Warracknabeal and Brim Flood Investigation – Hydrology and Hydraulics

June 2015

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PROJECT DETAILS

Project Name	Warracknabeal and Brim Flood Investigation
Client	Wimmera CMA
Client Project Manager	Clare Wilson
Water Technology Project Manager	Ben Hughes
Report Authors	Ben Hughes
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Cover Photo: January 2011 Inundation in Warracknabeal, showing the levee constructed immediately prior to the event (Source: Yarriambiack Shire Council)

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1. BACKGROUND

The townships of Warracknabeal and Brim are located in Western Victoria on Yarriambiack Creek, within the Wimmera River catchment and Wimmera CMA management area. During high flows in the Wimmera River, flow is distributed along Yarriambiack Creek between Glenorchy and Horsham, near Longerenong.

The distribution of flood flows to Yarriambiack Creek has caused several large floods along the waterway and in the townships of Warracknabeal and Brim. The most recent of these was during January 2011, other events large enough to cause flooding include 1909, 1981 and 1983. The January 2011 event was the largest historic event in living memory.

Prior to the January 2011 floodwaters arriving at Warracknabeal and Brim significant effort was put into the construction of earthen levees and sandbagging. These levees prevented significant damage to both townships, particularly in Warracknabeal where the number of properties inundated above floor during the 1% AEP design event was estimated at 79[1]. It is understood this was reduced to approximately 5 in the January 2011 event with the aid of the temporary mitigation works implemented. Some of the levees constructed during January 2011 in Both Warracknabeal and Brim remain in place; some have been moved and formally constructed and maintained by Yarriambiack Shire Council.

2. PROJECT PURPOSE

The Warracknabeal and Brim Flood Investigation was commissioned to increase the flood understanding and resilience for Warracknabeal and Brim and the Yarriambiack Creek floodplain. The investigations primary purpose is to ensure the community and government agencies are aware and prepared for a flood event to occur. This involves improvements to flood intelligence, planning and structural mitigation.

The original project extent included from immediately upstream of Warracknabeal to downstream of Brim (Galaquil E Road – Wimmera CMA/Mallee CMA boundary). This was extended at the upstream (southern) end to the Wimmera Highway Bridge on Yarriambiack Creek. The original and extended study area extents are shown in Figure 2-1.

[1] Water Technology - Warracknabeal and Brim Flood Study (2007)

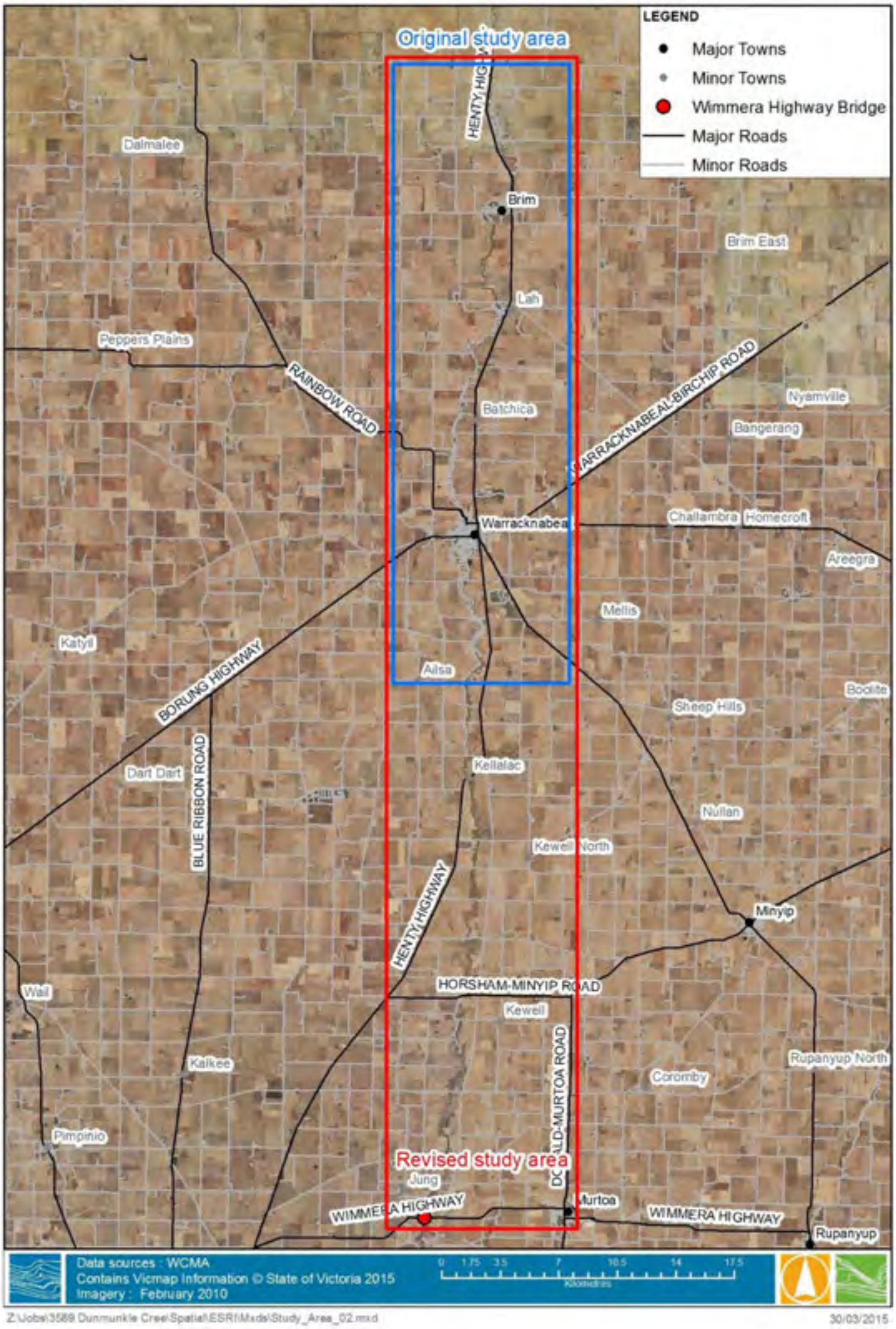


Figure 2-1 Original and extended study area extents

3. REPORTING PURPOSE

This Report is the second major report produced as part of the Warracknabeal and Brim Flood Investigation. The reporting stages area as follows, with major stages highlighted in **Bold**:

- **Site Visit, Inception and Data Collation Report (Completed)**
- LiDAR Verification Memo (Completed)
- Design Modelling - Remnant Levee Memo (Completed)
- **Hydrology and Hydraulics Report (This document)**
- Flood Warning Assessment Report
- Flood Mitigation Report
- Levee Engineering Design and Costing Memo
- Municipal Flood Emergency Plan Report
- Levee Design Summary Report
- **Final Warracknabeal and Brim Flood Investigation Report**

The purpose of this document is to present the methodology used to determine the calibration and design flows, hydraulic model calibration and intended methodology for hydraulic model design events. On completion of the Wimmera CMA review and approval process the remainder of the design events will be completed.

4. PREVIOUS REPORTING

4.1 Overview

Reports and Memos previously produced for during this project include:

- Site Visit, Inception and Data Collation Report
- LiDAR Verification Memo
- Design Modelling - Remnant Levee Memo

4.2 Site Visit, Inception and Data Collation Report

The Site Visit, Inception and Data Collation Report outlined and discussed the following:

- Site Visit – Undertaken on 5th September, 2014 by Clare Wilson (Wimmera CMA), Ben Tate and Ben Hughes (Water Technology). The sites visited along Yarriambiack Creek, within Warracknabeal and Brim.
- Streamflow gauge network – Yarriambiack Creek at Wimmera Highway Bridge (Jung), Wimmera River at Glenorchy.
- Previous studies – Warracknabeal and Beulah Flood Study, Wimmera River and Yarriambiack Creek Flow Modelling Study
- January 2011 event
- Yarriambiack Creek Flood Mechanisms – Stormwater inundation, Yarriambiack Creek direct catchment runoff, Wimmera River flow distribution
- Modelling Methodology – Hydrology and Hydraulics

The major outcomes from the report were the information available for calibration and the methodology used for development of the project's hydrology and hydraulics.

The January 2011 event was determined the most suitable to be used for calibration due to it being the largest event in living memory and the amount of calibration data available, including –

- Aerial photography (18th, 19th, 20th 21st January 2011)

- Peak flood height marks
- Significant community anecdotal evidence

The report also discussed the intended modelling methodology which is discussed throughout this report.

4.3 LiDAR Verification Memo

Three LiDAR datasets were available within the study area, two datasets were captured in 2005, and one in 2010. In 2005, LiDAR of Warracknabeal was captured individually, as well as LiDAR of the entire Wimmera CMA management region. Data was provided to Wimmera CMA by AAM Hatch as two separate datasets. During 2010, the Department of Environment and Primary Industries (DEPI – formerly Department of Sustainability and Environment) captured LiDAR as part of the Index of Stream Conditions (ISC) project. The available LiDAR dataset details were as follows:

- 2005 Warracknabeal LiDAR – Coverage of the Warracknabeal township. Provided as a 2 m resolution grid, 0.15m vertical accuracy, 0.55m horizontal accuracy.
- 2005 WCMA LiDAR – Coverage of the Wimmera CMA management area, excluding Warracknabeal. Provided as a 2 m resolution grid, 0.5m vertical accuracy, 1.5m horizontal accuracy.
- 2010 ISC LiDAR – Coverage of major waterways within WCMA management area. Provided as a 1m resolution grid, 0.2m vertical accuracy, 0.3m horizontal accuracy.

The available LiDAR data was verified in a two-step process:

- Verification against feature survey
    - four road crests within Warracknabeal
    - three Yarriambiack Creek road crests between Jung and Warracknabeal at major waterway crossings
    - two waterway cross sections upstream and downstream of each major waterway
- Comparison between the 2010 ISC and 2005 LiDAR datasets.

The analysis undertaken showed the 2010 ISC LiDAR data was to be within the stated vertical accuracy of 0.2 m. The survey and 2010 LiDAR data showed a good comparison in Warracknabeal. Between Jung and Warracknabeal the 2010 LiDAR levels were consistently higher than that surveyed. The 2005 LiDAR was shown to be a better match to the survey data in these locations. The 2005 LiDAR also showed a much better definition of the Yarriambiack Creek invert, where the 2010 LiDAR was impacted by water in the channel.

Given the 2010 ISC LiDAR data matched the surveyed data in the Warracknabeal township and the 2005 Floodplain LiDAR match more closely across the waterway and road crest transects south of Warracknabeal, it was determined a combination of both datasets be utilised as the base topographic data for this project.

The 2005 Regional WCMA LiDAR data was used as the base dataset across the model, with the Warracknabeal township adopting the 2010 ISC LiDAR in preference. Figure 4-1 shows the transition between the 2005 and 2010 LiDAR datasets. At the transition point the LiDAR datasets have similar levels preventing ensuring water movement will be as smooth as possible. The Yarriambiack Creek channel and weir pool were also inserted in the model topography within the Warracknabeal township using the 2005 LiDAR, as highlighted in Figure 4-1.

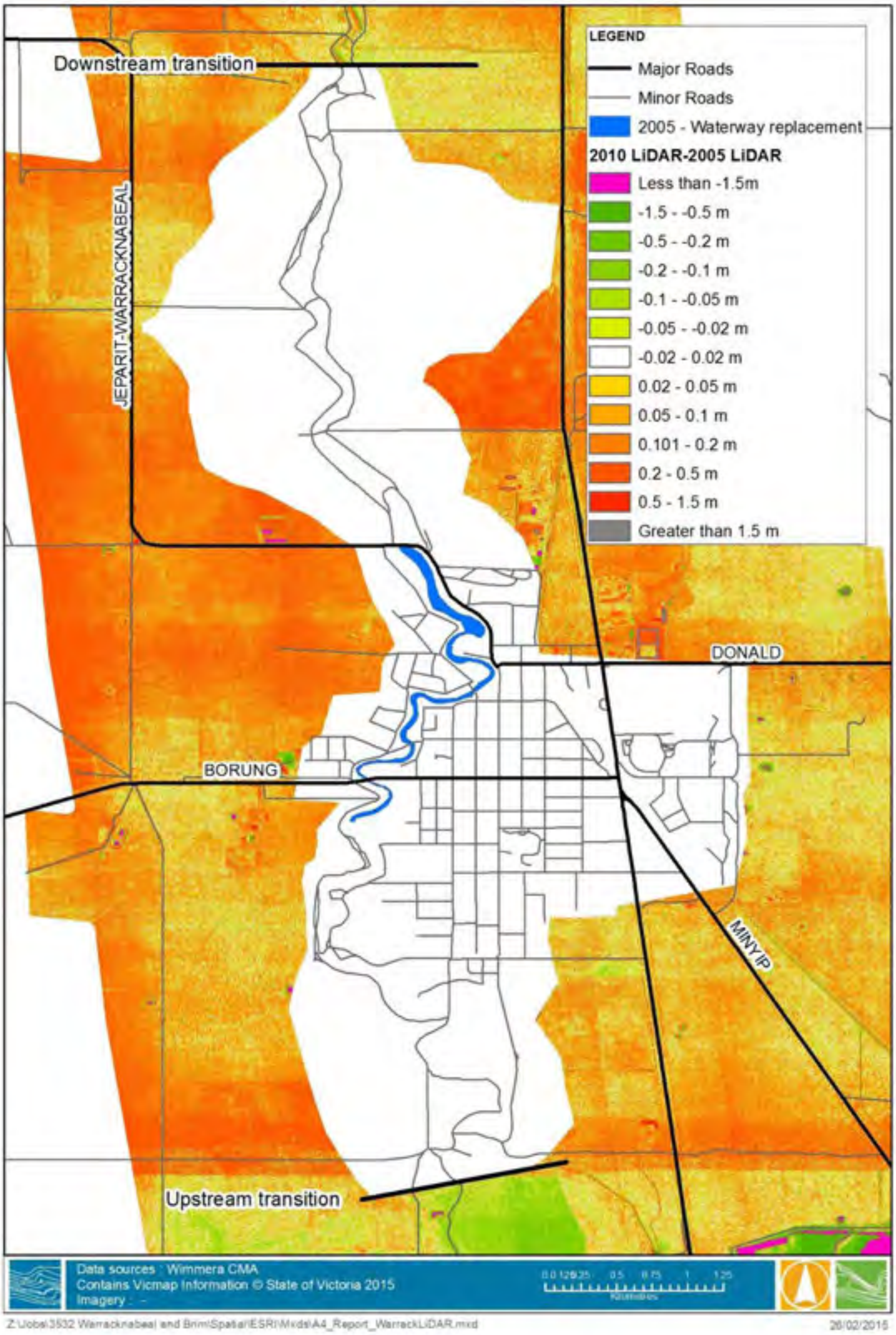


Figure 4-1 Transition between the 2005 and 2010 LiDAR Datasets.

4.4 Design Modelling - Remnant Levee Memo

The Design Modelling – Remnant Levee Memo discussed the how the remnant levees in Warracknabeal and Brim should be treated during the design modelling scenarios.

None of the levees constructed during January 2011 or altered since the January 2011 event are included in the Yarriambiack Shire Council Planning Scheme and are not part of a formal levee system. Levees in Warracknabeal are maintained by Council, however those at Brim are not.

The Draft Victorian Floodplain Management Strategy[2] states that unmaintained levees should be treated as if they do not exist. As a result any modelling or mapping completed should be undertaken with this taken into consideration, ensuring Planning Scheme layers and emergency management plans do not include the unmaintained levee as effective.

The Warracknabeal Levees have been altered, reconstructed since January 2011 and are maintained by Yarriambiack Shire Council as part of their general maintenance of walking tracks and gardens. The study Technical Reference Group determined to include the remnant levees in their current state in the design modelling completed during this study. This was due to their potential to reduce the inundation extent in some areas and increase it in others.

Levees remaining at Brim are unmaintained, of poor construction and if no change was made to them they would be likely to fail if an event large enough to reach them occurred. The Technical Reference Group determined they would not be included in the design modelling during this study.

5. AVAILABLE INFORMATION

5.1 Streamflow gauges

5.1.1 Overview

There are several streamflow gauges that provide information on the inundation potential along Yarriambiack Creek. The gauge most specific to the study area is Yarriambiack Creek at Wimmera Highway Bridge (Wimmera Highway) followed by Wimmera River at Glenorchy (Tail Gauge). The Wimmera Highway gauge is downstream of Two Mile Creek which returns flood water back to the Wimmera River from Yarriambiack Creek and provides a good representation of the flow escaping from the Wimmera River and entering the Yarriambiack Creek system. The Glenorchy gauge is the closest upstream Wimmera River gauge to the Yarriambiack Creek offtake and gives an indication of the Wimmera River flow prior to the offtake, excluding tributaries downstream of this point. Streamflow gauges are located on the Wimmera River at the following locations:

- Glynwylln
- U/S of Glenorchy Weir (inactive)
- Glenorchy Weir Tail Gauge
- Faux Bridge (inactive)
- Drung Drung (Gross's Bridge)
- Horsham (Walmer)

The location of these gauges is shown below in Figure 5-1.

