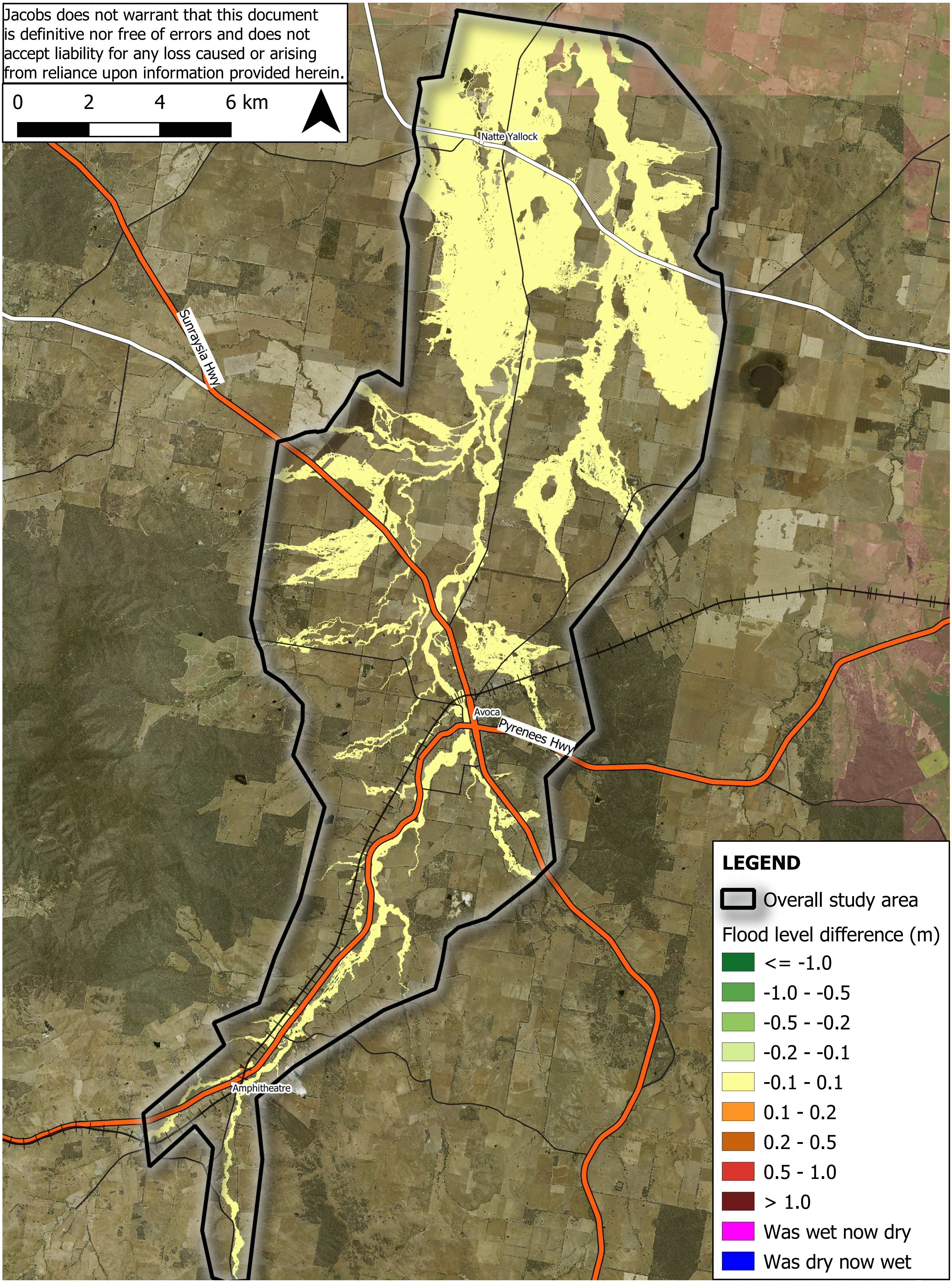


Figure 3.16: 1% AEP structure blockage sensitivity flood level difference map

Jacobs

3.4.3 Downstream boundary

To assess the impact that downstream boundary setup has on the modelled results in the study area a sensitivity analysis has been used to compare the adopted head versus flow boundary downstream boundary on the Avoca River 1D channel network (Section 3.2.6) to a fixed downstream water level. A fixed downstream water level of 197 m AHD was chosen which represents the level required to fill the floodplain at 1D channel downstream boundary approximately 3 km north of the Avoca River @ Archdale Junction stream gauge. The resulting sensitivity analysis results are shown in Figure 3.17.

The results show that model is not sensitive to the adopted downstream boundary setup as all flood level are within the mapping tolerance of $^{+}/_{-}$ 0.1 m for the 1% AEP event. Within the flood mapping limit there are no changes in peak flood level.