[2] DEPI – DRAFT Victorian Floodplain Management Strategy (2014)

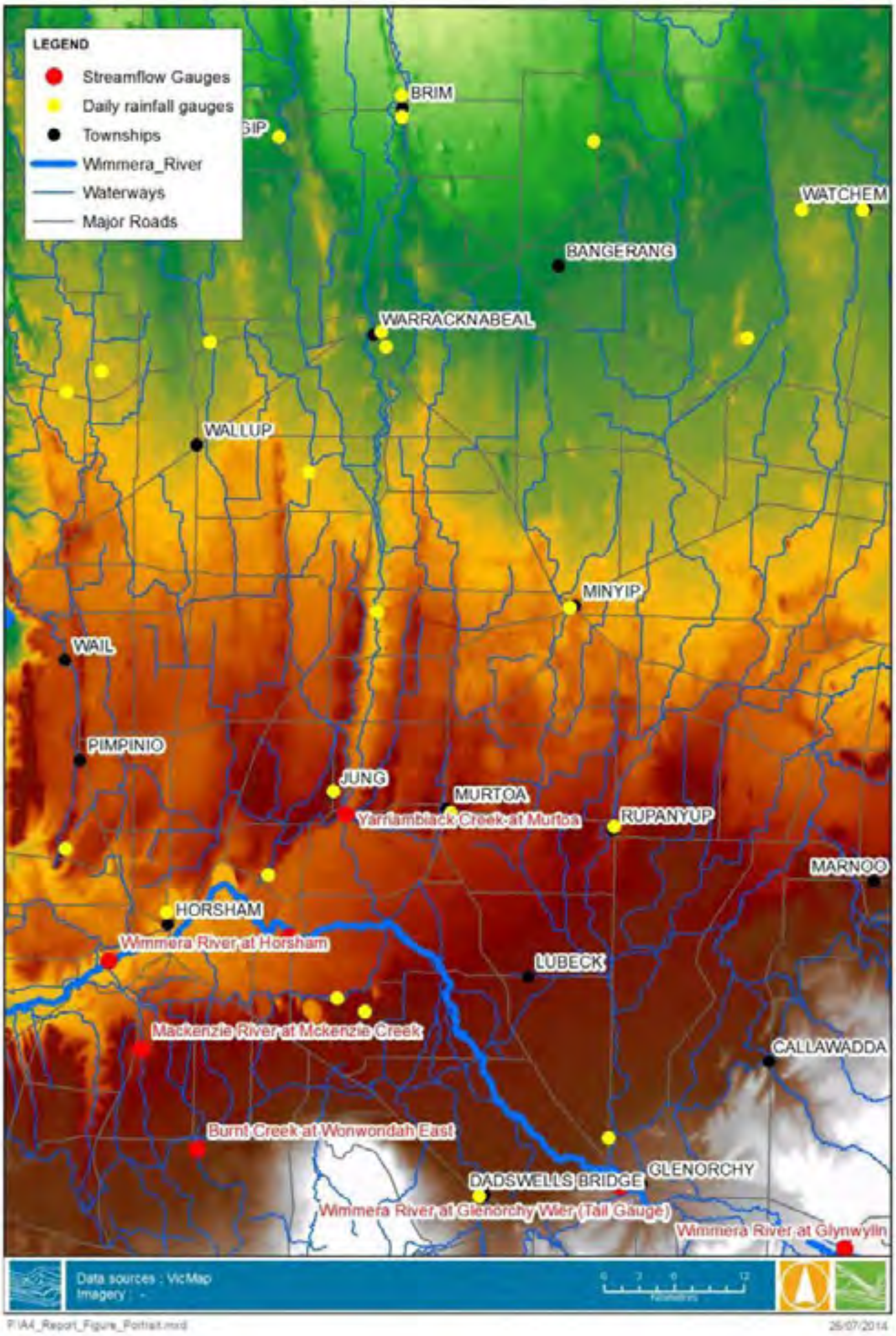


Figure 5-1 Streamflow gauges relevant to the study area

Active gauges of the most relevance to the study area are shown in Table 1.

Table 1 Active streamflow gauges most relevant to the study area

Gauge Name	Gauge Number	Gauge Record
Wimmera River at Eversley	415207C	1963 - Current
Wimmera R at Glynwylln	415206B	1956 - Current
Wimmera River at Glenorchy Weir (Tail Gauge)	415201B	1975 - Current
Yarriambiack Creek @ Wimmera Highway Bridge	415241	1978 - Current
Wimmera River at Drung Drung (Gross's Bridge)	415239A	1978 - Current
Wimmera River at Horsham (Walmer)	415200D	1975 - Current

Thiess Environmental Services Pty Ltd manage and maintain the streamflow gauging network across the Wimmera Catchment. Along with flow and water level recordings Thiess also supply quality code information to provide guidance on the quality of their flow estimations. In general, data with a Quality Code above 100 must be treated with caution. The full set of Thiess Quality Code Classifications in the extracted datasets is shown in Table 2.

Table 2 Thiess Quality Code Classifications

Quality Codes (QC)	Description
1	Unedited data
2	Good quality data - minimal editing required. Drift correction
8	Pool reading only - no flow condition.
9	Pool dry? no data collected
15	Minor editing. >+/-10mm drift correction
77	Correlation with other station, same variable only.
82	Linear interpolation across gap in records. (<0.5 day)
100	Irregular data, Use with caution. Beyond QC=50 or unexplained
104	Records manually estimated.
149	Rating extrapolated within 1.5x Max Qm
150	Rating extrapolated due to insufficient gauging (see additional quality info)
151	Data lost due to natural causes / vandalism (see additional quality info)
180	Data not recorded, equipment malfunction.
254	Rating table exceeded
255	No data exists

Gauges at Yarriambiack Creek at Wimmera Highway Bridge and Wimmera River at Glenorchy are most relevant to this study and particular focus was given to these gauges during the data review.

5.1.2 Yarriambiack Creek at Wimmera Highway Bridge

The Yarriambiack Creek streamflow gauge at Wimmera Highway Bridge has a reasonable span of record from 1978 to 2014; however there is a significant portion missing from 1986 to 2009. This only leaves 11 years of complete annual record, insufficient for a Flood Frequency Analysis. The largest event on record was recorded during January 2011.

Figure 5-2 shows the length of gauge record and the recorded Thiess Quality Code.

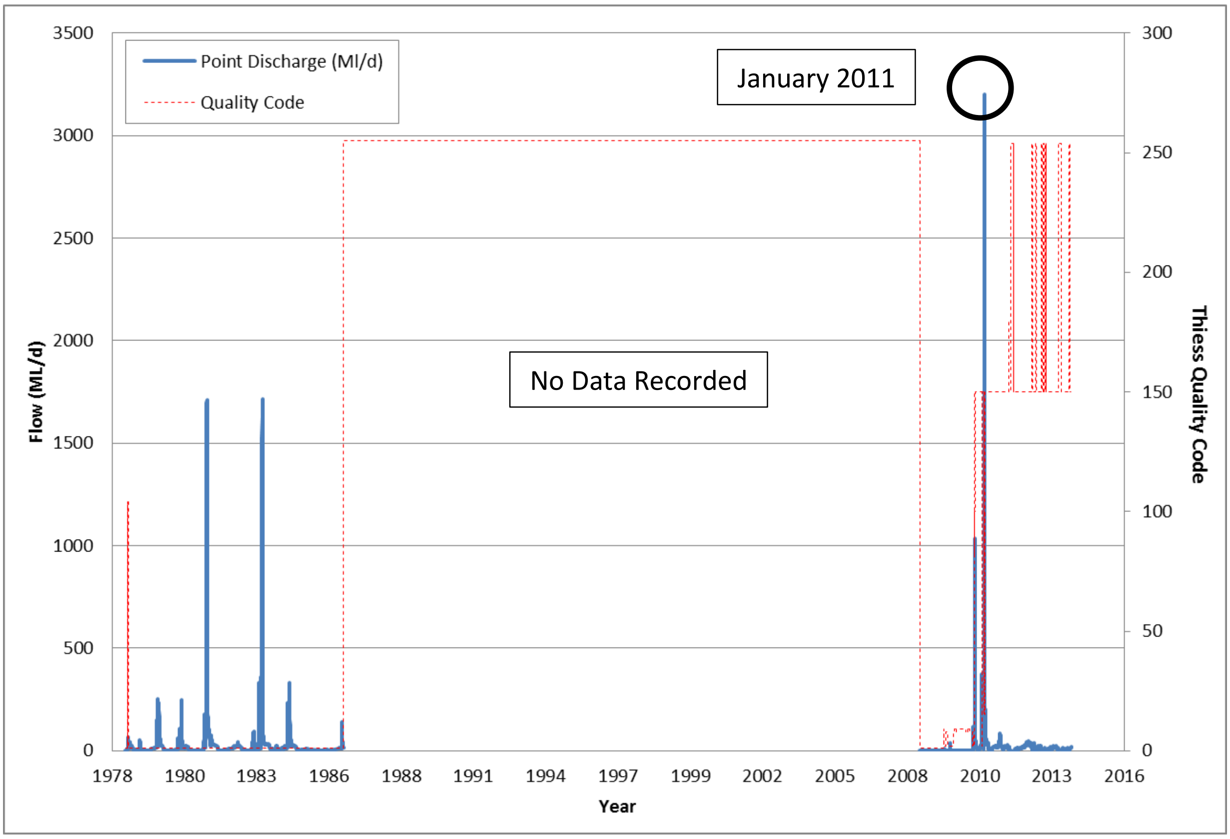


Figure 5-2 Gauge record at Yarriambiack Creek at Wimmera Highway Bridge showing flow and the Thiess Quality Code

The gauge record and quality codes indicate data post 2010 must be treated with some caution. The largest events recorded at the Wimmera Highway Bridge gauge prior to 2014 were January 2011, September 1983 and August 1981. The data Quality Codes show the data collected during the 1983 and 1981 events to be Unedited (QC 01). The January 2011 event peak flow was correlated to another station (QC 77). The correlation was completed to the Wimmera River at Walmer streamflow gauge to determine the hydrograph shape. The peak level was surveyed[3]. Flow data recorded either side of the January 2011 peak was in the extrapolated section of the rating curve due to insufficient gaugings (QC 150).

The January 2011 hydrograph is shown in Figure 5-3.

[3] Pers. Comm. Brent Deckert Thiess Environmental

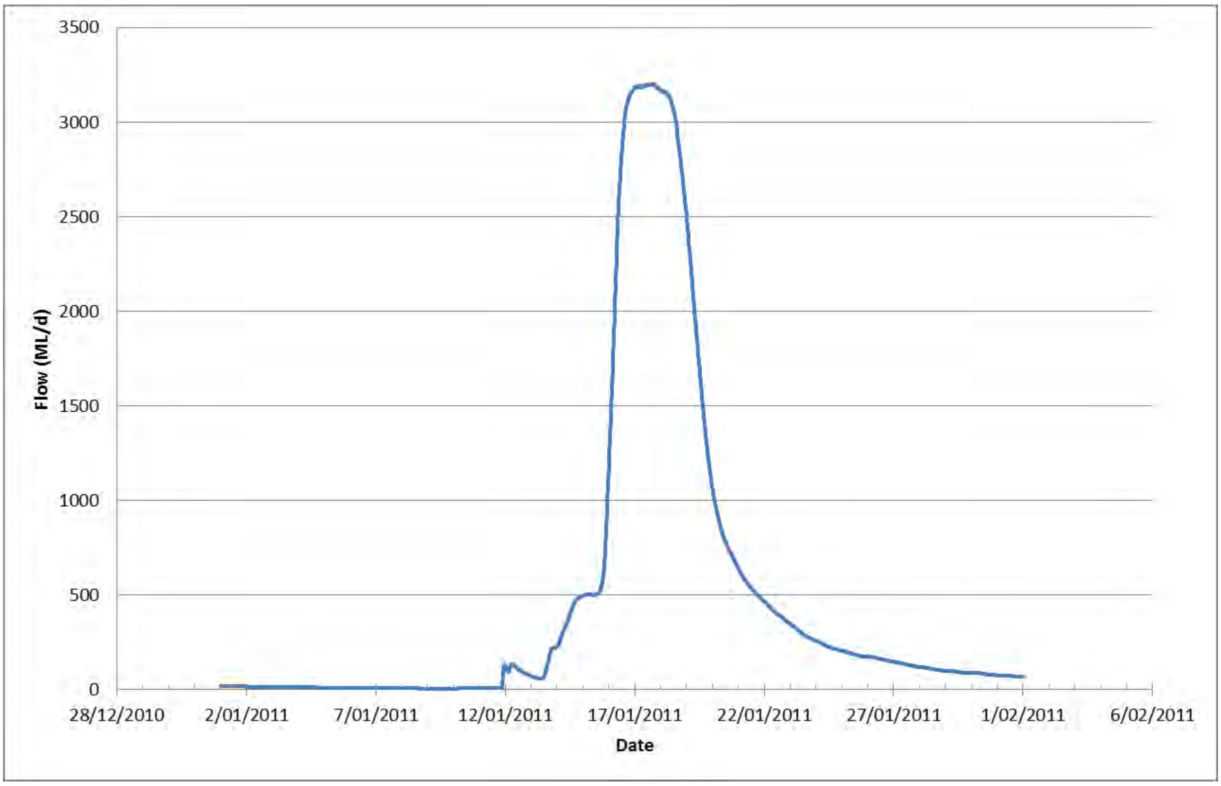


Figure 5-3 January 2011 hydrograph recorded at the Wimmera Highway Bridge gauge on Yarriambiack Creek

During January 2011 the gauge reached a maximum flow of 37 m^3/s (3,202 ML/d) and a gauge height of 2.335 m. The gauge rating curve shows is extrapolated at flows greater than 35.8 m^3/s (3,090 ML/d) at 2.30 m, reaching a maximum extrapolated flow of 40.5 m^3/s (3,500 ML/d) at 2.40 m. This puts the January 2011 event into the extrapolated region of the rating curve but still within the gauge heights recordable by the gauge.

The Yarriambiack Creek at Wimmera Highway Bridge gauge streamflow rating curve and measurements are shown in Figure 5-4.

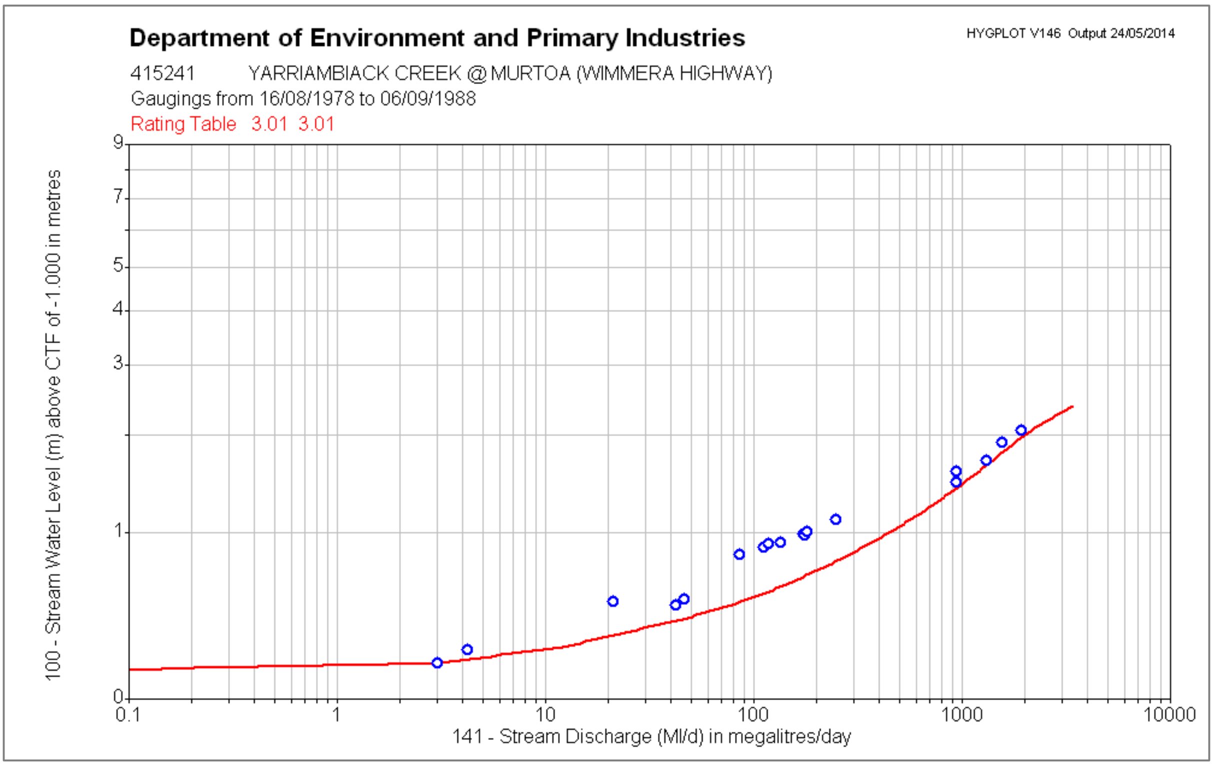


Figure 5-4 Yarriambiack Creek at Wimmera Highway Bridge streamflow gauge rating curve and measurements[4]

The rating curve is based on 18 measurements captured between 1978 and 1988. During the site inspection Wimmera CMA[5] indicated some uncertainty around the quality of the January 2011 event recording, and based on the quality codes of the data, this view is well founded.

Comparison of the 2004 and 2010 (ISC) LiDAR datasets completed in the LiDAR Verification Memo highlighted significant topographic changes have occurred in the direct vicinity of the Wimmera Highway Bridge gauge. Most notably the Main Western Channel was infilled as part of GWMWater's Channel Decommissioning Program in late 2010[6]. The difference between the LiDAR datasets is shown in Figure 5-5, the differences in elevation clearly highlight the removal of the channel embankment and two dams.

[4] DEPI - Water Measurement Information System (Accessed 27/10/2014)
[5] Pers. Comm. Clare Wilson (WCMA)
[6] Pers. Comm. Peter Cooper (GWMWater)

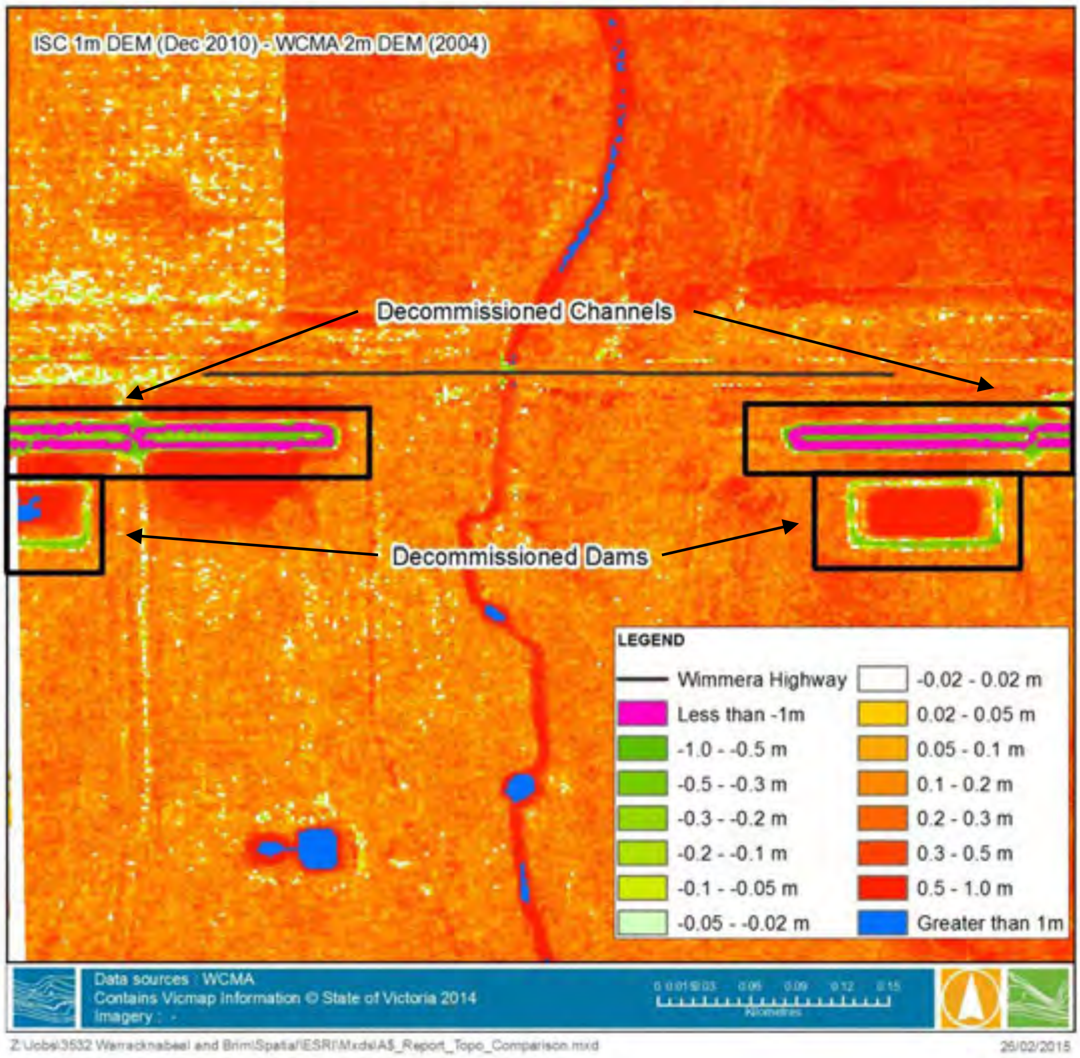


Figure 5-5 Difference between the 2004 and 2010 LiDAR datasets at the Wimmera Highway Bridge

A review of aerial photography captured during January 2011 indicated breakout flow from Yarriambiack Creek flowed overland in an area which would have previously been blocked by the Main Central Channel. This is highlighted in Figure 5-6.

Figure 5-6 Aerial imagery captured during January 2011 at the Wimmera Highway Bridge

Given all the previous ratings were captured prior to 1988 the change to topography and distribution of flood flows is not taken into account in the current rating curve.

5.1.3 Wimmera River at Glenorchy

The Wimmera River gauge at Glenorchy began gauging in 1910, with instantaneous gauging beginning in 1964. Several large events have been recorded in the period of instantaneous record. The largest was January 2011, followed by September 2010 and September 1988. Figure 5-7 shows the Glenorchy gauged flow record and the Thiess Quality Code data. The high flow events of 2011, 2010 and 1988 have peak flow quality codes of 150, 149 and 1 respectively. This indicates there is some uncertainty around the 2010 and 2011 peak flows as the flows were extracted from the extrapolated section of the rating curve. The highest flow prior to the extrapolated section of the curve is at 5.00 m gauge height, 413m^3/s (35,700 ML/d). The January 2011 event had a peak water level of 5.026 m and 451 m^3/s (38,970 ML/d), only marginally in the extrapolated section of the rating curve.

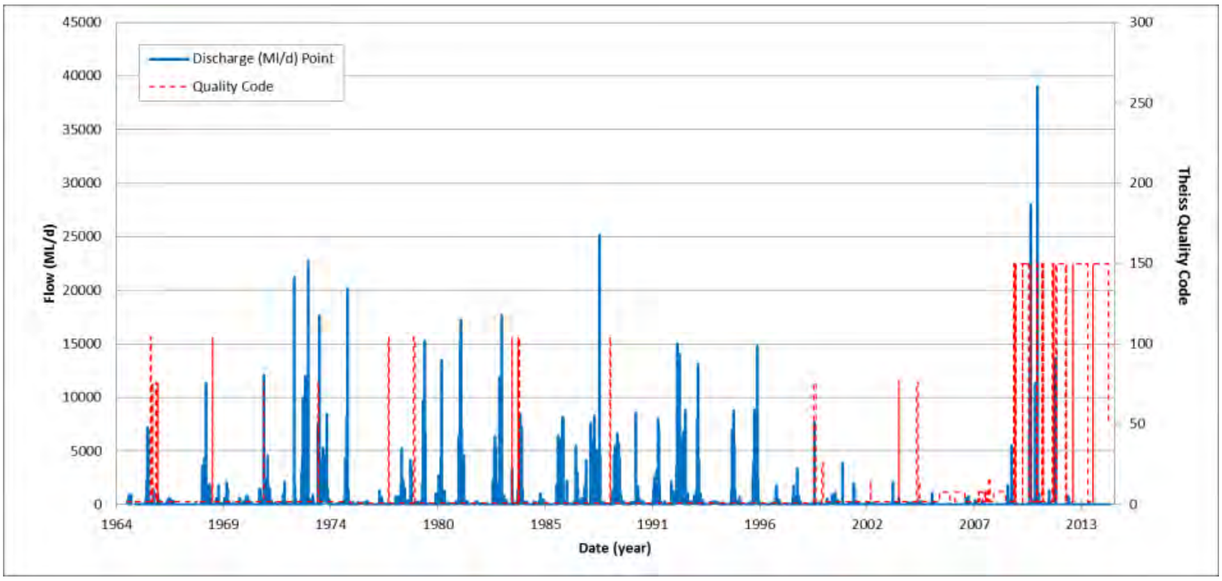


Figure 5-7 Wimmera River at Glenorchy instantaneous gauge record and Thiess Quality Code Data

The Wimmera River at Glenorchy rating curve and measurements are shown in Figure 5-8. Between 1964 and 2013, 306 gaugings have been taken to form the basis of the rating curve. At low flows less than 1000 ML/d there is some scatter in the measured flows; however the scatter is reduced at the upper end matching relatively consistently.

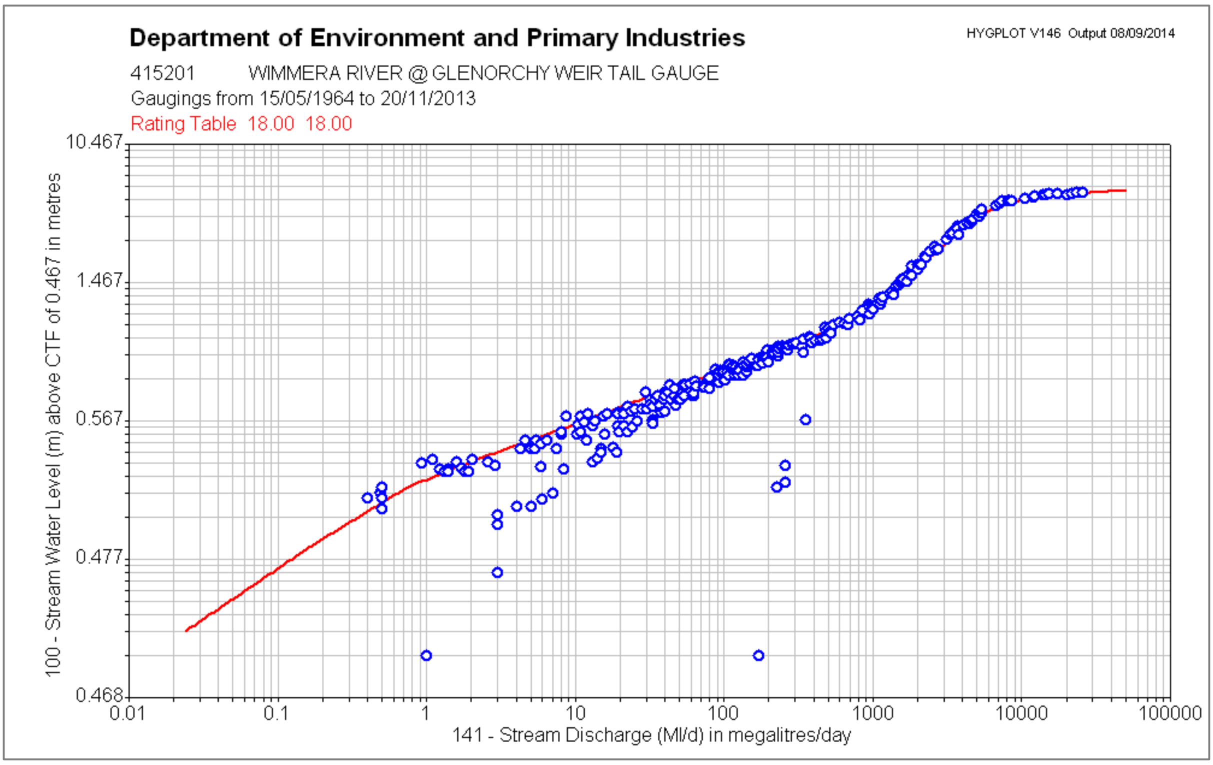


Figure 5-8 Wimmera River at Glenorchy streamflow gauge rating curve and measurements[4]

5.2 Previous Studies

Yarriambiack Creek has been subject to numerous hydrologic and hydraulic investigations. These investigations were utilised in the development of this project. The most relevant investigations completed on Yarriambiack Creek are shown below:

- Bureau of Meteorology (BoM) - Wimmera River Basin URBS Model (2004)
- Snowy Mountains Engineering Corporation Victoria (SMEC) – Assessment of the impact of priority structures on natural flow regimes and flooding in Yarriambiack Creek (Parts 1 and 2) (2001)
- WBM Oceanics Australia (WBM)– Yarriambiack Creek Flood Investigation Study (2003)
- Kellogg Brown & Root (KBR) – Yarriambiack Creek Management Plan (2004)
- Water Technology - Warracknabeal and Beulah Flood Study (2007)
- Water Technology – Wimmera River and Yarriambiack Creek Flow Modelling Study (2009)
- Water Technology – Beulah Flood Investigation (2012)

The Warracknabeal and Beulah Flood Investigation and the Wimmera River and Yarriambiack Creek Flow Modelling Study were of most use in this project as they contain the most recent and relevant information.

5.2.1 Warracknabeal and Beulah Flood Study[1]

Overview

The Warracknabeal and Beulah Flood Study completed flood modelling and mapping of Warracknabeal and Beulah for the 10%, 5%, 2%, 1% and 0.5% AEP events. Review of the study inputs and outputs in this project focuses on work undertaken at Warracknabeal.

Given the lack of streamflow data in Yarriambiack Creek and the importance of the Wimmera River distribution to Yarriambiack Creek the hydrology component of the study had a degree of uncertainty. During the study several types of models were constructed. Each of these models is discussed below progressing from the development of flows from the Upper Wimmera River catchment to the development of design flood levels in Warracknabeal.

Upper Wimmera Catchment

Design flood hydrographs were developed for the upper Wimmera catchment to the Wimmera River/Yarriambiack Creek offtake using a hydrologic model. Modelling was completed in URBS (Unified River Basin Simulator). The URBS model was developed and calibrated by the Bureau of Meteorology (BoM) in 2004 and used for design flows only.

Wimmera River/Yarriambiack Creek offtake

The flow split between flood hydrographs at Wimmera River/Yarriambiack Creek offtake was determined using a coarse two dimensional (2D) hydraulic model (25m grid resolution). The hydraulic model covered from Faux Bridge on the Wimmera River to the Wimmera Highway on Yarriambiack Creek to downstream of the confluence of Two Mile Creek and the Wimmera River. The hydraulic model extent is shown in Figure 5-9. The model was calibrated using gauged flows at Faux Bridge at the upstream end and known outflows on Yarriambiack Creek at the Wimmera Highway gauging station. The September 1983 event was selected for calibration as it was covered by the concurrent period of record. The calibration results are shown in Table 3 and Figure 5-10

Table 3 1983 observed and modelled flows at Faux Bridge and the Wimmera Highway

Event	Wimmera River at Faux Bridge	Yarriambiack Creek at Wimmera Highway	
	Observed peak flow (m^3/s)	Observed peak flow (m^3/s)	Modelled peak flow (m^3/s)
September 1983	217 (18750 ML/d)	19.9 (1,720 ML/d)	12.6 (1,090 ML/d)

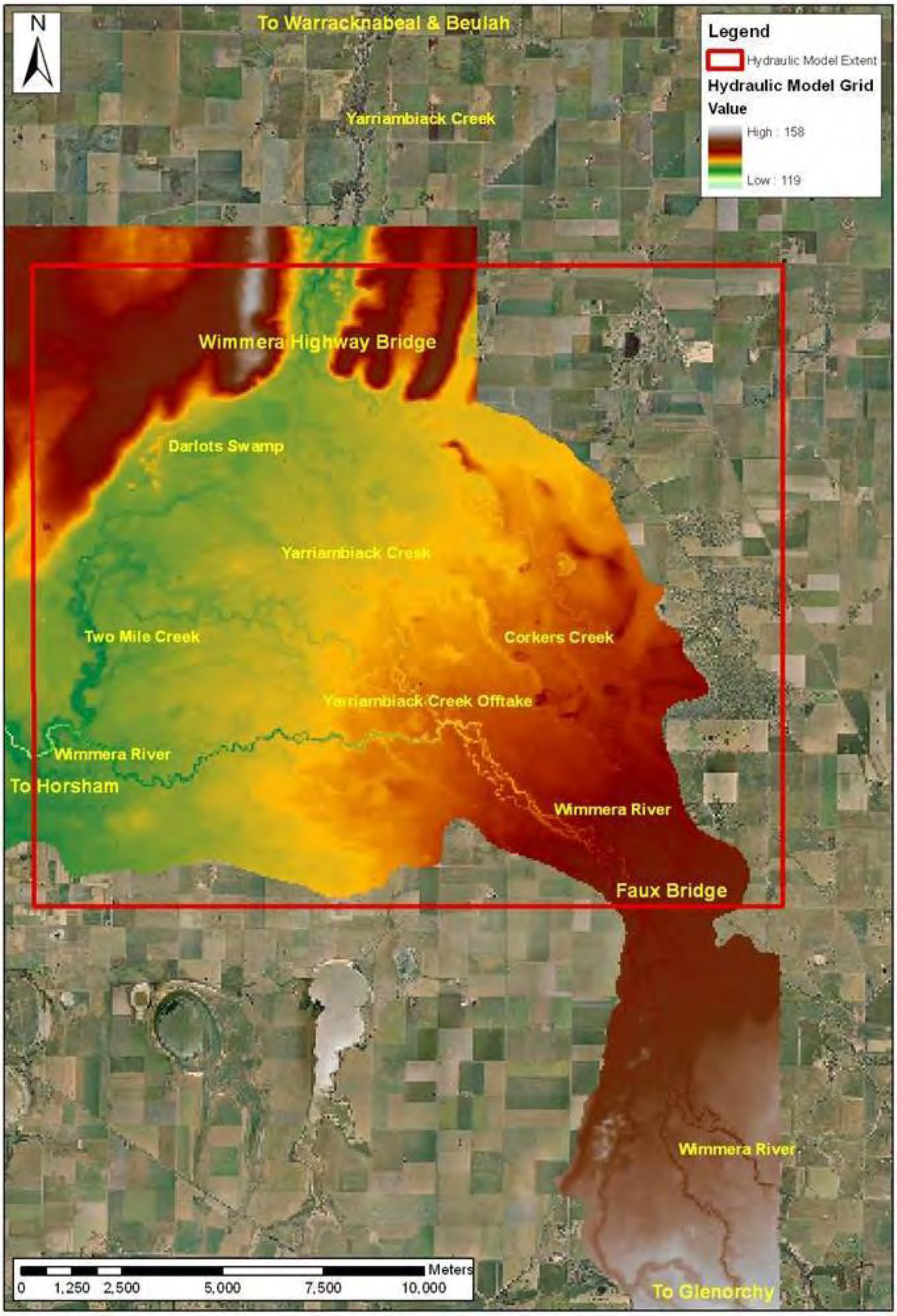


Figure 5-9 Wimmera River/Yarriambiack Creek offtake 2D hydraulic model[1]

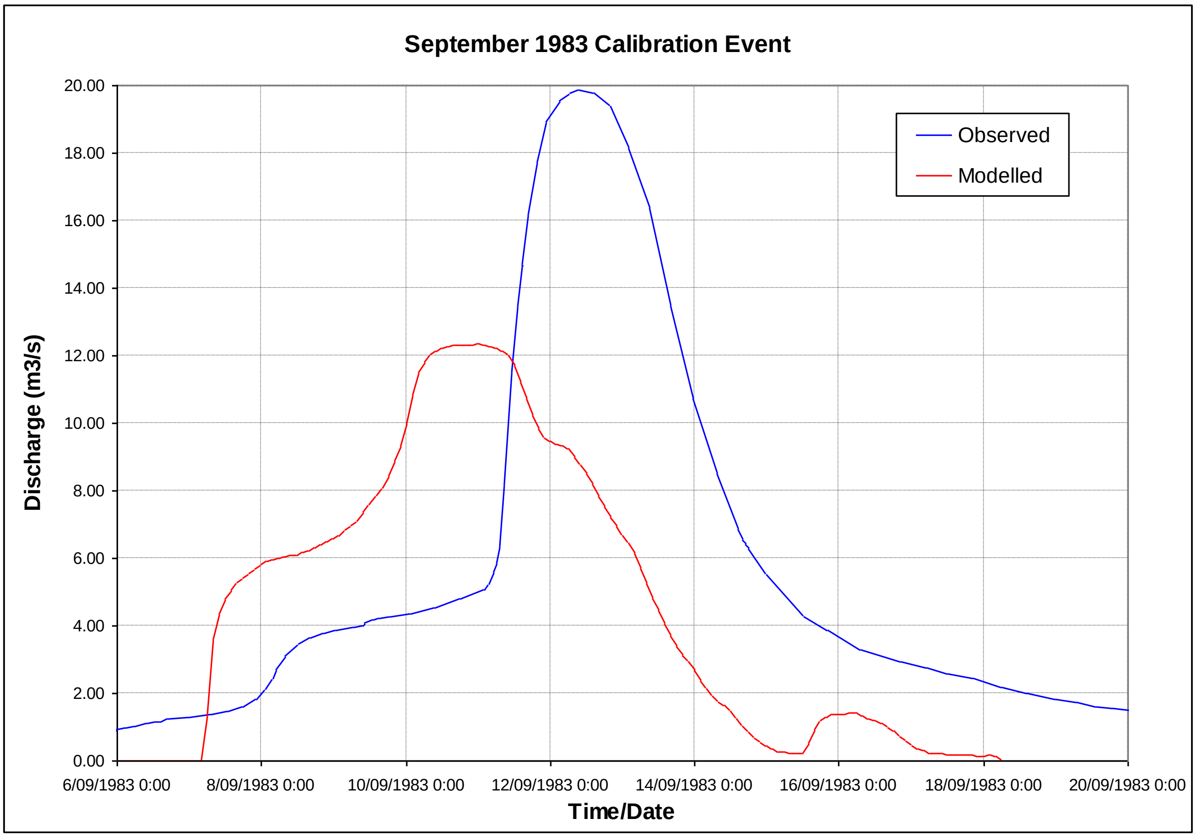


Figure 5-10 Modelled and observed hydrographs for Yarriambiack Creek at Wimmera Highway for September 1983[1]

Due to the disparity in the observed and modelled hydrographs at the Wimmera Highway Bridge and a lack of any other information, a ratio of peak modelled to peak observed flow (19.9/12.6 = 1.58) considered appropriate to determine the design flow hydrographs at the Wimmera Highway. The application of the flow split and scaled flows is shown in

Table 4.