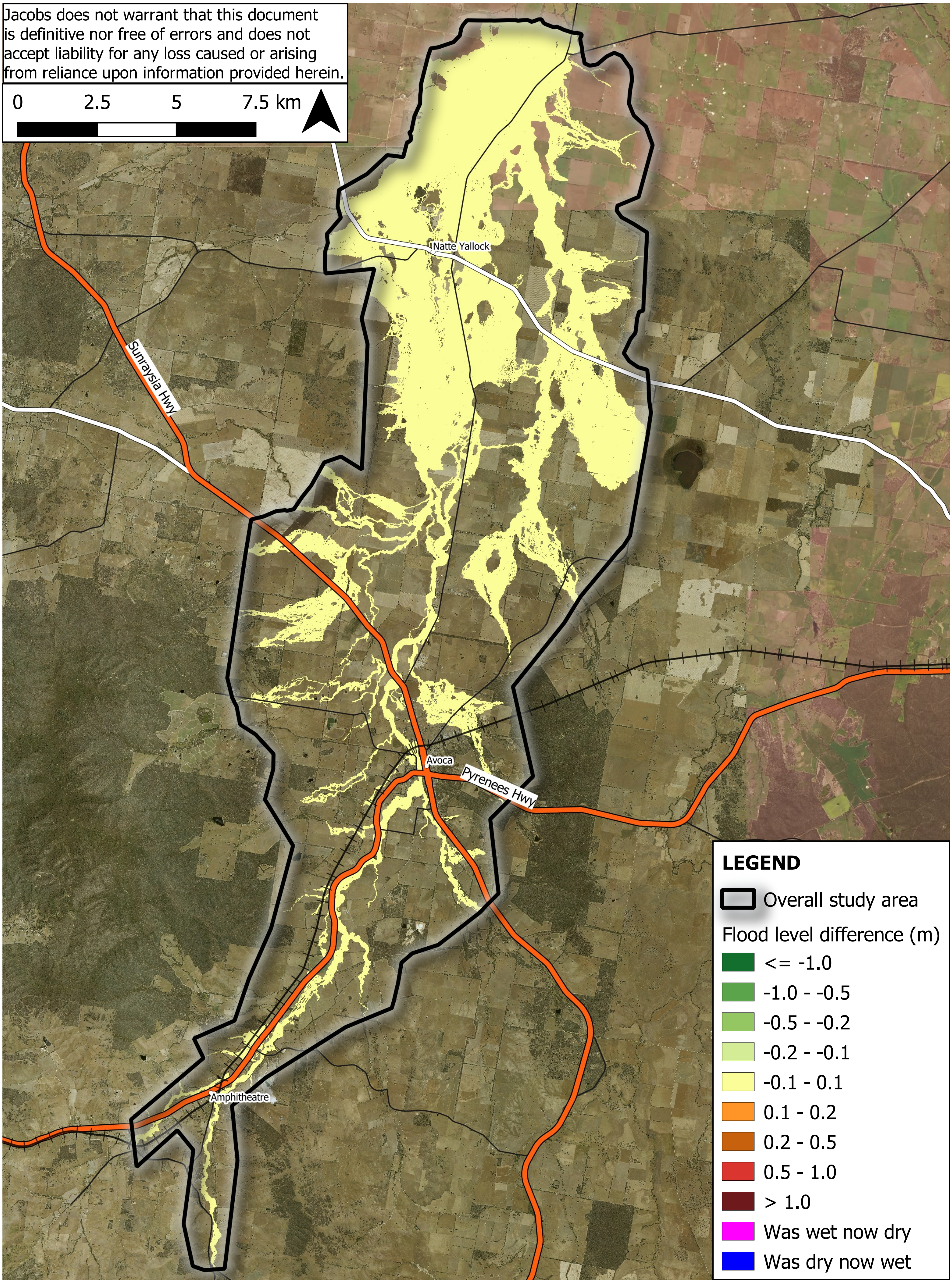


Figure 3.17: 1% AEP downstream boundary sensitivity flood level difference map

Jacobs

4. Quality assurance

To ensure that the flood modelling for the Investigation produces acceptable flood mapping and other outputs and is suitable for use in further flood intelligence and warning, flood mitigation and planning scheme amendment tasks the flood modelling methodology, models and outputs were independently reviewed by a third party.

This section outlines the internal review process.

4.1 Hydrologic modelling review

The internal review of the hydrologic modelling included the following checks:

- Review of the at-site FFA input parameters and results
- Review of the RORB model extent, sub-catchment definition (including in relation to inflow boundary requirements of the TUFLOW model), fraction impervious values, reach alignments and reach types
- A review of the model calibration and validation output results, including a review of the adopted parameters for design event modelling

4.2 Hydraulic (TUFLOW) model review

The internal review of the TUFLOW models included the following checks:

- Review of appropriate model file setup and run commands
- Review of model extent and resolution, including checks for 'glass walling' of flood extents against the model boundary
- Review of the model's representation of the underlying topography, including representation of the hydraulic structures and controls
- Hydraulic structure (culverts, bridges and weirs) are consistent with the best available data
- Inflow and outflow boundaries are appropriate and located sufficiently far away as to not influence results within the area of interest
- Model health/stability checks including:
  - Graphing and checking of dt timeseries
  - Warning and Error messages including negative depth warning checks
  - Check of flood mapping and animations to identify unrealistic flood velocities and levels
  - Check of 1D timeseries outputs to identify unrealistic flood velocities and levels

5. Flood mapping and intelligence outputs

This section describes the existing conditions and climate change flood mapping and intelligence outputs. The flood maps are presented in the accompanying Flood Mapping Report (Jacobs 2019b).

TUFLOW produces a geo-referenced flood mapping dataset that allows for the peak flood level at every model cell to be tracked and flood mapping representing the peak water levels across the flood mapping limit can be extracted.

The flood mapping outputs presented in this section have also been translated into Victorian Flood Database (VFD2) format.

While the flood model extends approximately 3 km north of the Avoca River @ Archdale Junction stream gauge to allow for model calibration, the study area encompasses the area of the floodplain within the Pyrenees Shire. As such a flood mapping limit approximately 3 km north of Natte Yallock has been adopted. Due to limited detailed topography been available (refer to Section 3.2.2 for details), the extent of mapping is also limited to the west of Natte Yallock. While the flood mapping limits do not include the Avoca River @ Archdale Junction stream gauge, where appropriate intelligence outputs have been related to the gauge as a point of reference.

The flood mapping and intelligence outputs presented in this section represent the adopted design flood events which are a theoretical flood representing a specific likelihood of occurrence (for example the 1% AEP flood). As identified during the community consultation and flood modelling tasks there are several variables which can influence flood behaviour in the Upper Avoca River catchment. Of note is the seasonality, type and location of crops across the lower floodplain which varies between events.

5.1 Flood depth mapping

The flood depth mapping is presented in Figure D.1 to Figure D.48 of the Flood Mapping Report (Jacobs 2019b). Flood depth mapping presents the maximum or peak depth of inundation across the floodplain for each design event.

The regional maps (Figure D.1 to Figure D.12) show 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 Figure D.13 to Figure D.24 show that 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, in Avoca Figure D.25 to Figure D.36 show that the floodplain is well contained along Avoca River and contributing tributaries corridors, with the exception of shallow flooding across the paddocks north-east of town. Along the main Avoca River corridor, from the 20% AEP event Figure D.25 the backs of the residential properties on the eastern bank are inundated along with the Lions Park which is inundated to depths above 1.5 m and the Avoca Public Park where the oval is inundated to depths below 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 (Figure D.29). 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.

Figure D.37 to Figure D.48 show that flooding in Natte Yallock is characterised by broad flooding across the floodpains 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 (Figure D.37) 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.

5.2 Flood level mapping

The flood level mapping is presented in Figure L.1 to Figure L.48 of the Flood Mapping Report (Jacobs 2019b). Flood level mapping presents the maximum or peak depth of inundation across the floodplain for each design event and is useful in setting flood levels for design and planning purposes. The flood level mapping also includes 1 m flood level contours.

5.2.1 Flood 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 5.1. Historic event levels, recorded levels presented at the gauges, are coloured blue while the climate change scenarios are coloured red.

It is of note, that in Natte Yallock immediately upstream of the Maryborough-St Arnaud Road bridge there is very little difference between peak flood levels in Avoca River channel. This is because as the events increase in magnitude, the flow across the floodplain increases due to breakout flows but the flow in the channel does not increase proportionally.

Table 5.1: 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.

5.3 Flood velocity mapping

The flood velocity mapping is presented in Figure V.1 to Figure V.48 of the Flood Mapping Report (Jacobs 2019b). Flood velocity mapping can depict both the speed and direction of the flow. Flow direction is represented by vectors (arrows depicting flow direction) but has not been presented in this mapping for clarity reasons.

As shown in the flood velocity mapping, velocities along the Avoca River corridor are often greater than 2 m/s, including on the narrow floodplains through the Amphitheatre (Figure V.13 to Figure V.24) and Avoca (Figure V.25 to Figure V.36) townships in all design flood events. Across the lower floodplain areas around Natte Yallock velocities are mostly below 0.75 m/s. In Natte Yallock (Figure V.37 to Figure V.48). The velocities are mostly below 0.75 m/s on the west and 0.375 m/s on the east bank for all design flood events. However, along the north-south roads on the west bank higher flow velocities are observed up to approximately 1.5 – 2 m/s, including into the entrance of the Natte Yallock Recreational Reserve. High velocities are observed in the flowpath to the west of the township.

5.4 Flood velocity x depth (hazard) mapping

The flood velocity x depth (hazard) mapping is presented in Figure H.1 to Figure H.48 of Jacobs (2019b). It should be noted that this mapping only presents velocity x depth results and that flood hazard as described in ARR 2019 is also a function of depth and velocity individually.

As expected, the flood velocity x depth (hazard) mapping is consistent with the depth and velocity where, the highest hazard or most dangerous areas are found along the Avoca River corridor and tributaries, particular through Amphitheatre and Avoca.

As per ARR 2019 and DELWP (2019) velocity x depths of greater than 0.3 m^2/s are considered dangerous for small vehicles and velocity x depths of greater than 0.4 m^2/s are considered unsafe for children. Even in the more frequent events, 20% (Figure H.1) and 10% AEP (Figure H.2), there are areas in the lower floodplain that exceed these criteria which become broader as the flood events increase in magnitude. As shown in Figure H.41 for the 1% AEP, immediately to the west of the main township area of Natte Yallock there is a broad area of high velocity x depth.

5.5 Building and property inundation

Counts of inundated buildings and properties for the Amphitheatre, Avoca and Natte Yallock township areas are presented in Table 5.2 and Table 5.3 respectively. The inundated properties are also mapped on the depth maps for each township (Jacobs 2019b). No floor level data was available for Amphitheatre and Avoca, while not all floors were surveyed for Natte Yallock.

Table 5.2: Inundated buildings

AEP	Amphitheatre	Avoca	Natte Yallock	
			Inundated	Above flood level[1]
20%	-	2	16	2
10%	-	6	16	3
5%	-	7	16	3
2%	-	11	19	3
1%	-	14	19	4
0.5%	-	14	20	5
0.2%	-	15	21	5
PMF	14	16	22	9
10% AEP RCP 4.5	-	7	17	3
10% AEP RCP 8.5	-	8	17	3
1% AEP RCP 4.5	-	14	20	4
1% AEP RCP 8.5	-	15	20	5

1. Floor level survey captured post 2010 flood event. Refer to Jacobs (2019a) for details.

Table 5.3: Inundated properties

AEP	Amphitheatre[1]	Avoca[1]	Natte Yallock[2]
20%	45	87	74
10%	49	99	74
5%	51	109	75
2%	54	124	75
1%	54	132	75
0.5%	59	135	75
0.2%	65	141	75
PMF	192	435	75
10% AEP RCP 4.5	51	110	75
10% AEP RCP 8.5	54	117	75
1% AEP RCP 4.5	60	135	75
1% AEP RCP 8.5	65	141	75

1. Includes properties within the Township, Rural Living and other township related planning zones.
2. Natte Yallock is represented as Farming Zone in the planning scheme. As such the properties included in counts are bounded by Ross Street, Henderson Lane and Cains Road with some properties with nearby properties residencies included.

5.6 Road inundation

Road inundation depths are presented in Table 5.4 for the locations shown in Figure 5.1. The roads that have been inundated to a depth greater than 0.3 m have been highlighted in red.