Table 4 Design flow splits[1]

Design Event (AEP)	Peak Flow (m³/s)			Flow Split (%)
	Wimmera River at Faux Bridge	Yarriambiack Creek at Wimmera Highway (modelled raw)	Yarriambiack Creek at Wimmera Highway (scaled up)	Yarriambiack Creek /Wimmera River
20%	207 (17,885 ML/d)	12.3 (1,063 ML/d)	19.4 (1,676 ML/d)	9.4 (812 ML/d)
10%	290 (25,056 ML/d)	13.7 (1,184 ML/d)	21.6 (18,66 ML/d)	7.4 (639 ML/d)
5%	358 (30,931 ML/d	20.0 (17,28 ML/d)	31.6 (2,730 ML/d)	8.8 (760 ML/d)
2%	454 (39,226 ML/d)	28.3 (2,445 ML/d)	44.8 (3,871 ML/d)	9.8 (847 ML/d)
1%	513 (44,323 ML/d)	36.8 (3,180 ML/d)	58.1 (5,020 ML/d)	11.3 (976 ML/d)
0.5%	524 (45,274 ML/d)	38.1 (3,292 ML/d)	60.2 (5,201 ML/d)	11.4 (985 ML/d)

Yarriambiack Creek - Wimmera Highway Bridge to Warracknabeal:

Flood hydrographs determined at the Wimmera Highway Bridge were routed along Yarriambiack Creek to Warracknabeal via a one dimensional (1D) hydraulic model. The model extent is shown in Figure 5-11.

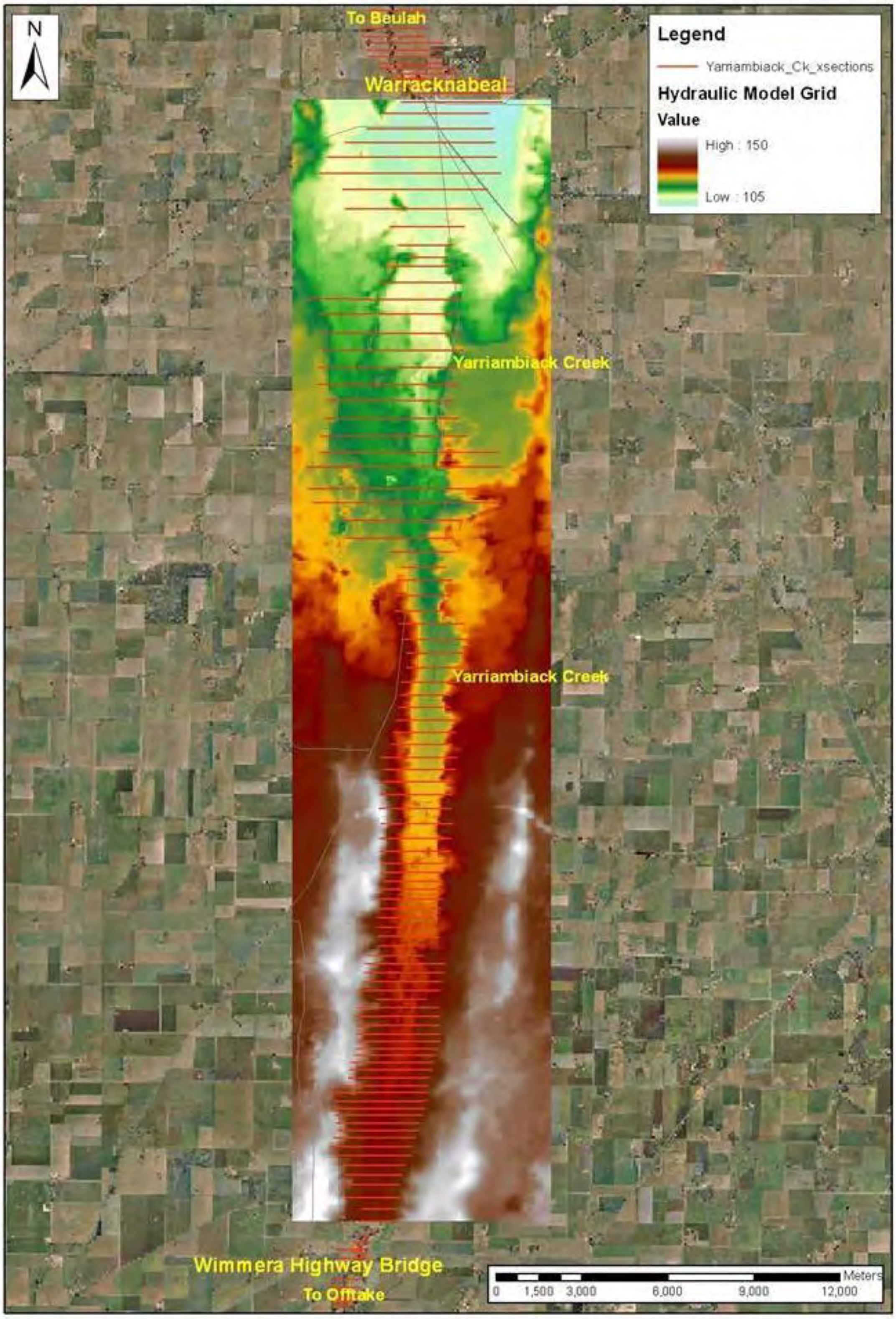


Figure 5-11 Yarriambiack Creek 1D hydraulic model[1]

The 1D model was calibrated utilising an estimated peak flow from the September 1983 event upstream of the Warracknabeal Weir, where the observed peak flow at the Wimmera Highway Bridge was attenuated from 19.8 m^3/s (1,715 ML/d) to 12.9 m^3/s (1,114 ML/d). The method of flow estimation during September 1983 is unknown. A seepage rate was applied as the primary calibration parameter where 3.2 mm/hr was adopted.

The scaled design flood hydrographs at the Wimmera Highway Bridge were applied to the 1D model with the calibration seepage rate applied. The resulting design flows for Warracknabeal are shown in Table 5.

Table 5 Design flows adopted for the Wimmera Highway Bridge and Warracknabeal[1]

Design Event (AEP)	Peak Flow (m^3/s)	
	Yarriambiack Creek at Wimmera Highway	Yarriambiack Creek at Warracknabeal
20%	19.4 (1676 ML/d)	13.3 (1149 ML/d)
10%	21.6 (1866 ML/d)	14.7 (1270 ML/d)
5%	31.6 (2730 ML/d)	20.7 (1788 ML/d)
2%	44.8 (3871 ML/d)	31.3 (2704 ML/d)
1%	58.1 (5020 ML/d)	41.4 (3577 ML/d)
0.5%	60.2 (5201 ML/d)	43.7 (3776 ML/d)

Warracknabeal – Riverine Inundation

Riverine inundation within Warracknabeal was assessed for the 20%, 10%, 5%, 2%, 1%, 0.5% and PMF events. The linked one dimensional (1D) and two-dimensional (2D) unsteady hydraulic model, MIKEFlood, was the principal tool for the hydraulic analysis. The model topography was based on a 5 m topographic grid resolution.

The bridge crossings at Jamouneau Street and Borung Highway were modelled as 1D MIKE 11 structures and dynamically coupled with the two dimensional model. The weir at the Rainbow Road Bridge was modelled as open without restriction.

A gauge board is located on Yarriambiack Creek at Warracknabeal at the weir. Design estimates for the gauge board were determined for the gauge board as shown in Table 6.

Table 6 Design flood level estimates for the Warracknabeal Weir gauge board

Design Event (AEP)	Depth (m)	Elevation (m AHD)
10%	2.41	108.22
5%	2.67	108.47
2%	2.86	108.66
1%	2.90	108.70
0.5%	2.92	108.72

Warracknabeal – Stormwater Inundation

Stormwater inundation in Warracknabeal was determined for the 1% AEP event only. Similar to riverine inundation, stormwater modelling was undertaken in MIKEFlood. A rainfall excess depth was applied to the model topography based on design IFD parameters and Zone 2 design temporal patterns outlined in Australian Rainfall and Runoff[7]. The net design rainfall was determined by applying an initial loss of 15 mm and continuing loss of 3 mm/hour. For a range of storm durations, the 12 hour storm duration indicated the greatest rainfall excess at 56 mm. This depth was applied directly to the Warracknabeal hydraulic model topography.

Project Outputs

There were numerous project outputs produced during the Warracknabeal and Beulah Flood Investigation based on the modelling described above. These outputs included:

- Flood level and extent mapping for the modelled AEP events
- Flood damages assessment
- Structural mitigation option assessment
- No structural mitigation option assessment (LSIO, FO planning layers)

5.2.2 Wimmera River and Yarriambiack Creek Flow Modelling Study[8]

Overview

The Wimmera River and Yarriambiack Creek Flow Modelling Study[8] undertook hydrologic and hydraulic modelling of the Wimmera River and Yarriambiack Creek between Glenorchy, Horsham and Warracknabeal. Both current and "pre-European" catchment-waterway-floodplain conditions were assessed. The study was completed with two specific flow regimes in mind, both low-medium flows and high flood flows.

The review and summary of the Wimmera River and Yarriambiack Creek Flow Modelling Study focused on the current (2009) catchment-waterway-floodplain conditions, with high flood flow regime.

Similar to the Warracknabeal and Brim Flood Investigation, the complex nature of flow distribution of Wimmera River flows to Yarriambiack Creek resulted in the development and use of several hydrologic and hydraulic models. A hydrologic model was developed for the Wimmera River and a series of 1D/2D hydraulic models were developed from Glenorchy to Horsham to Warracknabeal. Each of these models is discussed below progressing from the development of flows from the Upper Wimmera River catchment to the development of design flood levels in Yarriambiack Creek between the Wimmera Highway Bridge and Warracknabeal. The numerous hydraulic model extents are shown in Figure 5-12. The models of primary interest to this study are Faux Bridge to Offtake, Offtake to Warracknabeal and the local scale model of the Wimmera Highway Bridge and gauge on Yarriambiack Creek.

[7] Engineers Australia – Australian Rainfall and Runoff (1999)
[8] Water Technology – Wimmera River and Yarriambiack Creek Flows Study (2009)

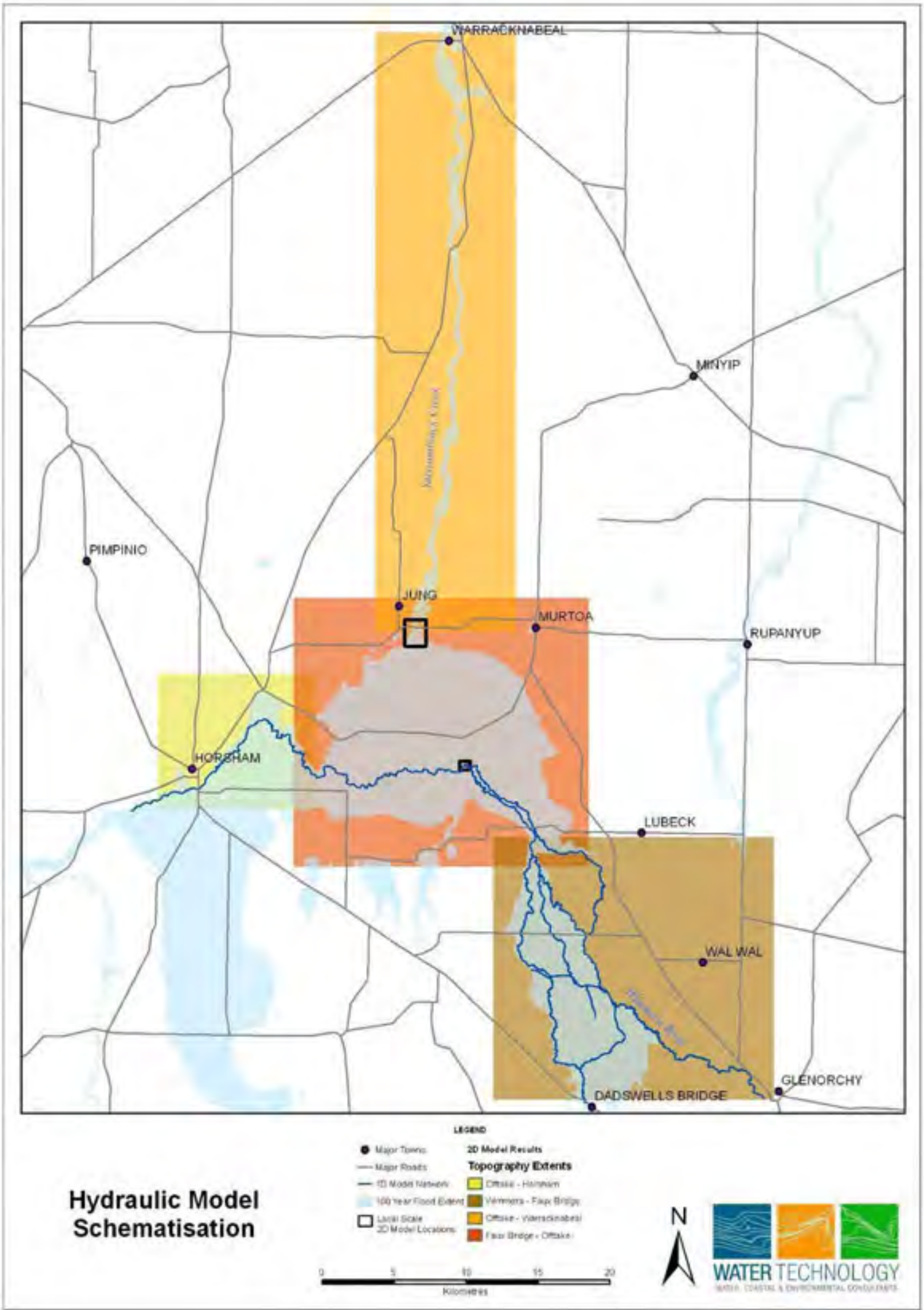


Figure 5-12 Separate hydraulic model extents[8]

Upper Wimmera Catchment/Runoff Routing

URBS was the principal tool employed to estimate flood hydrographs for the Wimmera River catchment. The URBS model was the same as that used in the Warracknabeal and Beulah Flood Investigation, developed by the BoM[9]. The model was separated into two separate sections, upstream and downstream of Glenorchy. Some changes to the model were made to ensure the URBS model outputs suited the hydraulic model inflow locations. As such, the model was recalibrated using the August 1981, September 1983, September 1988 and October 1996 events as a basis. Calibration was undertaken at Wimmera River gauges located at Glenorchy, Faux Bridge and Horsham, as well as Burnt Creek at Wonwondah East. Design flow estimates were verified to Flood Frequency Analysis (FFA) undertaken at Wimmera River gauges at Glenorchy and Horsham, undertaken during the Glenorchy Flood Study and Horsham Flood Study respectively. URBS model losses were adjusted to meet the FFA values to give final design flows. Glenorchy is the closest active gauge to the Yarriambiack Creek offtake. A comparison of the Glenorchy URBS and FFA peak design flow estimates are shown in Table 7.

Table 7 URBS and FFA peak design flow estimates for Glenorchy[8]

Design Event (AEP)	Peak Flow (m^3/s)	
	Glenorchy Flood Study FFA[10]	URBS Modelling (IL 20 mm, CL 2.5 mm/hr)
5%	272 (23,501 ML/d)	266 (22982 ML/d)
2%	336 (29030 ML/d)	348 (30067 ML/d)
1%	380 (32832 ML/d)	435 (37584 ML/d)

Faux Bridge to Offtake

The Faux Bridge to Offtake was developed with a 25 m grid resolution topography. The model had a very similar extent to that created during the Warracknabeal and Beulah Flood Study. The model was calibrated using both surveyed flood heights and the Yarriambiack Creek gauge at the Wimmera Highway for events in September 1983 and August 1981.

The modelled and observed flows for the 1981 and 1983 events are shown in Figure 5-13 and Figure 5-14 respectively.