Table 5.4: 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

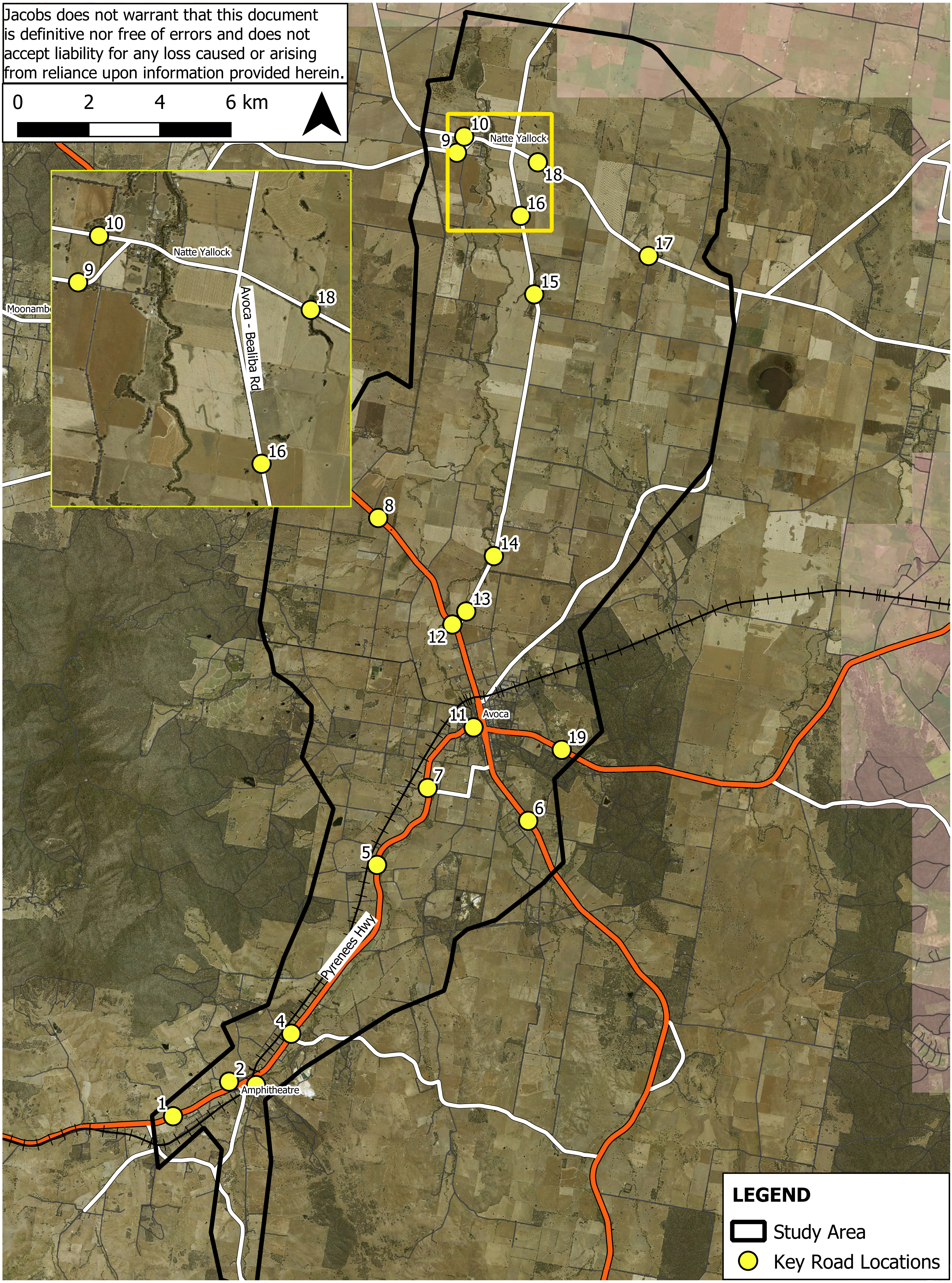


Figure 5.1: Road inundation reporting locations

Jacobs

5.7 Travel times and hydrographs

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 5.5. 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; as described in Section 2.7.4 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 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.

The AEP event design RORB hydrographs at the Avoca River @ Amphitheatre gauge, Avoca Township and Avoca River @ Archdale junction gauge are shown in Figure 5.2, Figure 5.3 and Figure 5.4 respectively. The PMF event hydrographs are presented in Figure 5.5. A comparison of the 10% and 1% AEP climate change hydrographs are shown in Figure 5.6 and Figure 5.7 respectively.

Table 5.5: 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

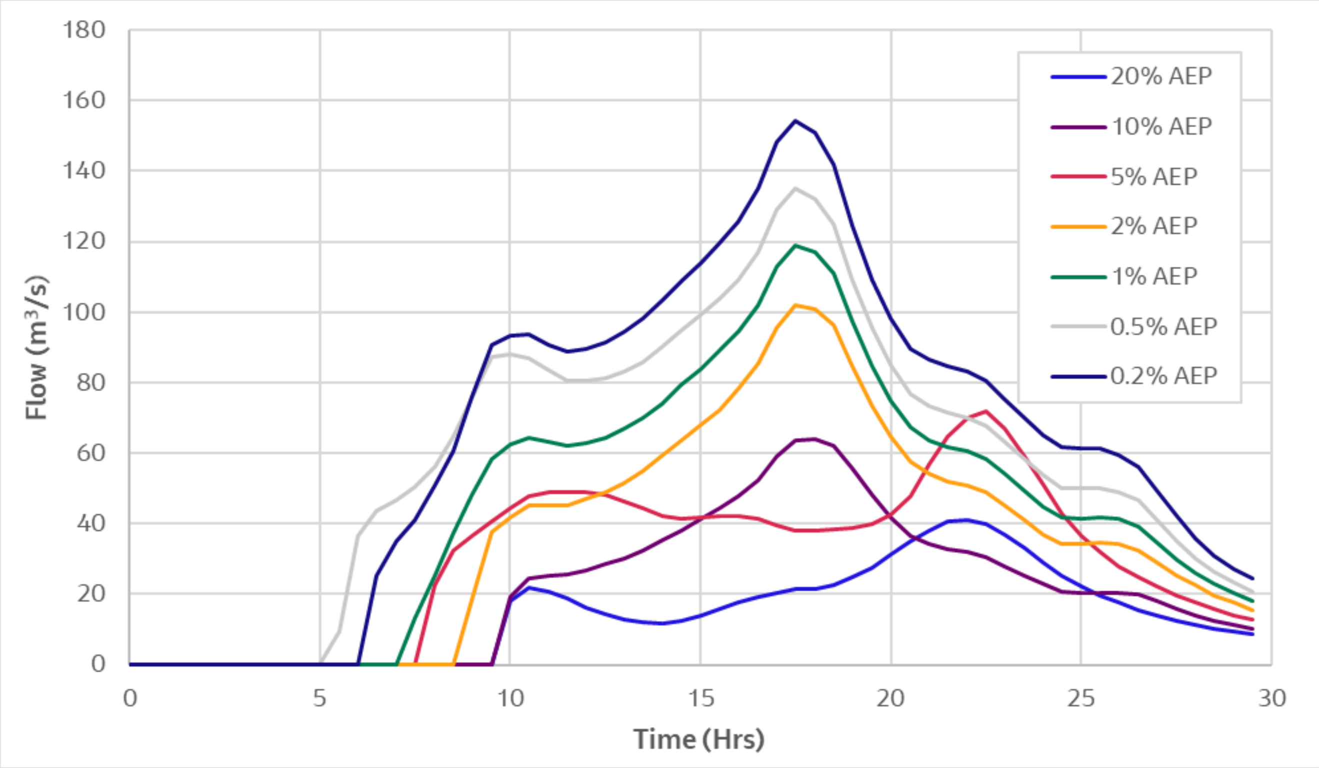


Figure 5.2: Avoca River @ Amphitheatre TUFLOW design event hydrographs

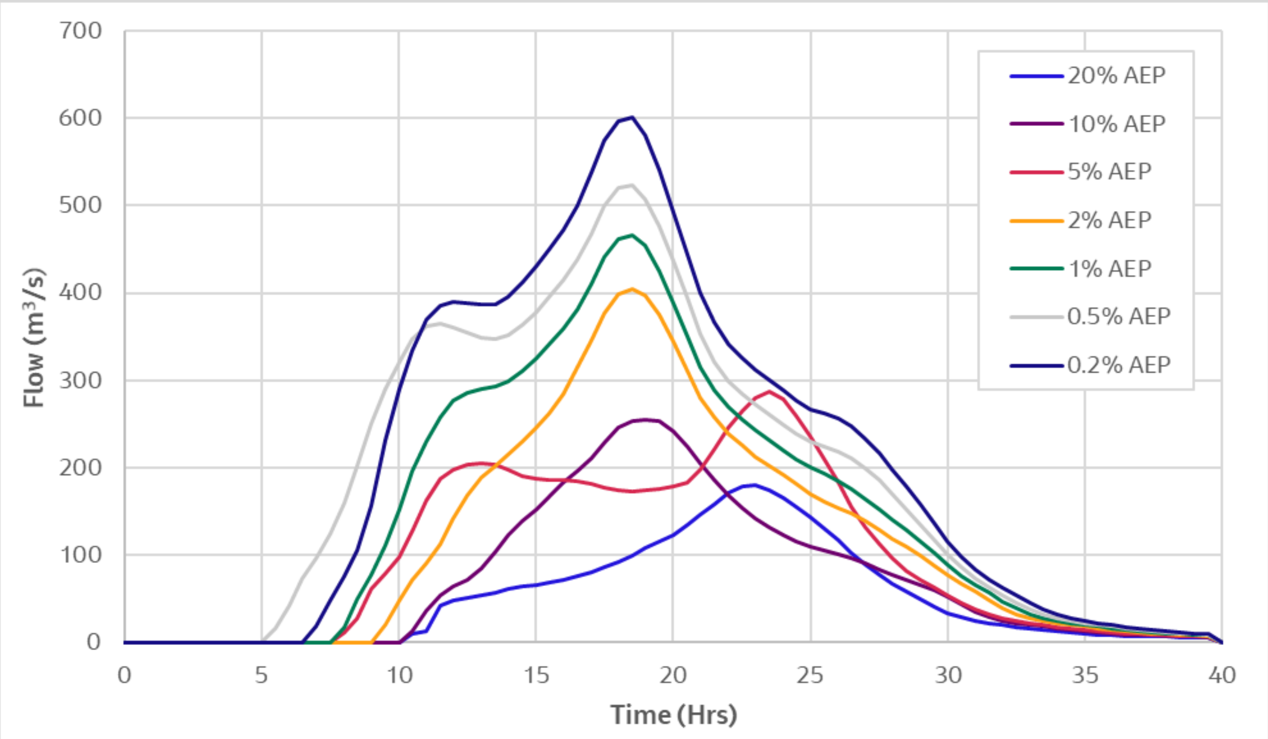


Figure 5.3: Avoca township TUFLOW design event hydrographs

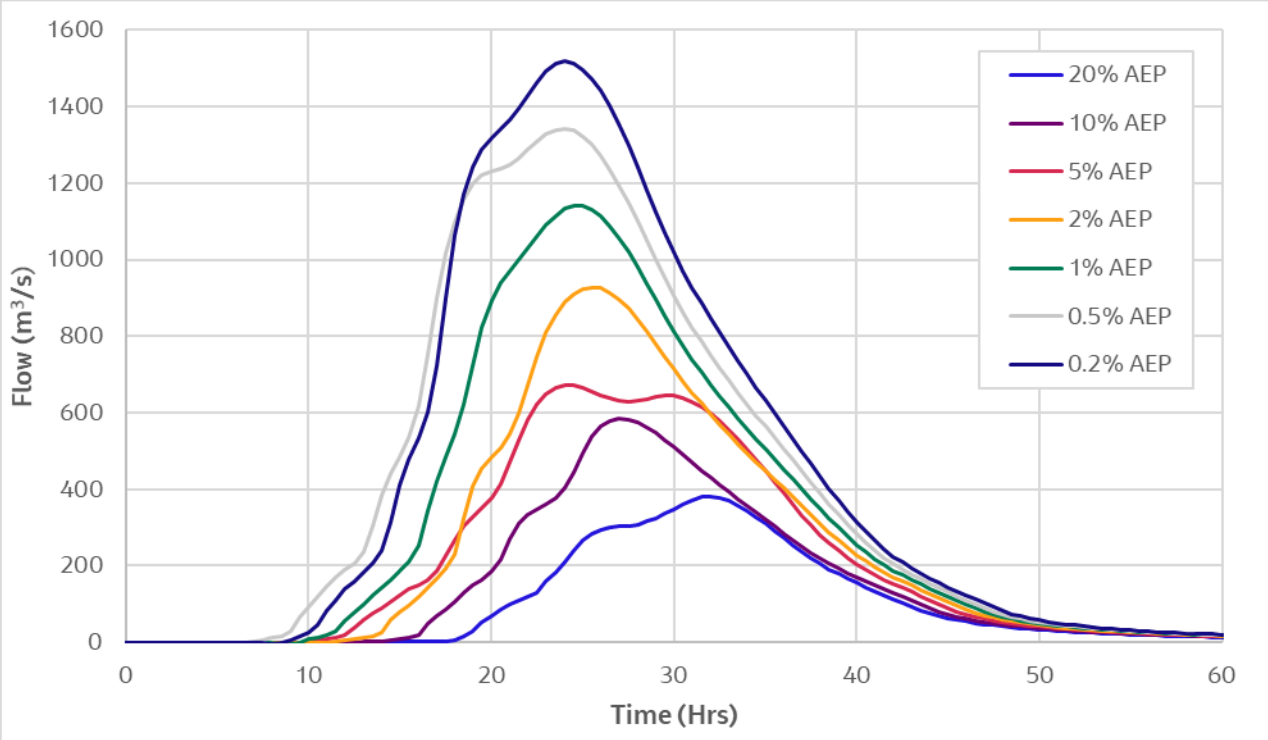


Figure 5.4: Avoca River @ Archdale Junction TUFLOW design event hydrographs

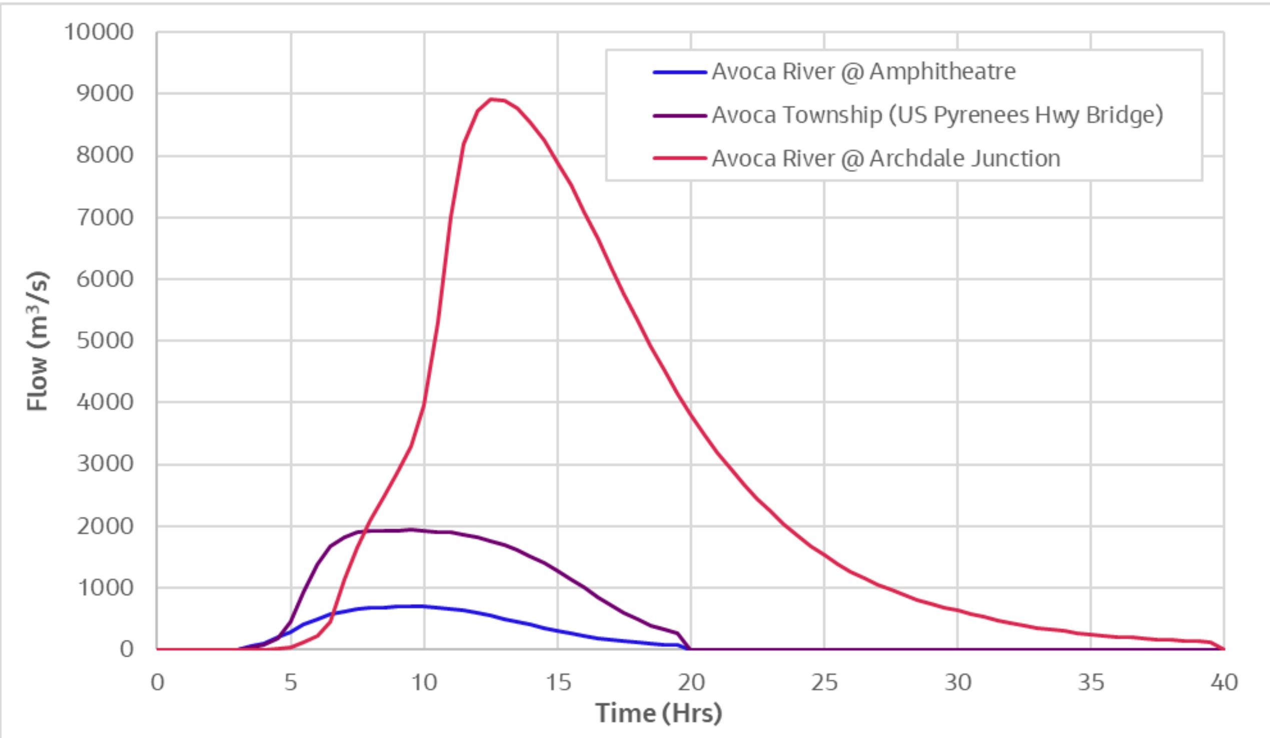


Figure 5.5: PMF TUFLOW design event hydrographs

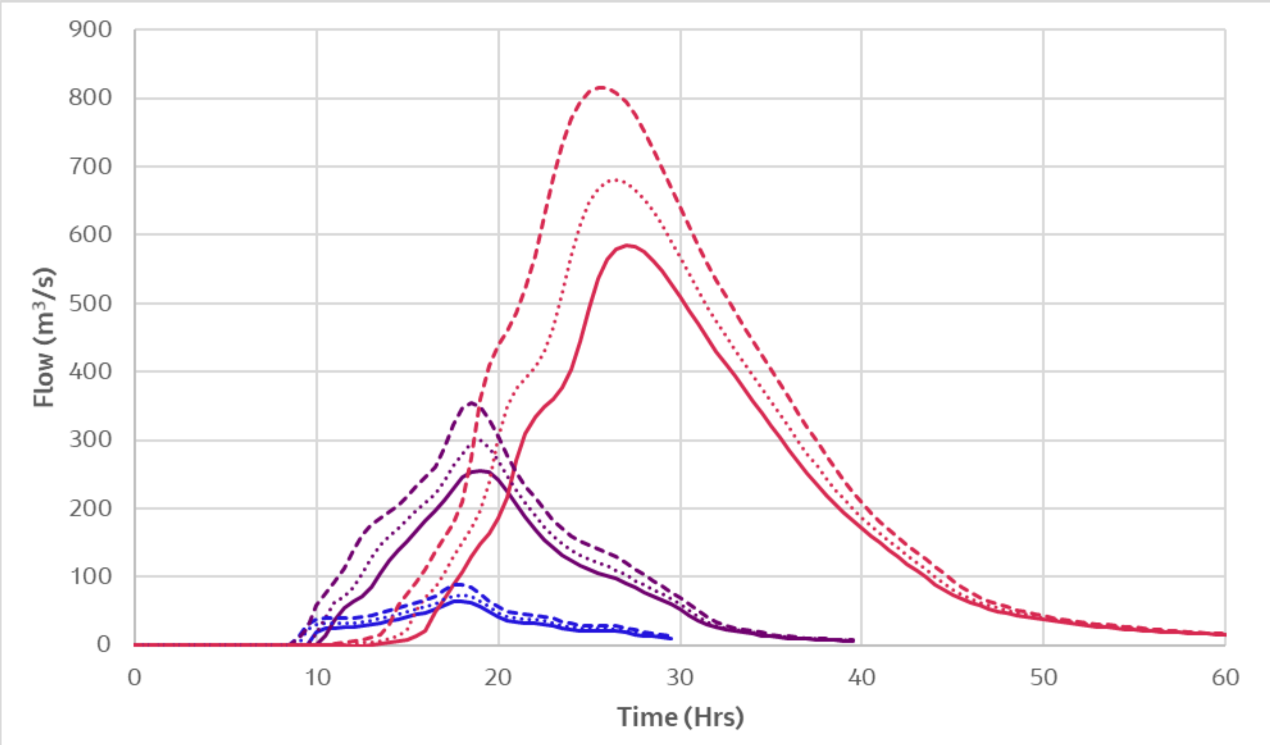


Figure 5.6: 10% AEP climate change TUFLOW design event hydrographs

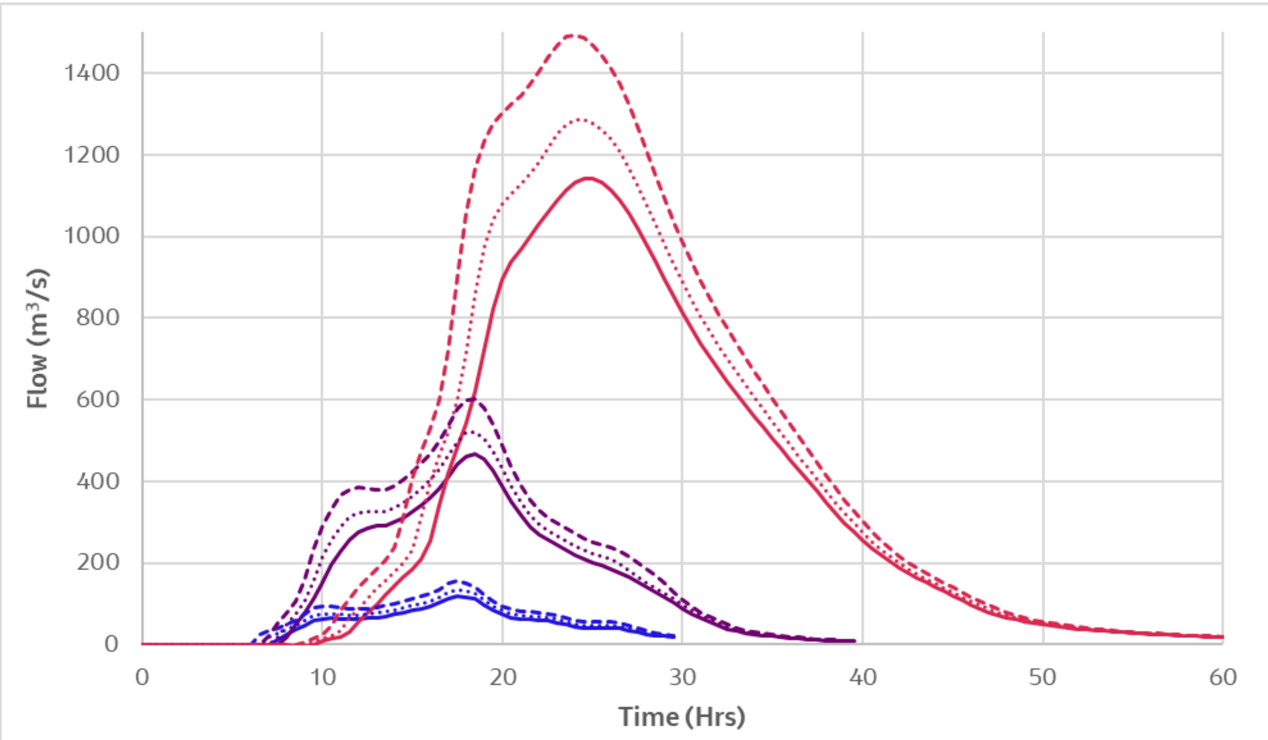


Figure 5.7: 1% AEP climate change TUFLOW design event hydrographs

5.8 Flood animations

Flood animations have been produced for the following scenarios. These have been provided alongside this report.