[9] BoM – Wimmera Region URBS model (2001)
[10] Water Technology – Glenorchy Flood Study (2006)

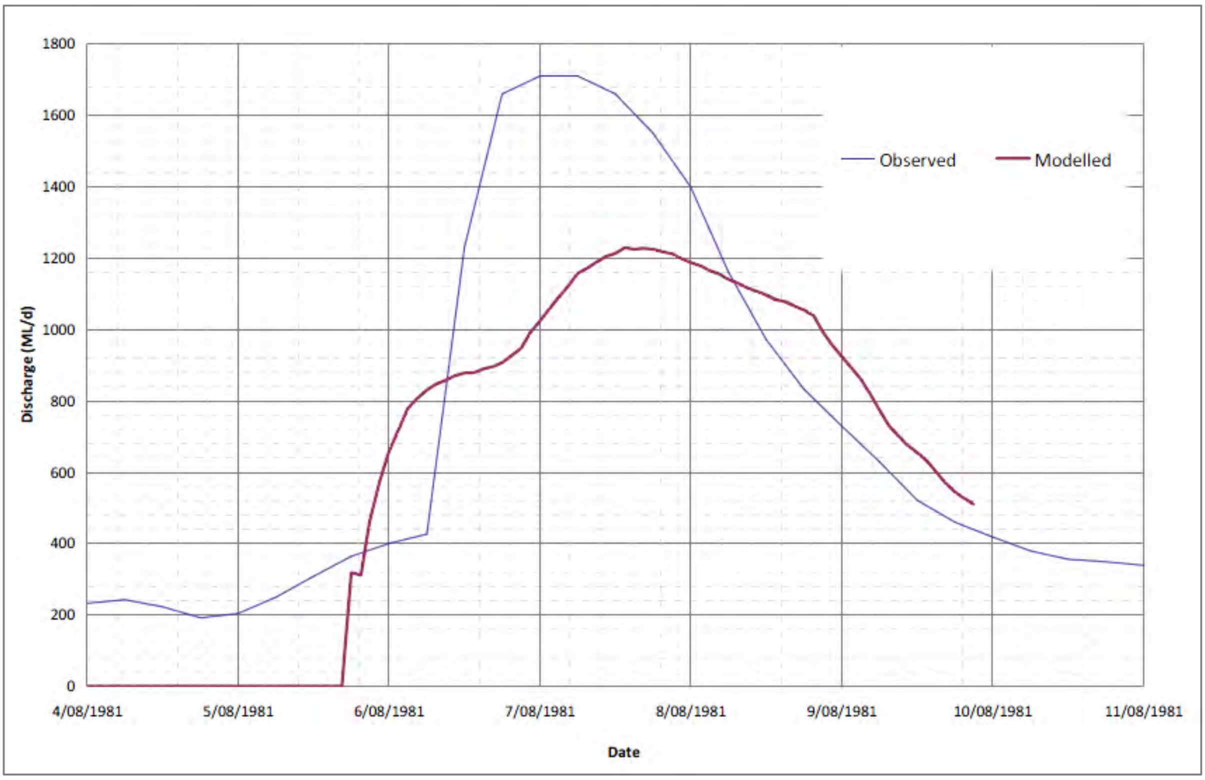


Figure 5-13 Modelled and observed hydrographs on Yarriambiack Creek at the Wimmera Highway for August 1981[8]

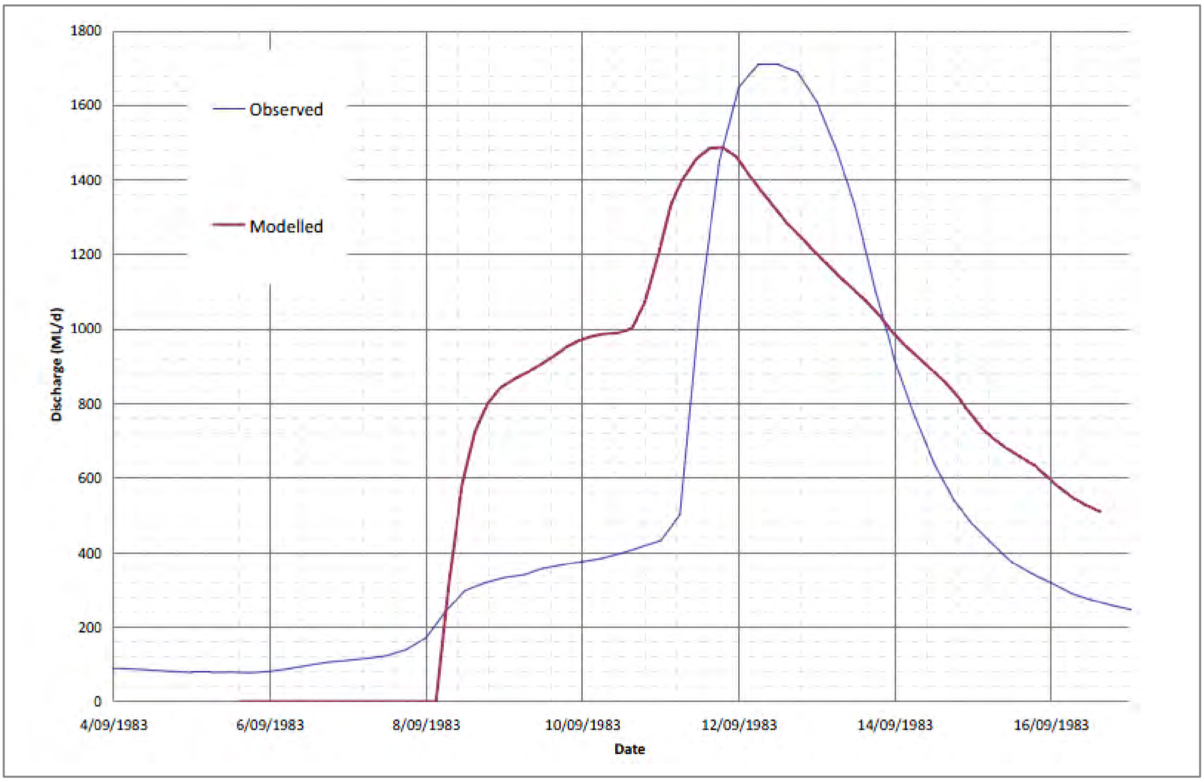


Figure 5-14 Modelled and observed hydrographs for Yarriambiack Creek at the Wimmera Highway for September 1983[8]

In both events the modelled flow is under that observed. The difference in the modelled and observed peak flows is shown in Table 8.

Table 8 Modelled and observed peak flows for Yarriambiack Creek at Wimmera Highway for August 1981 and September 1983[8]

Event	Peak Flow (m^3/s)		Difference	
	Observed	Modelled	m^3/s	%
August 1981	19.8 (1711 ML/d)	14.2 (1227ML/d)	5.6 (484 ML/d)	28.3%
September 1983	19.9 (1719ML/d)	17.2 (1486ML/d)	2.7 (233 ML/d)	13.6%

Design modelling applied to the Faux Bridge to Offtake model determined the peak flows for Yarriambiack Creek at the Wimmera Highway Bridge as shown in Table 9. Only the 20%, 5% and 1% AEP events were modelled.

Table 9 Design flows at Wimmera Highway Bridge on Yarriambiack Creek[8]

Design Event (AEP)	Peak Flow (m^3/s)
20 %	10.9 (942 ML/d))
5 %	16.9 (1460 ML/d)
1 %	36.6 (3162 ML/d)

Local Scale Hydraulic Model – Wimmera Highway Bridge

The local scale model of the Wimmera Highway Bridge was used to verify the simulation of flood behaviour adjacent to the bridge. The model was run with a steady state upstream flow boundary matching the peak flow recorded at the Wimmera Highway gauge for the 1981 and 1983 events respectively.

The hydraulic model had a 2m grid resolution and the road culverts were included as 1D elements. The model extent is shown in Figure 5-15.

The modelled and observed heights at the Wimmera Highway Bridge are shown in Table 10.

Table 10 Modelled and observed levels at the Wimmera Highway Bridge on Yarriambiack Creek for August 1981 and September 1983[8]

Event	Gauged level (m AHD)		Difference (m)
	Observed	Modelled	
August 1981	132.932	132.94	0.008
September 1983	132.935	132.95	0.015

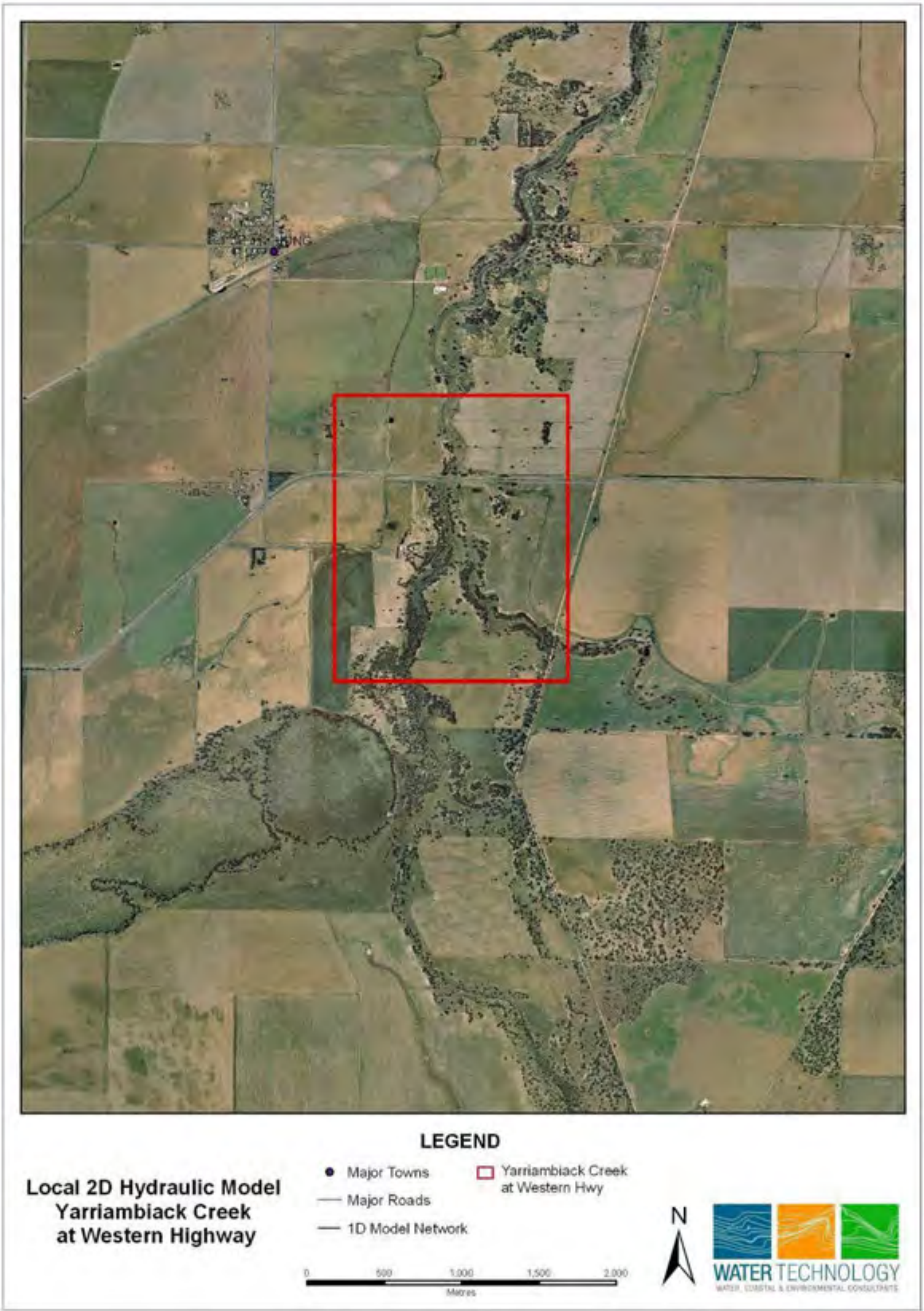


Figure 5-15 **Model extent - Local scale model of Yarriambiack Creek at the Wimmera Highway Bridge**

5.2.3 Discussion

Both the Warracknabeal and Beulah Flood Study and Wimmera River and Yarriambiack Creek Flows Study developed flow estimates for the Yarriambiack Creek gauge at the Wimmera Highway. A comparison of the events that were modelled in both studies is shown in Table 11.

Table 11 Design flow comparison at Wimmera Highway Bridge on Yarriambiack Creek between the Warracknabeal and Beulah Flood Investigation (2007) [1] and the Wimmera River and Yarriambiack Creek Flows Study (2009)[8]

Design Event (AEP)	Peak Flow (m^3/s)	
	Warracknabeal and Beulah Flood Investigation (2007)[1]	Wimmera River and Yarriambiack Creek Flows Study (2009)[8]
20 %	19.4 (1,676 ML/d)	10.9 (942 ML/d)
5 %	31.6 (2,730 ML/d)	16.9 (1,460 ML/d)
1 %	58.1 (5,020 ML/d)	36.6 (3,162 ML/d)

Design flows determined in the Warracknabeal and Beulah Flood Investigation[1] were significantly larger than that determined in the Wimmera River and Yarriambiack Creek Flows Study[8]. Both studies used a hydraulic model covering approximately from Faux Bridge on the Wimmera River to the Wimmera Highway on Yarriambiack Creek. The Wimmera River and Yarriambiack Creek Flows Study underwent a more significant model calibration process for this modelling with two events simulated (rather than one) and surveyed flood heights also used. Both studies used the 1983 event in the calibration process. The Wimmera River and Yarriambiack Creek Flows Study[8] calibration matched the observed peak flow much closer than that undertaken in the Warracknabeal and Beulah Flood Study[1] with a difference between the modelled and observed peak flood flows of 2.7 m^3/s (233 ML/d) (13.6%) and 7.3 m^3/s (631 ML/d) (36.7%) respectively. However, it must be noted the accuracy of the flows recorded at the Wimmera Highway Bridge is uncertain and is discussed further in Section 7.3.1. The differences in modelled and observed flows is likely to be due to model schematisation and the models that were available during each study.

5.3 January 2011

5.3.1 Summary

Rainfall in mid-January 2011 caused widespread flooding across Victoria with the Wimmera Region particularly impacted. The Wimmera River experienced high streamflows and as a result distributed significant flows into the Yarriambiack Creek.

Flooding and the consequent damage was the largest in recent times and in some areas was the largest flood on record.

The January 2011 event was significant for the entire area covered by this investigation.

5.3.2 Rainfall

During January 2011 the Warracknabeal Museum rainfall gauge recorded rainfall totals of 77, 38 and 36 mm on Monday the 10th, Wednesday the 12th and Friday the 14th of January respectively.

Direct runoff caused localised flooding in and around Warracknabeal after the initial rainfall. The Warracknabeal daily rainfall record for January 2011 is shown in Figure 5-16.

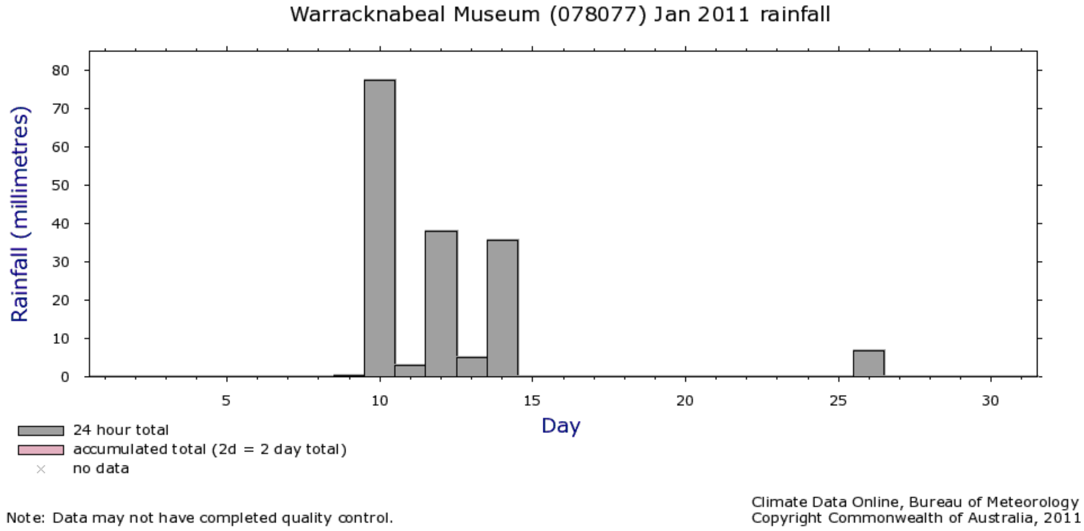


Figure 5-16 Warracknabeal Museum daily rainfall records (1st – 31st January 2011)[11]

5.3.3 Stream Flows

As discussed in Section 4.3, the gauges most reflective of potential inundation within Warracknabeal, Brim and Yarriambiack Creek are the Wimmera River at Glenorchy and Yarriambiack Creek at the Wimmera Highway Bridge.

The Wimmera River gauge at Glenorchy reached a peak flow rate during January 2011 of 451 m^3/s (38,466 ML/d) at 7:30 am, 15 January 2011, the highest gauging on record. The January 2011 peak flow is 16 m^3/s (1,382 ML/d) larger than the 1% AEP event estimated by the URBS runoff routing undertaken during the Wimmera River and Yarriambiack Creek Flows Study (435 m^3/s)(37,584 ML/d) and 71 m^3/s (6,134 ML/d) larger than the 1% AEP event determined during the Glenorchy Flood Study FFA (380 m^3/s) (32,832 ML/d).

The Yarriambiack Creek gauge at the Wimmera Highway reached a peak flow rate of 37 m^3/s (3,186 ML/d) at 12:40 am on 17 January 2011. This was also the highest recording in the gauge record.

When compared to the design flows estimated for the gauge location during the Warracknabeal and Brim Flood Investigation, the event was between a 5 and 2% AEP event at 31.6 m^3/s (2,730 ML/d) and 44.8 m^3/s (3,870 ML/d) respectively.

When compared to the design flows estimated for the gauge location during the Wimmera River and Yarriambiack Creek Flows Study, the event was a 1% AEP event with the design estimate 36.6 m^3/s (3,162 ML/d).

5.3.4 Observed Inundation

There were several datasets showing the inundation that occurred during January 2011. This data included:

[11] BoM – Climate Data Online (http://www.bom.gov.au/climate/data/)

- Aerial photography captured on the 18th, 19th, 20th and 21st January (image extents shown in Figure 5-17) covering the entire study area
- Peak inundation extent estimated by Wimmera CMA using aerial imagery, on ground photography and community information (estimated peak inundation extent shown in Figure 5-18) covering upstream of Warracknabeal to downstream of Brim.
- Peak water level survey points captured by Ferguson and Perry Surveying immediately post the January 2011 event (survey points are shown in Figure 5-19)
- Peak water level survey points highlighted by the community captured during the initial stages of this project (Survey points are shown in Figure 5-20)
- There was also numerous ground and aerial based photos captured by the community.

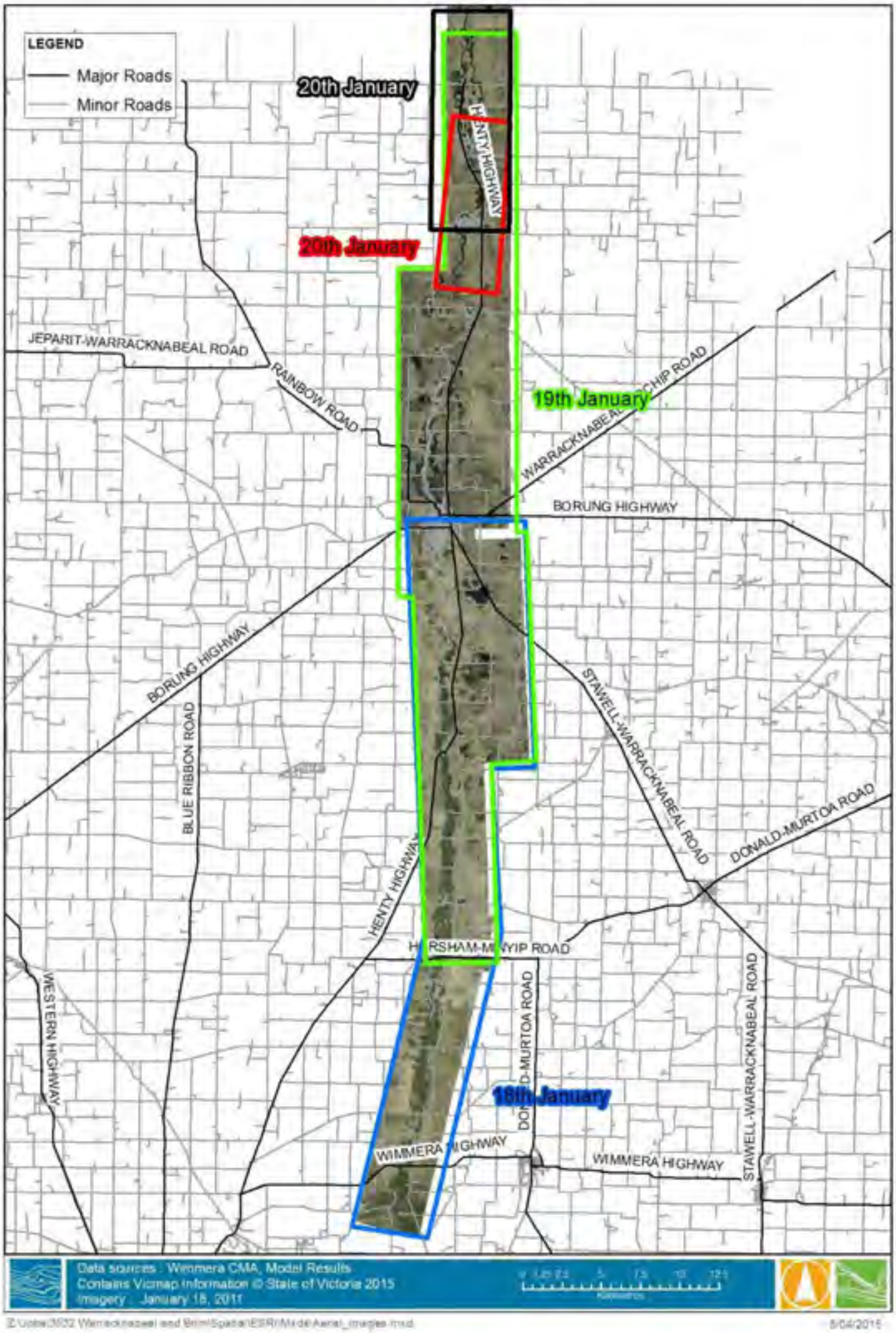


Figure 5-17 Aerial photography captured of Yarriambiack Creek during the January 2011 event

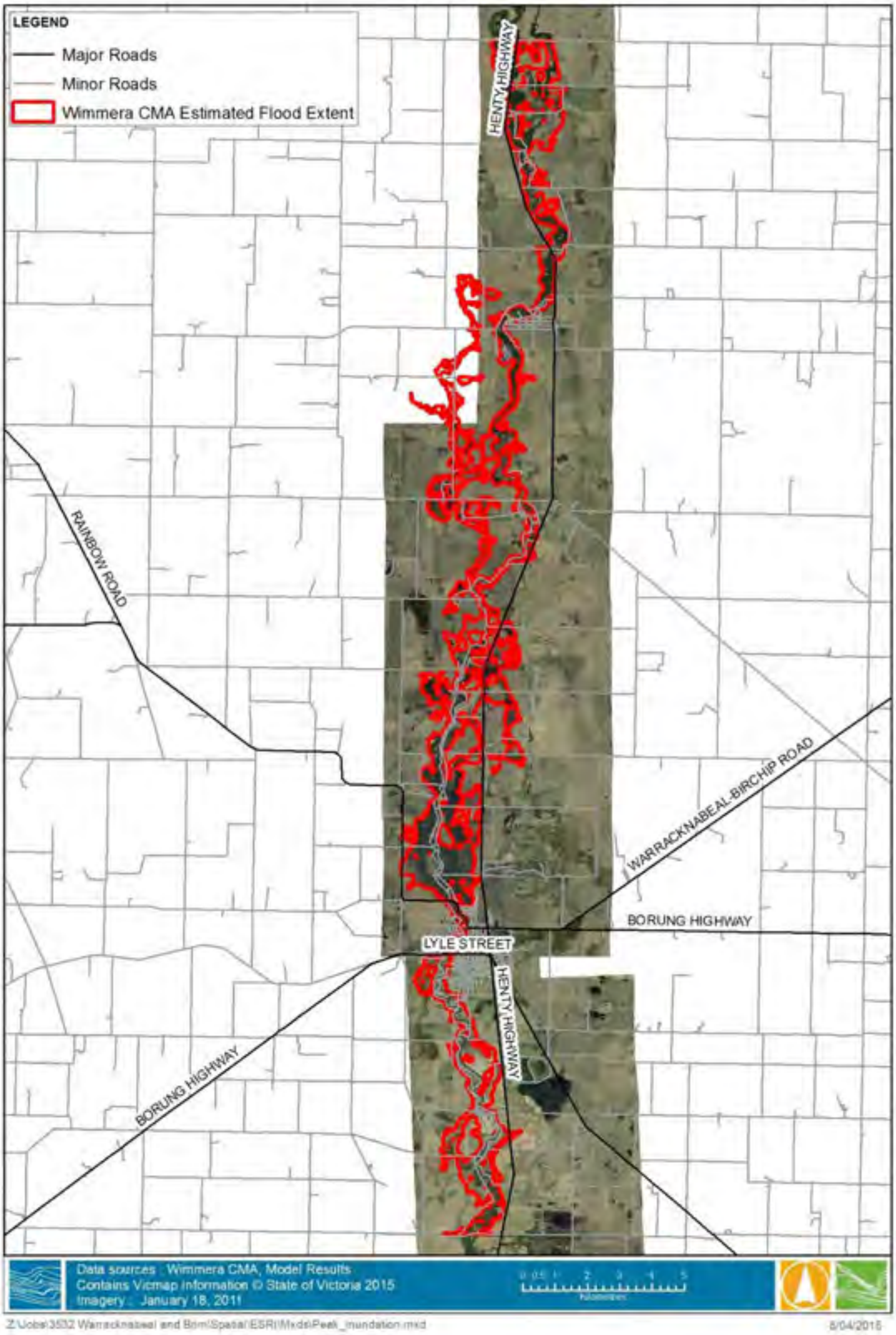


Figure 5-18 Peak inundation extent estimated by Wimmera CMA

Figure 5-19 Survey points captured by Ferguson and Perry Surveying immediately post the January 2011 event

Figure 5-20 **Survey points highlighted by the community captured during the initial stages of this project**

6. FLOOD MECHANISMS

6.1 Overview

There are numerous contributing catchment areas between the Yarriambiack Creek offtake and Warracknabeal, as well as between Warracknabeal and Brim. There is also a direct storm water catchment area for both townships. This results in potentially three separate potential flood mechanisms within the study area: local stormwater runoff, Yarriambiack Creek catchment runoff and Wimmera River distributary flow.

6.2 Direct Stormwater Contribution

Direct stormwater runoff impacts on the study area township areas of Warracknabeal and Brim. Historically, Brim is less prone to this form of inundation. Stormwater runoff rarely impacts on rural properties unless there is a property specific drainage issue (blocked drainage pipes etc.).

Warracknabeal is particularly susceptible to stormwater inundation at the southern and western extents of the township. This is due to the natural fall of the topography and surrounding infrastructure.

This is demonstrated in Figure 6-1, showing inundation in Warracknabeal during the January 2011 storm event. These areas were not inundated from the creek but from local runoff. The impact of the Borung Highway and Warracknabeal Birchip Road is highlighted especially well. This area was visited during the site inspection and issues surrounding the localised catchment area to the south and former GWMWater infrastructure were raised. Gardiner and Cemetery Street were highlighted as areas with potential stormwater issues by Yarriambiack Shire Council Staff. There were several properties in these areas inundated below floor.

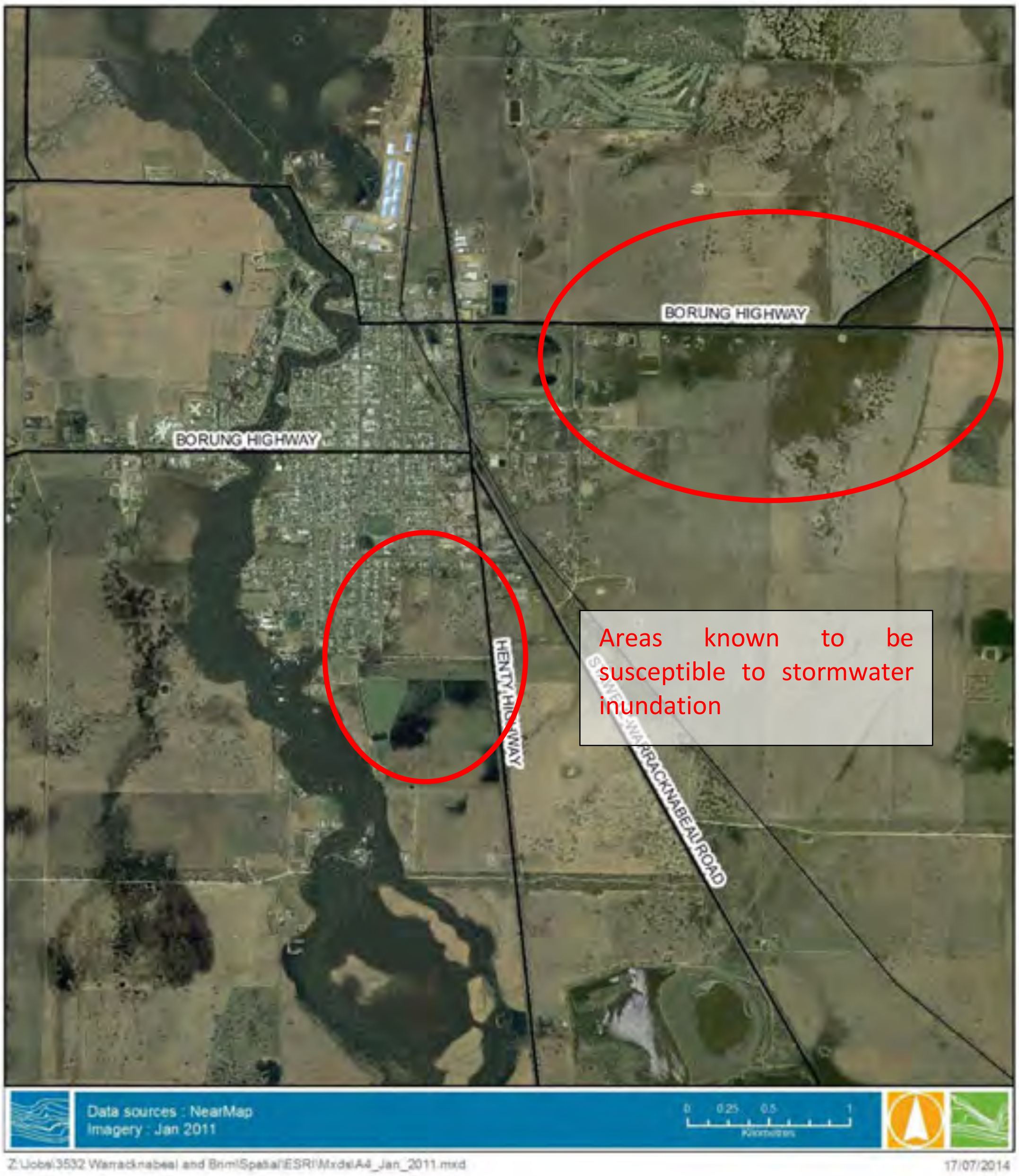


Figure 6-1 Inundation in Warracknabeal observed 19th January 2011 (NearMap)

Direct stormwater inundation is not as significant in Brim as in Warracknabeal, aerial imagery of the January 2011 event show some localised pooling of water however no properties were reported as inundated by Wimmera CMA, Yarriambiack Shire Council or during the site inspection.

Figure 6-2 Inundation in Brim observed on 19 January 2011

6.3 Yarriambiack Creek catchment Contribution

There is a local catchment contribution to Yarriambiack Creek, with the catchment varying between 5-12 km in width between the offtake point from the Wimmera River and Brim. Rainfall occurring within this catchment area causes flow in Yarriambiack Creek prior to the flow distributed from the Wimmera River if/when it occurs.

Typically, the local catchment contribution induced peak flow in Yarriambiack Creek occurs before the distributed flow. The local catchment contribution flows historically have been significantly less than the distributed flows and previous investigations have highlighted that flood inundation is more likely to occur via flood distributed from the Wimmera River. The Yarriambiack Creek catchment contribution is likely to prime the creek, providing an initial flow and minor water level in the creek prior to a Wimmera River distributed flow.

6.4 Wimmera River distributed flow Contribution

The primary cause of inundation across Warracknabeal, Brim and the Yarriambiack floodplain is flow distributed to Yarriambiack Creek via the Wimmera River. Yarriambiack Creek offtakes from the Wimmera River between Glenorchy and Horsham. During high flows the majority of the flow distribution to Yarriambiack Creek returns to the Wimmera River via Two Mile Creek. However, approximately 30% continues along Yarriambiack Creek to Warracknabeal and Brim approximately 50 km and 70 km north of the Yarriambiack Creek offtake respectively. A demonstration of flow distribution is shown in Figure 6-3.

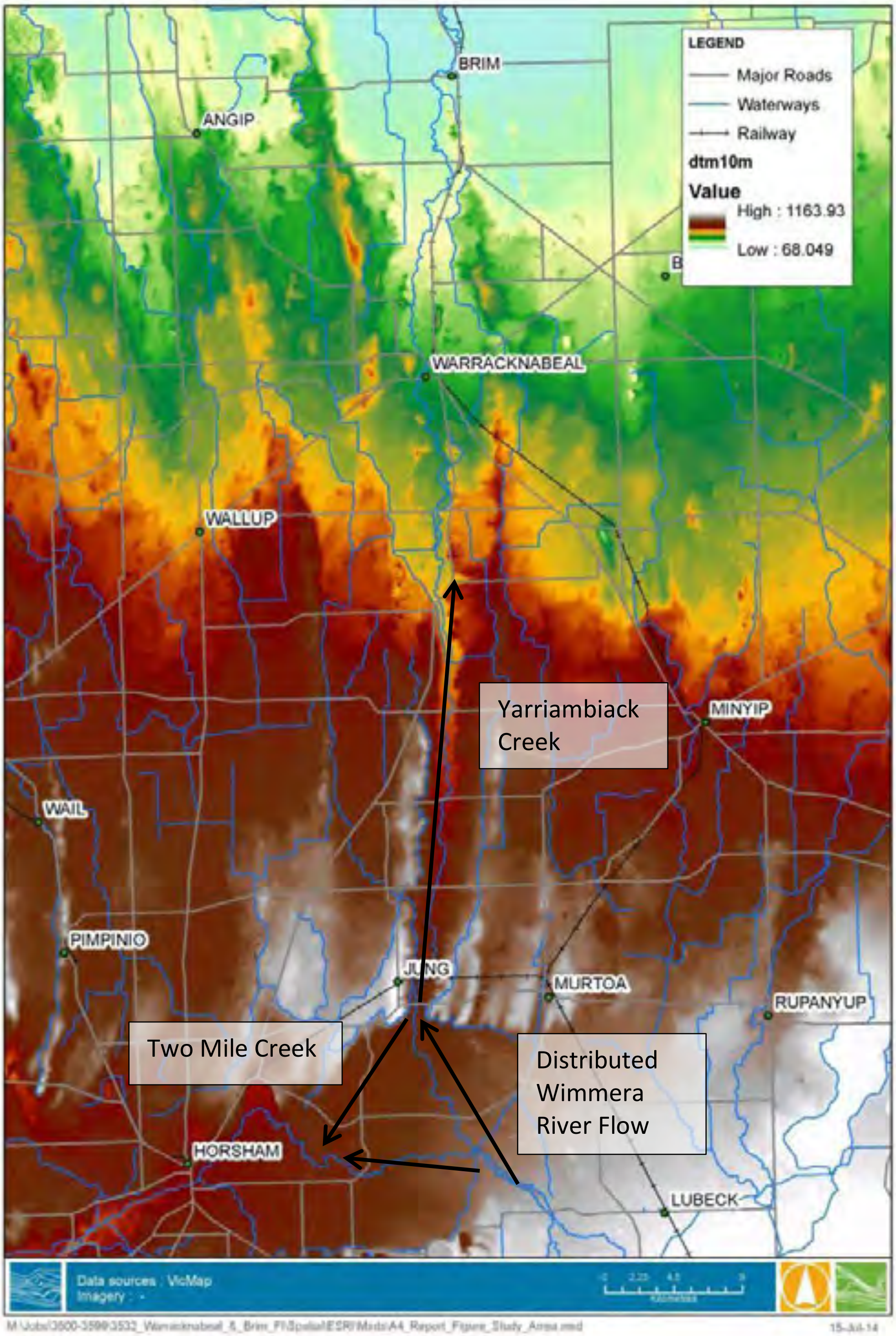


Figure 6-3 **Flow distribution to Yarriambiack Creek from the Wimmera River, return through Two Mile Creek and north toward Warracknabeal and Brim**

7. HYDROLOGY AND HYDRAULICS

7.1 Overview

As described above, Yarriambiack Creek is a distributary system and as such the hydrology is quite complex. The accuracy of the flood mapping is reliant on a strong understanding of the distributed flows from the Wimmera River. This study has investigated the distributed flows in a high level of detail.

Uncertainty surrounding the rating curve at the Wimmera Highway at Yarriambiack Creek gauge, previous studies and the recent high flow event recorded in January 2011 has resulted in a complex calibration and design hydrology and hydraulics process required for this project. The lack of certainty surrounding the flows distributed to Yarriambiack Creek has led to a methodology which links the hydrology and hydraulics to achieve the highest possible certainty in flows distributed and therefore in the final modelled water levels and extents.

The January 2011 event was chosen as the primary source of hydraulic model calibration because of its size, significance to the local community and the amount of recent calibration data available. The September 2010 event was used as a verification event.

The determination of calibration and design flows was completed using gauge records, a combination of hydraulic models and Flood Frequency Analysis (FFA).

This section of the report breaks the project hydrology and hydraulics components into the following sections:

- Methodology – Outline of the hydrology and hydraulics methodology.
- Hydraulic Model Construction/Simulation – What models were utilised and how each model was constructed for each component of the project and why.
- Calibration – Determination of calibration flows and the model calibration process.
- Design – Determination of design flows for the study area and a preliminary 1 % AEP extent.
- Discussion – Discussion of the methodology undertaken.

7.2 Methodology

To determine reliable calibration and design flows a strong emphasis was placed on improving our understanding of the flows distributed to Yarriambiack Creek from the Wimmera River. This involved the following steps:

- Confirm/redefine January 2011 flows at the Yarriambiack Creek at Wimmera Highway streamflow gauge by the construction of a localised hydraulic model at the gauge and review of the current rating curve.
- Test current and redefined flows at the Wimmera Highway streamflow gauge across the study area for the January 2011 event comparing to surveyed peak flood heights and aerial imagery.
- Refine the hydraulic model calibration for the January 2011 event based on the redefined flows.
- Model the September 2010 event using the constructed rating curve
- Determine design flows based on the Wimmera River at Glenorchy streamflow record, URBS model of the Mt William Creek catchment, Mt William Creek Flood Investigation design flows, FFA and historic flow distribution.

Design modelling will be completed post review of the methodology by Wimmera CMA, Yarriambiack Shire Council, the Steering Committee and the Department of Environment, Land, Water and Planning (DELWP) technical review panel.

7.3 Hydraulic Model Construction/Simulation

7.3.1 Yarriambiack Creek at Wimmera Highway – Gauge Model

To gain a more thorough understanding of flows distributed to Yarriambiack Creek, a revised rating curve at the Wimmera Highway at Yarriambiack Creek gauge was developed using a hydraulic model of the gauge location. A model of the gauge was constructed during the Wimmera River and Yarriambiack Creek Flows Study[8], as discussed in Section 5.2.2. This model included the Main Western Channel which was decommissioned in late 2010 as discussed in Section 5.1.2. The removal of the channel resulted in the hydraulic model not covering a sufficient area representing all floodplain flows.