1. September 2010 – Regional Model
2. January 2011 – Regional Model
3. September 2016 – Regional Model
4. 1% AEP – Regional Model
5. 1% AEP – Amphitheatre Model
6. 1% AEP – Avoca Model
7. 1% AEP – Natte Yallock Model

6. Recommendations

This Flood Modelling Report details the hydrologic and hydraulic modelling methodology, and in conjunction with the Flood Mapping Report (Jacobs 2020b), presents the flood mapping and intelligence outputs for the current and future climate conditions.

This report shows that good calibration to the recorded data has been achieved for both the RORB hydrologic and TUFLOW hydraulic models and that resulting flood mapping is appropriate to be used for further Investigation outputs including:

- Update of the Municipal Flood Emergency Plan (MFEP)
- Flood warning feasibility assessment
- Structural flood mitigation option assessment
- Preparation of planning scheme amendment overlays

7. References

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Appendix A. Calibration and validation storm event data

September 2010 Calibration Event

Pluviographs		Total Rainfall Depths		
Gauge No.	**Name**	**Gauge No.**	**Name**	**Total Rainfall Depth (mm)**
408216	Forest Creek @ Amphitheatre Reservoir H.G.	408216	Forest Creek @ Amphitheatre Reservoir H.G.	96.2
081038	Natte Yallock	081000	Avoca (Post Office)	91.2
408206	Avoca River @ Archdale Junction	081122	Avoca (Homebush)	81.6
		081038	Natte Yallock	78.8
		081127	Avoca River @ Archdale Junction	73.6
		079039	Redbank	92.7
		079031	Moonambel	75.6