To ensure the topographic information available was as accurate as possible feature survey was captured of the Wimmera Highway and the Yarriambiack Creek culvert. Survey included four cross sections of Yarriambiack Creek, the Wimmera Highway road deck level and culvert details (obvert, invert, width etc.). The survey undertaken is shown in Figure 7-1.

The model was constructed using MikeFlood, utilising both 2D (floodplain) and 1D elements (culvert structure and downstream boundary). The model was constructed based on the 2005 LiDAR dataset with feature survey incorporated at the Wimmera Highway. The model was constructed with a 3 m topographic resolution with the model schematisation shown in Figure 7-2. The Wimmera Highway culvert was represented in 1D with the 2D domain linking to a short 1D branch of Yarriambiack Creek with a flow-height relationship at the end of the model as the downstream boundary.

Figure 7-1 Yarriambiack Creek at Wimmera Highway – Feature Survey

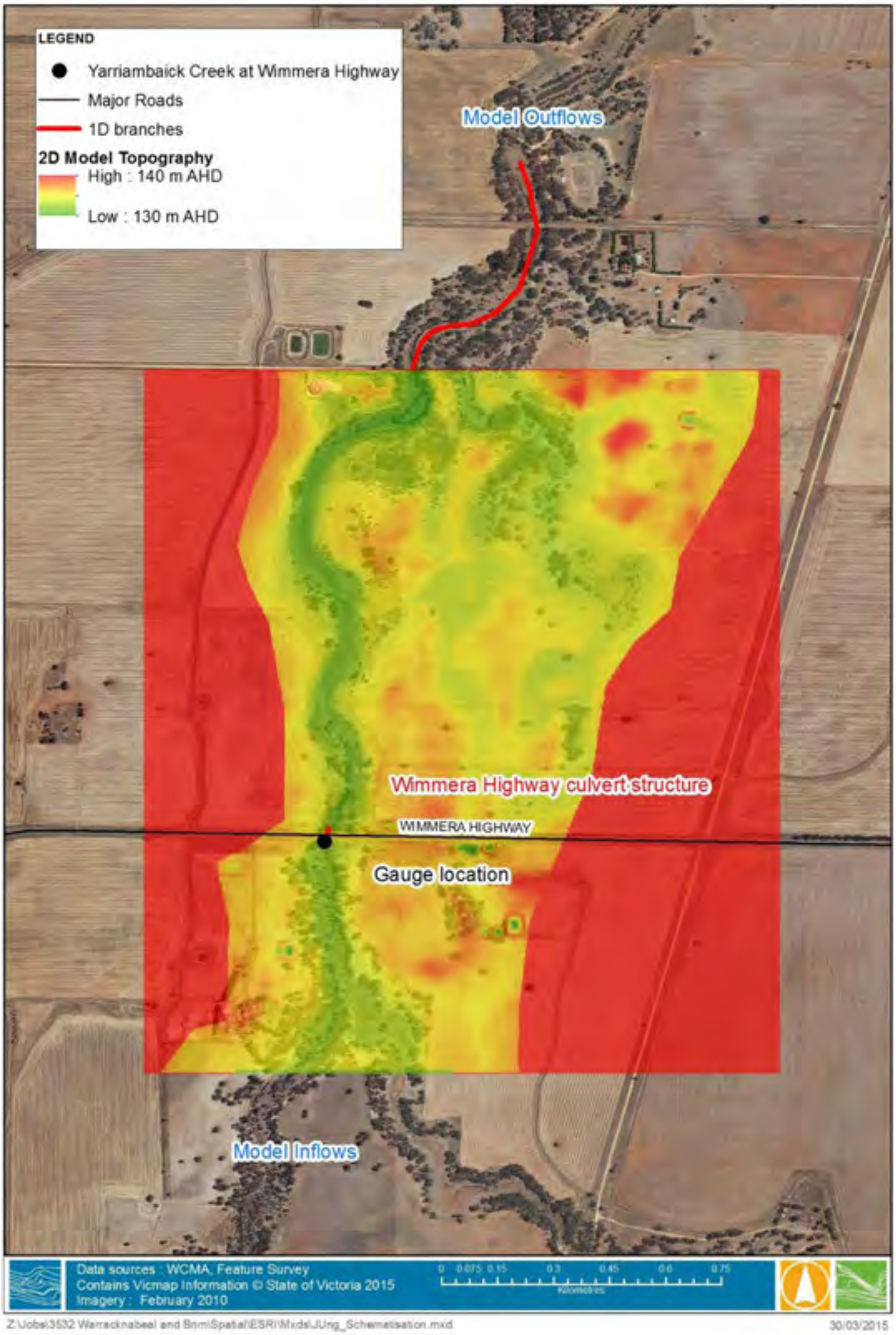


Figure 7-2 Yarriambiack Creek at Wimmera Highway – Hydraulic Model Structure

7.3.2 Wimmera River – Yarriambiack Creek distribution

The Wimmera River to Yarriambiack Creek flow distribution was defined during the Wimmera River Yarriambiack Creek Flows Study[8]. As discussed in Section 5.2.2, a series of models spanning from Glenorchy to Horsham and Yarriambiack Creek from the offtake to upstream of Warracknabeal were developed. The model also covered Mt William Creek downstream of Dadswells Bridge. The Mt William Creek Flood Investigation[12] also covered Mt William Creek in which flows at Dadswells Bridge were determined for the January 2011 event as well as the full range of design events to be modelled in this project. The calibration of the Mt William Creek RORB model used varying Kc and loss values across five interstation areas. The Kc values varied between 12-70 while initial and continuing losses varied from 0 mm to 110 mm and 0 mm/hr to 6.9 mm/hr respectively.

A schematisation of the model inflows and distribution to Yarriambiack Creek is shown in Figure 7-3.

This model was used as an additional comparison point for flows at the Wimmera Highway gauge during January 2011 and to assist in the determination of design flows entering the study area.

[12] WBMBMT - Mt William Creek Flood Investigation (2014)

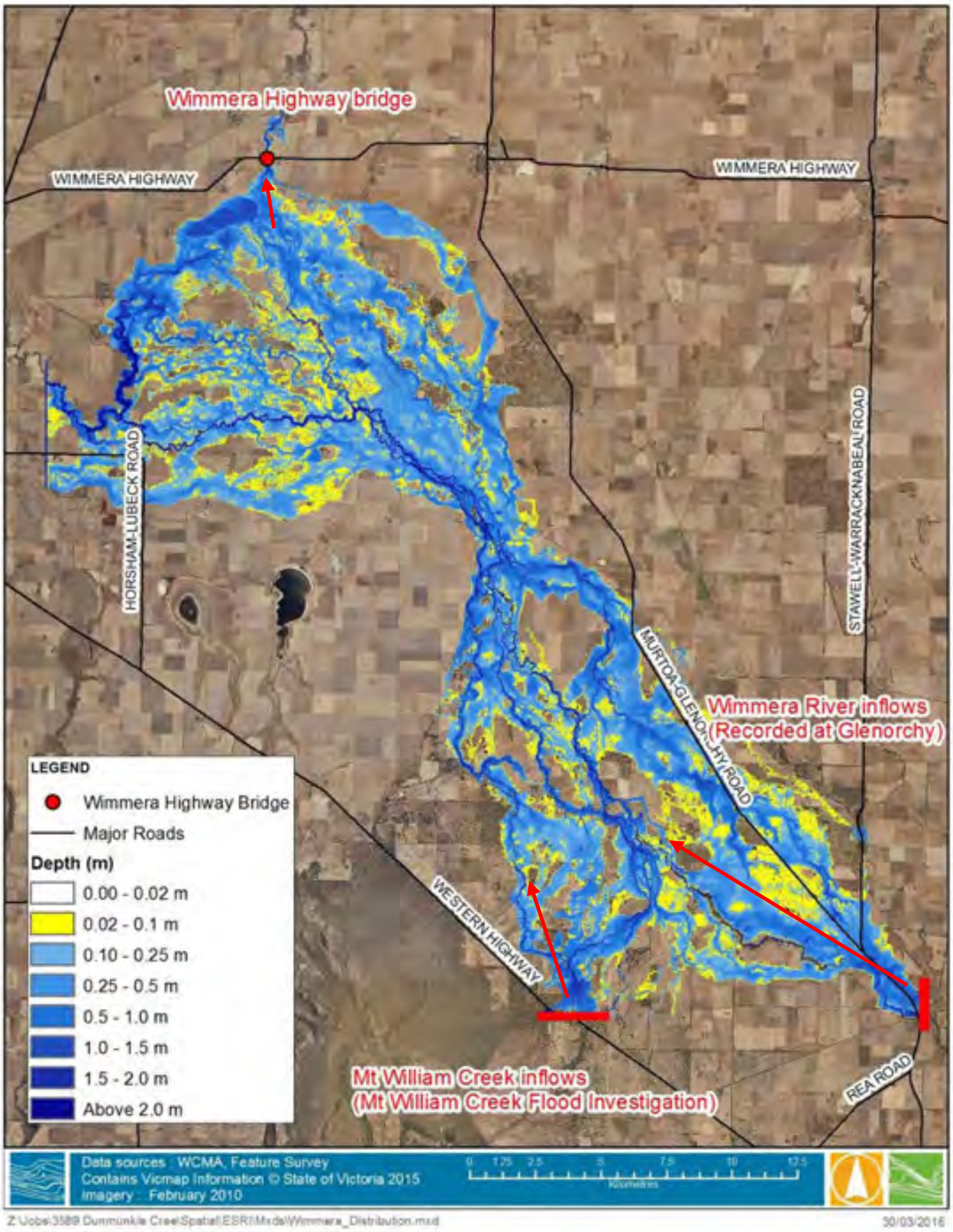


Figure 7-3 **January 2011 – Hydraulic model structure Wimmera River at Glenorchy to Yarriambiack Creek at Wimmera Highway and Mt William Creek at Dadswells Bridge to Mt William – Wimmera River confluence**

7.3.3 Study area floodplain model

Modelling of the study area was completed in Mike Flexible Mesh. A mesh of the study area's topography was developed utilising the 2005 Wimmera CMA LiDAR dataset as the base topographic dataset, with the Warracknabeal township covered by the 2010 ISC Data. The Yarriambiack Creek channel through Warracknabeal was represented using the 2005 Warracknabeal township LiDAR, as discussed in Section 4.3.

Flexible Mesh models are comprised of triangular or quadrilateral elements. Yarriambiack Creek and the surrounding floodplain were modelled using a square 6 m resolution mesh, with the townships of Brim and Warracknabeal and Brim modelled using a square 3 m resolution mesh. The model extent and resolutions are shown in Figure 7-4.

Features that were not accurately represented in the model topography due to the model resolution (road crests, channel embankments, levees) were inserted using the Dike feature in Mike Flexible Mesh or by direct changes to the mesh itself. The following additional detail was inserted to the topography:

- Wimmera Highway
- Jung Weir
- Banyena Road
- Horsham Minyip Road
- Dimboola Minyip Road
- Ailsa Road
- Borung Highway
- Warracknabeal Weir
- Brim Weir

Several channels which were observed to block flow during January 2011 were removed from design modelling scenarios if they had since been decommissioned.

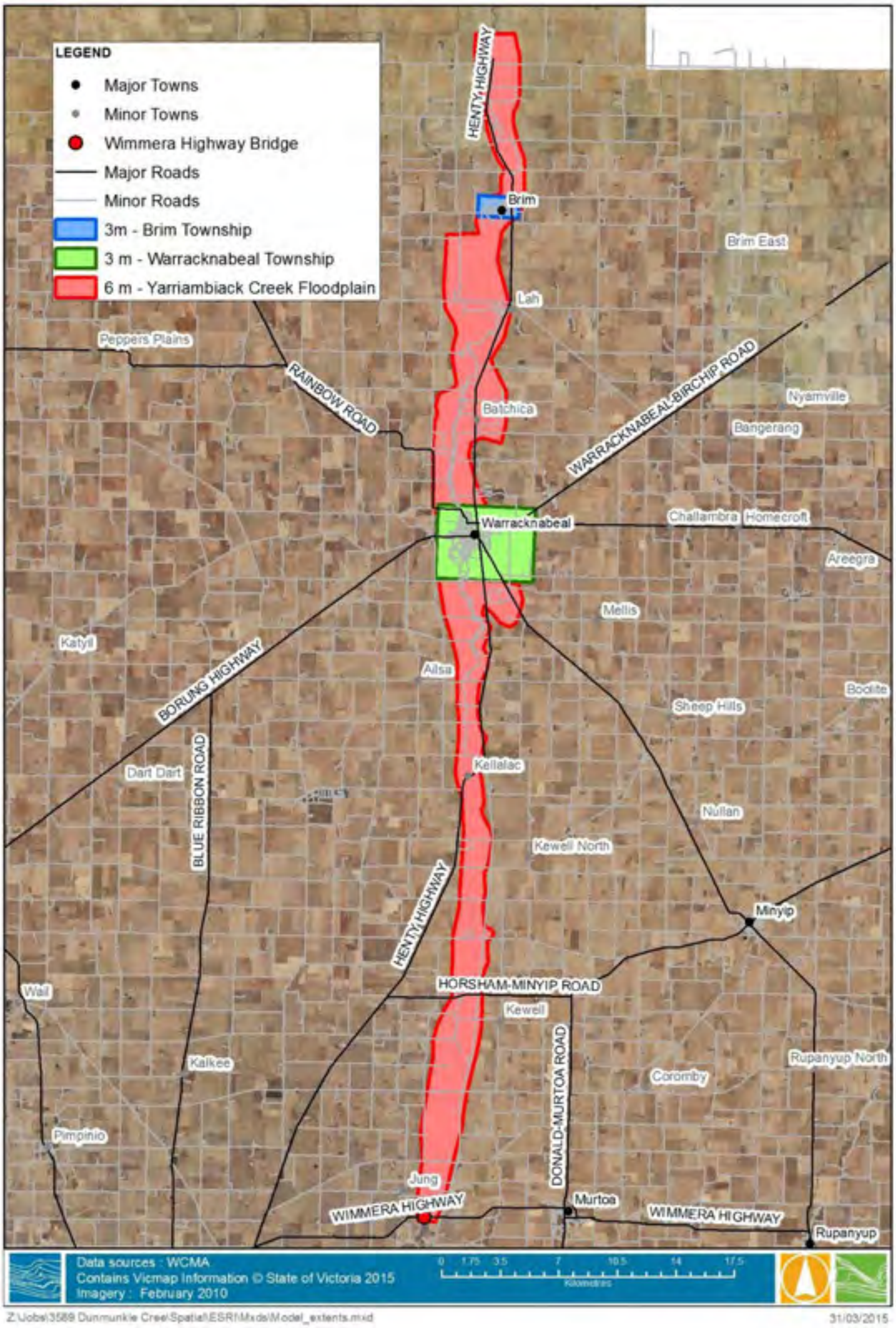


Figure 7-4 Yarriambiack Creek model extent and mesh resolutions

7.4 Hydraulic Model Calibration

7.4.1 Overview

During this project the January 2011 event was used as the main source of calibration, this was followed by calibration to the September 2010 event. As discussed previously the January 2011 event caused extensive flooding across the Wimmera region and is broadly regarded as larger than the 1% AEP event across most areas upstream of Horsham. The September 2010 event was somewhat smaller than January 2011 with the majority of the rainfall occurring in the upper catchment with significant inflows from tributaries downstream of Concongella Creek.

7.4.2 January 2011

Estimating the Yarriambiack Creek Flow

The Wimmera Highway gauge model was used to develop a revised rating curve for the Yarriambiack Creek at Wimmera Highway streamflow gauge. Initially, the revised rating was intended to match the current adopted rating at lower flows for which gaugings have been undertaken. However, this could not be achieved regardless of the roughness used and culvert assumptions made. This will be discussed further later in this section.

Once it became apparent matching the current rating curve was not possible, the broader Yarriambiack Creek floodplain model was tested using the current adopted January 2011 hydrograph to broadly test how the gauged flows and observed peak water levels matched. The comparison indicated the current flow estimates of the January 2011 event were well below that which actually occurred. A comparison of the modelled extent overlayed on aerial imagery captured during January 2011 is shown in Figure 7-5, showing a significant underestimation.

Due to the large difference in observed inundation and model results using the January 2011 gauged flows the revised rating curve determined by the Wimmera Highway gauge model was used to determine a revised January 2011 hydrograph.

A comparison of the current and revised rating curve is shown in Figure 7-6, the peak level achieved during January 2011, culvert obvert and Wimmera Highway road deck height are also shown.

The hydraulic model generated rating curve is quite different than the current rating. The modelled rating curve shows several changes in grade, where the water level and flow rate relationship changes. The currently adopted rating curve is very smooth but when compared to the historic gaugings does not show a strong correlation, Figure 5-4. These differences are due to the method used to determine each curve:

- The current adopted rating is based on a series of measured heights and flow rates where a generalised curve is fitted to these observations, the curve is representative of the best fit to the range of measured data. The gaugings were all taken between 1978 and 1988. Significant change could have occurred to the channel at the gauge site since the gaugings.
- The hydraulic model derived rating curve is based on the hydraulic constraints at the site represented in the model. The most notable differences in the rating curves is the increase in grade once the culvert obvert is exceeded and the significant decrease in grade once the Wimmera Highway road deck level is exceeded. This reflects accurately the actual behaviour of a river upstream of a bridge structure. When water levels hit the bridge infrastructure water levels increase rapidly as flow increases due to the blockage, once water levels overtop the road the water level increase is much smaller because the floodplain capacity is much larger than the waterway opening under the bridge.

As an additional test to further confirm the appropriateness of the Yarriambiack Creek January 2011 flow estimate, the Wimmera River and Yarriambiack Creek[8] model was run. This model simulation used the Wimmera River hydrograph at Glenorchy and the Mt William Creek flows as upstream boundaries to the model and extracted the modelled flow at the Wimmera Highway Bridge gauge.

For the January 2011 event the model predicted a peak flow of 69.8 m^3/s (6,030 ML/d) as distributed to Yarriambiack Creek.

A comparison of the recorded flows at the Wimmera Highway Bridge using the current rating curve, the revised rating curve and the modelled flow distributions to Yarriambiack Creek by the model developed during the Wimmera River and Yarriambiack Creek Flow Investigation[8] are shown in Figure 7-7, with a peak flow comparison shown in Table 12.