January 2011 Calibration Event

Pluviographs		Total Rainfall Depths		
Gauge No.	**Name**	**Gauge No.**	**Name**	**Total Rainfall Depth (mm)**
408216	Forest Creek @ Amphitheatre Reservoir H.G.	408216	Forest Creek @ Amphitheatre Reservoir H.G.	295.8
081038	Natte Yallock	081000	Avoca (Post Office)	213.3
408206	Avoca River @ Archdale Junction	081122	Avoca (Homebush)	203
408800	Avoca Water Treatment Plant	081038	Natte Yallock	201.6
		081127	Avoca River @ Archdale Junction	192.2

Pluviographs		Total Rainfall Depths		
Gauge No.	Name	Gauge No.	Name	Total Rainfall Depth (mm)
		079039	Redbank	218.5
		079031	Moonambel	205.6

September 2016 Calibration Event

Pluviographs		Total Rainfall Depths		
Gauge No.	Name	Gauge No.	Name	Total Rainfall Depth (mm)
408216	Forest Creek @ Amphitheatre Reservoir H.G.	408216	Forest Creek @ Amphitheatre Reservoir H.G.	110
408218	Redbank Creek @ Redbank Reservoir H.G.	081000	Avoca (Post Office)	84
408206	Avoca River @ Archdale Junction	081122	Avoca (Homebush)	85.1
408800	Avoca Water Treatment Plant	081038	Natte Yallock	88.6
		081127	Avoca River @ Archdale Junction	73.6
		079039	Redbank	83

August 1992 Validation Event

Pluviographs		Total Rainfall Depths		
Gauge No.	Name	Gauge No.	Name	Total Rainfall Depth (mm)
079086	Navarre (Avon No. 3)	089105	Lookout Hill	45

Pluviographs		Total Rainfall Depths		
Gauge No.	**Name**	**Gauge No.**	**Name**	**Total Rainfall Depth (mm)**
081038	Natte Yallock	081000	Avoca (Post Office)	41.4
089105	Lookout Hill	081038	Natte Yallock	32.7
		088038	Lexton	31.8
		079039	Redbank	51
		079031	Moonambel	49.8

September 1996 Validation Event

Pluviographs		Total Rainfall Depths		
Gauge No.	**Name**	**Gauge No.**	**Name**	**Total Rainfall Depth (mm)**
079086	Navarre (Avon No. 3)	089105	Lookout Hill	75
407211	Bet Bet Creek @ Bet Bet	081000	Avoca (Post Office)	61.8
089105	Lookout Hill	081122	Avoca (Homebush)	46.8
		081038	Natte Yallock	48.2
		088038	Lexton	45.2
		079039	Redbank	69
		079031	Moonambel	64.5

Appendix B. ARR DataHub output summary

```
Results - ARR Data Hub
[STARTTXT]

Input Data Information
[INPUTDATA]
Latitude,-37.034599
Longitude,143.413717
[END_INPUTDATA]

River Region
[RIVREG]
Division,Murray-Darling Basin
River Number,8
River Name,Avoca River
[RIVREG_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v1
[END_RIVREG]

ARF Parameters
[LONGARF]
Zone,Southern Temperate
a,0.158
b,0.276
c,0.372
d,0.315
e,0.000141
f,0.41
g,0.15
h,0.01
i,-0.0027
[LONGARF_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v1
[END_LONGARF]

Storm Losses
[LOSSES]
ID,11471.0
Storm Initial Losses (mm),27.0
Storm Continuing Losses (mm/h),4.4
[LOSSES_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v1
[END_LOSSES]

Temporal Patterns
[TP]
code,MB
Label,Murray Basin
[TP_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v2
[END_TP]

Areal Temporal Patterns
[ATP]
```

code,MB
arealabel,Murray Basin
[ATP_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v2
[END_ATP]

Median Preburst Depths and Ratios
[PREBURST] min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),1.7 (0.118),1.8 (0.086),1.8 (0.072),1.8 (0.061),1.5 (0.041),1.3 (0.029)
90 (1.5),2.3 (0.137),2.0 (0.083),1.7 (0.060),1.5 (0.044),1.5 (0.037),1.6 (0.032) 120 (2.0),1.5 (0.079),1.2 (0.046),1.0 (0.032),0.8 (0.022),1.5 (0.033),2.0 (0.038) 180 (3.0),1.6 (0.074),1.1 (0.039),0.9 (0.024),0.6 (0.014),2.0 (0.039),3.0 (0.051) 360 (6.0),1.0 (0.036),1.5 (0.040),1.9 (0.041),2.2 (0.042),2.9 (0.045),3.4 (0.046) 720 (12.0),0.0 (0.000),0.7 (0.014),1.2 (0.020),1.6 (0.024),3.5 (0.042),4.8 (0.052) 1080 (18.0),0.0 (0.000),0.4 (0.006),0.6 (0.009),0.9 (0.011),1.2 (0.012),1.4 (0.013) 1440 (24.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.1 (0.001),0.1 (0.001) 2160 (36.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000) 2880 (48.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000) 4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000) [PREBURST_META]
Time Accessed,29 November 2019 05:00PM
Version,2018_v1 Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST]

Interim Climate Change Factors
[CCF]
,RCP 4.5,RCP6,RCP 8.5
2030,0.816 (4.1%),0.726 (3.6%),0.934 (4.7%)
2040,1.046 (5.2%),1.015 (5.1%),1.305 (6.6%)
2050,1.260 (6.3%),1.277 (6.4%),1.737 (8.8%)
2060,1.450 (7.3%),1.520 (7.7%),2.214 (11.4%)
2070,1.609 (8.2%),1.753 (8.9%),2.722 (14.2%)
2080,1.728 (8.8%),1.985 (10.2%),3.246 (17.2%)
2090,1.798 (9.2%),2.226 (11.5%),3.772 (20.2%)

[CCF_META]
Time Accessed,29 November 2019 05:00PM
Version,2019_v1
Note,ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website. [END_CCF]

Baseflow Factors
[BASEFLOW]
Downstream,0
Area (km2),3967.231488
Catchment Number,10879
Volume Factor,0.584185
Peak Factor,0.146085
[BASEFLOW_META]
Time Accessed,29 November 2019 05:00PM
Version,2016_v1
[END_BASEFLOW]

[ENDTXT]

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