Figure 7-5 Yarriambiack Creek floodplain model – January 2011 gauged flow flood extent

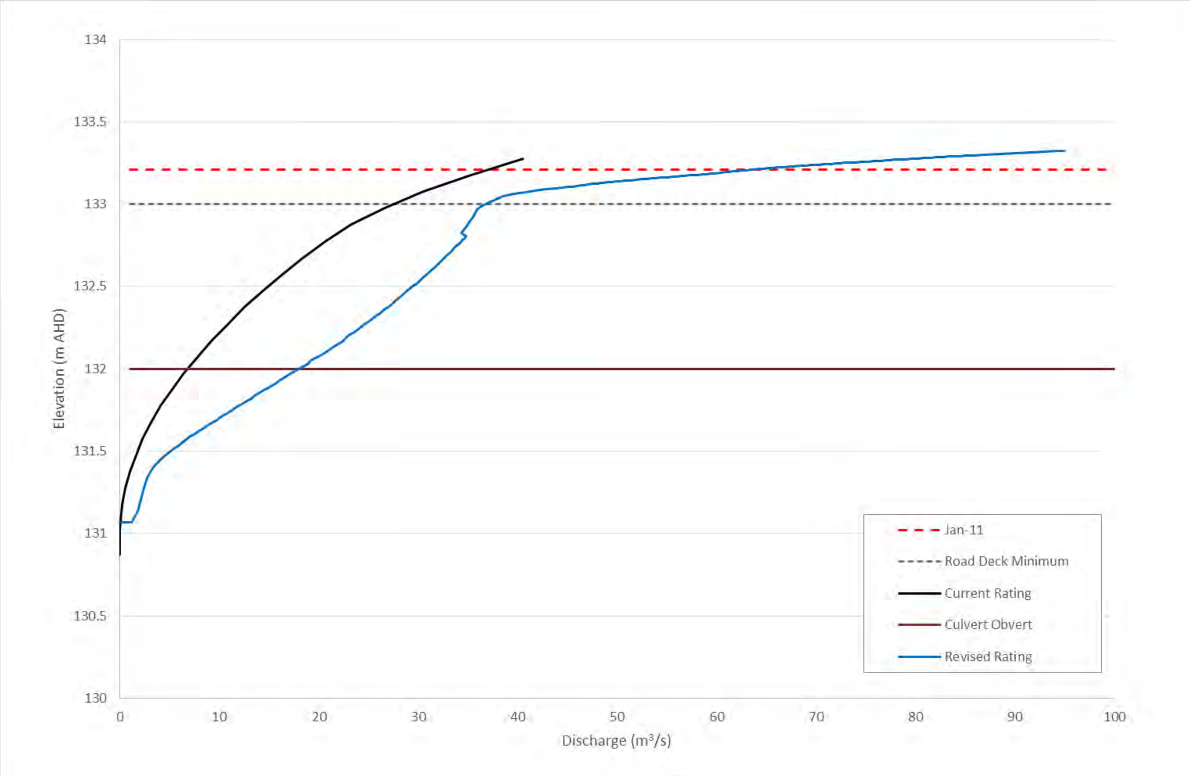


Figure 7-6 Yarriambiack Creek at Wimmera Highway – Current and revised rating curves

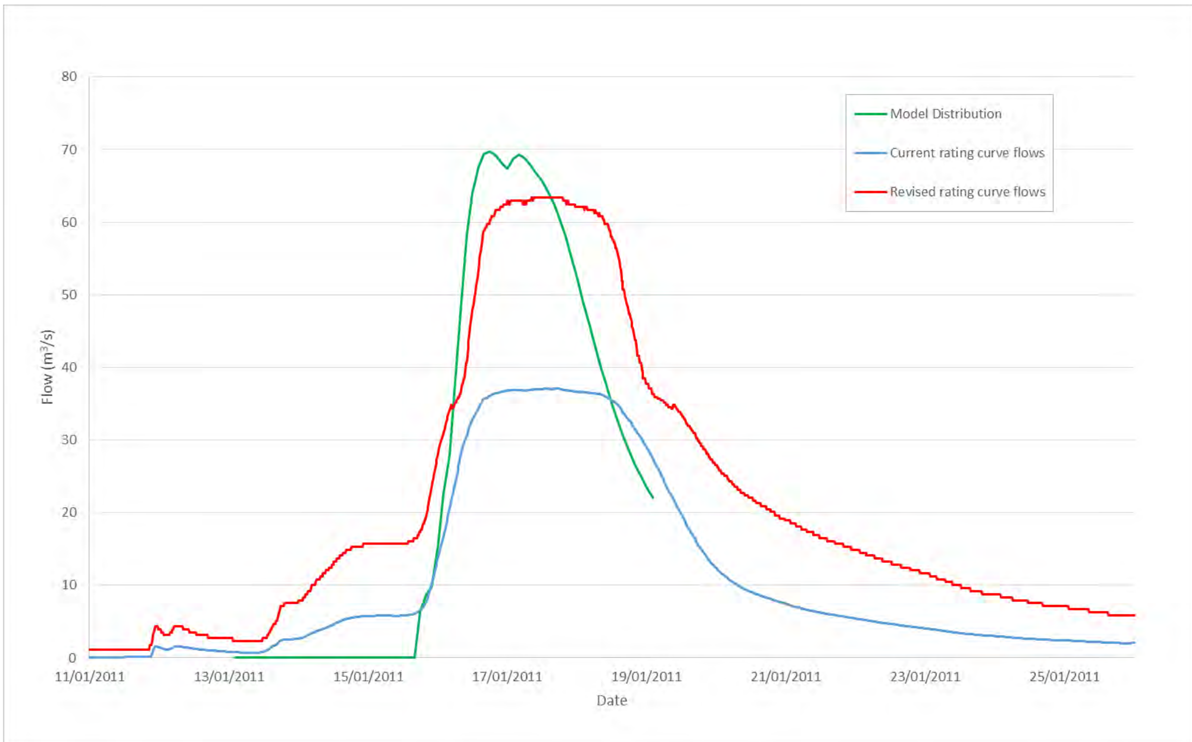


Figure 7-7 January 2011 – Flows at the Yarriambiack Creek at Wimmera Highway for the current rating curve, revised rating curve and hydraulic model distribution

Table 12 January 2011 – Peak flow estimate comparison for Yarriambiack Creek at Wimmera Hwy Gauge

	Current Rating Curve	Revised Rating Curve	Wimmera River modelled distribution
Peak flow (m^3/s)	30.4 (2,627 ML/d)	63.4 (5,478 ML/d)	69.75 (6,026 ML/d)

The peak water level recorded at the Wimmera Highway gauge was 133.21 m AHD. The modelled Wimmera River and Yarriambiack Creek January 2011 event produced a water level at the gauge location of 133.24 m AHD, just 0.03 cm greater than that observed at the gauge. This further verifies that the currently adopted rating curve and Yarriambiack Creek flow of 30.4 m^3/s (2,627 ML/d) for the January 2011 flood event is a significant underestimate, and that the revised rating curve is estimating flow far more accurately.

Verifying the Yarriambiack Flow and Calibrating Hydraulic Model

The broader Yarriambiack Creek floodplain model was run for the January 2011 event, with flows derived from the revised rating curve. The model results showed that using the revised rating curve the observed inundation extent and observed flood heights matched well. The model calibration was completed with a constant roughness of 0.04 Manning's 'n'. This is consistent with an average value used for cultivated areas[13] and considered appropriate for use in this project.

As discussed in Section 5.3.4 there were two sets of peak flood level calibration points captured by Wimmera CMA. An initial dataset captured by Ferguson and Perry Surveying immediately post the January 2011 event and a second set highlighted by members of the community captured during the initial stages of this project. Given several years have passed since the January 2011 event Water Technology view the Ferguson and Perry Surveying peak flood heights as more accurate than those captured more recently.

The Ferguson and Perry dataset included 24 flood marks spread across Yarriambiack Creek and the entire study area. The model calibration of the January 2011 event matched all of the observed flood heights within 0.25 m. Table 13 shows the range of differences between the modelled and surveyed peak flood heights with a graphic representation shown in Figure 7-8.

Table 13 January 2011 – Ferguson and Perry Surveying peak flood height comparison

Difference (Modelled – Observed)	No. of points within classification
-0.25 m to -0.2 m	3
-0.2 m to -0.15 m	0
-0.15 m to -0.1 m	1
-0.1 m to 0.1 m	20

Figure 7-8 identifies the locations of the three points where the difference between the modelled and observed levels is greater than 0.1 m as area A and B. A closer perspective of these areas is shown in Figure 7-9 and Figure 7-10 respectively.

[13] Chow – Open Channel Hydraulics (1941)

Figure 7-8 January 2011 – Ferguson and Perry Surveying peak flood height comparison

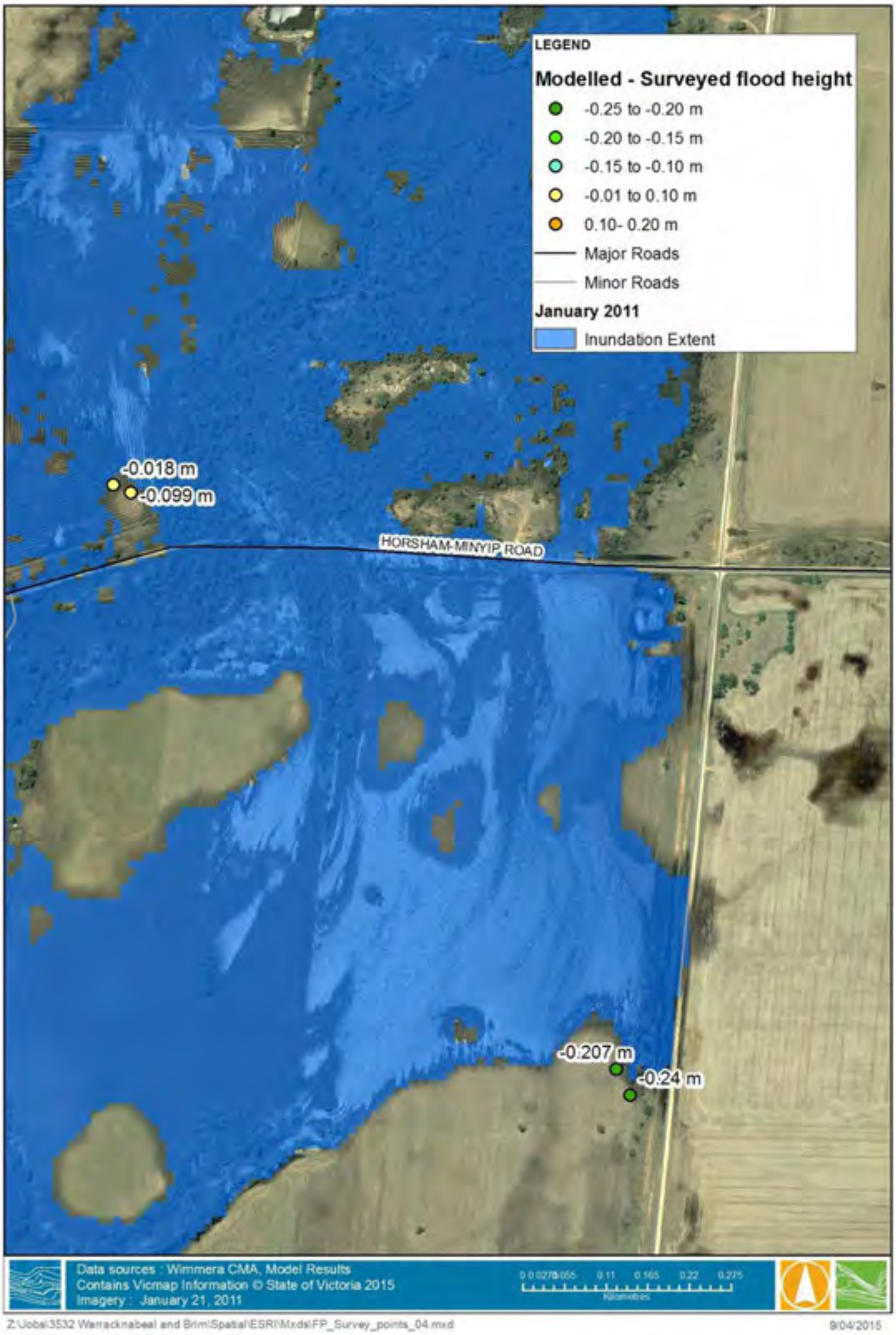


Figure 7-9 January 2011 – Ferguson & Perry Surveying peak flood height comparison – Area A

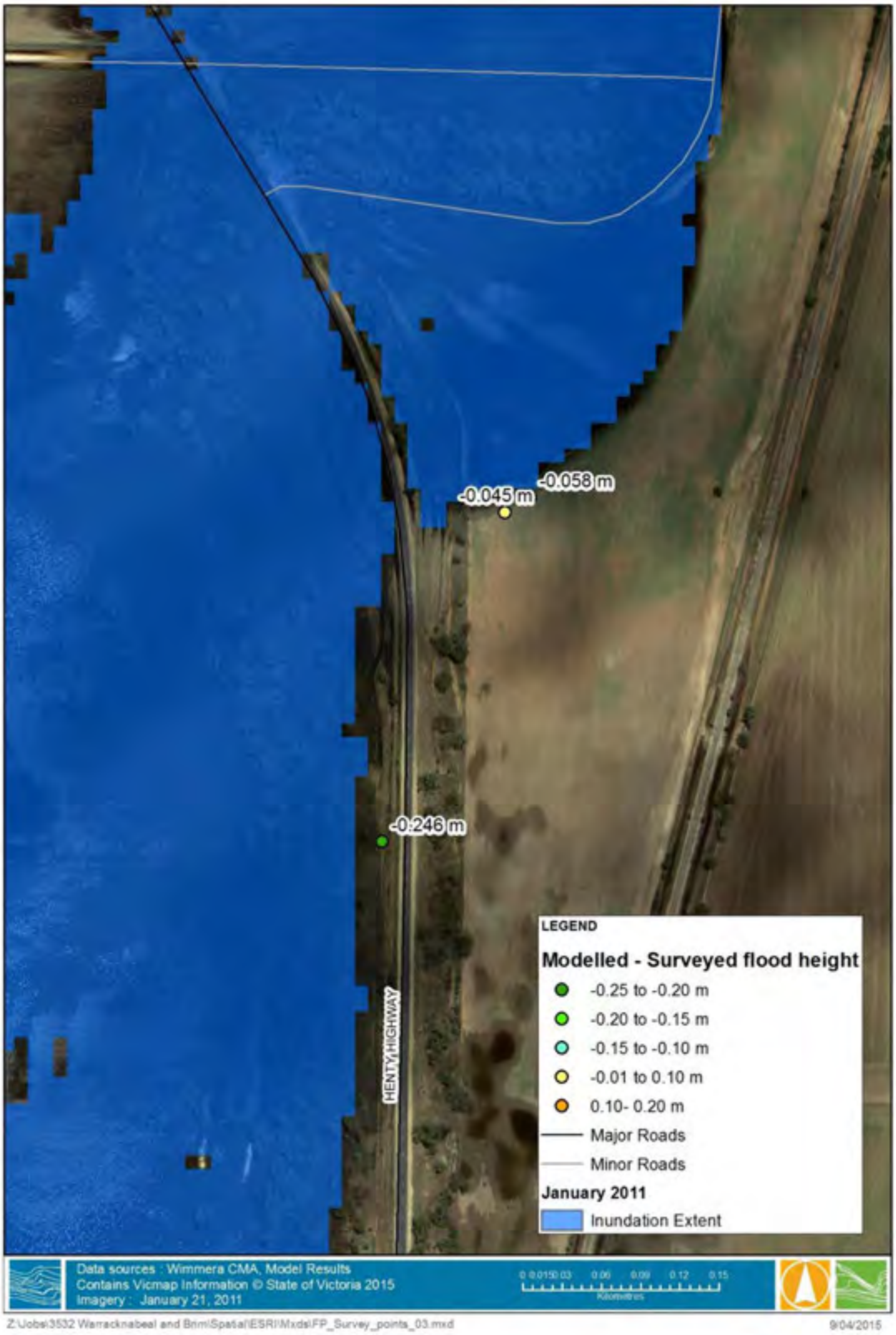


Figure 7-10 January 2011 – Ferguson & Perry Surveying peak flood height comparison – Area B

The community highlighted dataset included 15 flood marks all downstream of Warracknabeal. The model calibration of the January 2011 event matched all of the observed flood heights within 0.5 m. Table 14 shows the range of differences between the modelled and surveyed peak flood heights with a graphic representation shown in Figure 7-11.

Table 14 January 2011 – Community collected peak flood height comparison

Difference (Modelled – Observed)	No. of points within classification
-0.5 m to -0.25 m	4
-0.25 m to -0.2 m	1
-0.2 m to -0.15 m	0
-0.15 m to -0.1 m	1
-0.1 m to 0.1 m	4
0.1 m to 0.15 m	1
0.15 m to 0.2 m	0
0.2 m to 0.25 m	2
0.25 m to 0.5 m	2

Figure 7-11 identifies the locations of points where the difference between the modelled and observed levels is greater than 0.2 m as area A, B, C, D and E. A closer perspective of these areas is shown in respectively.

Area A shows two points in close proximity up and downstream of Batchica West Road. Downstream of the surveyed levels match the model results closely, while model results upstream of Batchica West Road are more than 0.4 m above that surveyed. A closer inspection of the surveyed levels showed the downstream level was 103.40 m AHD, while the upstream surveyed level was 102.91 m AHD. Given the surveyed upstream level is lower than that downstream it is obvious some error with the surveyed points has occurred. The modelled flood extents in this area exceed the aerial imagery captured, however the imagery available is only for the 19th January and the peak flood levels at this location are expected to have occurred sometime after this.

Area B shows a cluster of four points with the modelled level lower than that surveyed. Two within 0.1 m and one outside 0.25m. There is also a surveyed point to the west of Yarriambiack Creek which appears to be disconnected from the main riverine inundation. This point is most likely a result of direct stormwater pooling.

Area C focuses on the Brim township with two points both showing the model results are higher than the observed levels. The model extents in this area match the aerial photography captured on the 21st January. In the vicinity of the Brim Recreation Reserve Clubroom LiDAR levels indicate the topography at the inundation edge was around 94.85-94.90 m AHD. The surveyed level at this location (water tank) was 94.37 m AHD. The modelled level at this location was 94.89 m AHD. This indicates the surveyed level at the tank is not reflective of the peak water level.

Area D includes two surveyed flood heights. One showing the model results to be lower than that surveyed, the other higher. The aerial imagery in this area shows a good match with the model results.

Area E includes three surveyed flood heights, one matching the modelled results closely and two where the model results are more than 0.25m lower than the surveyed levels. The model extents are showing slightly less inundation than that observed in aerial photography captured on the 21st. At the second most southern point the LiDAR levels at the inundation extent are approximately 91.75-91.80 m AHD. This compares to a surveyed level of 91.85 m AHD and a modelled level of 91.59 m AHD.

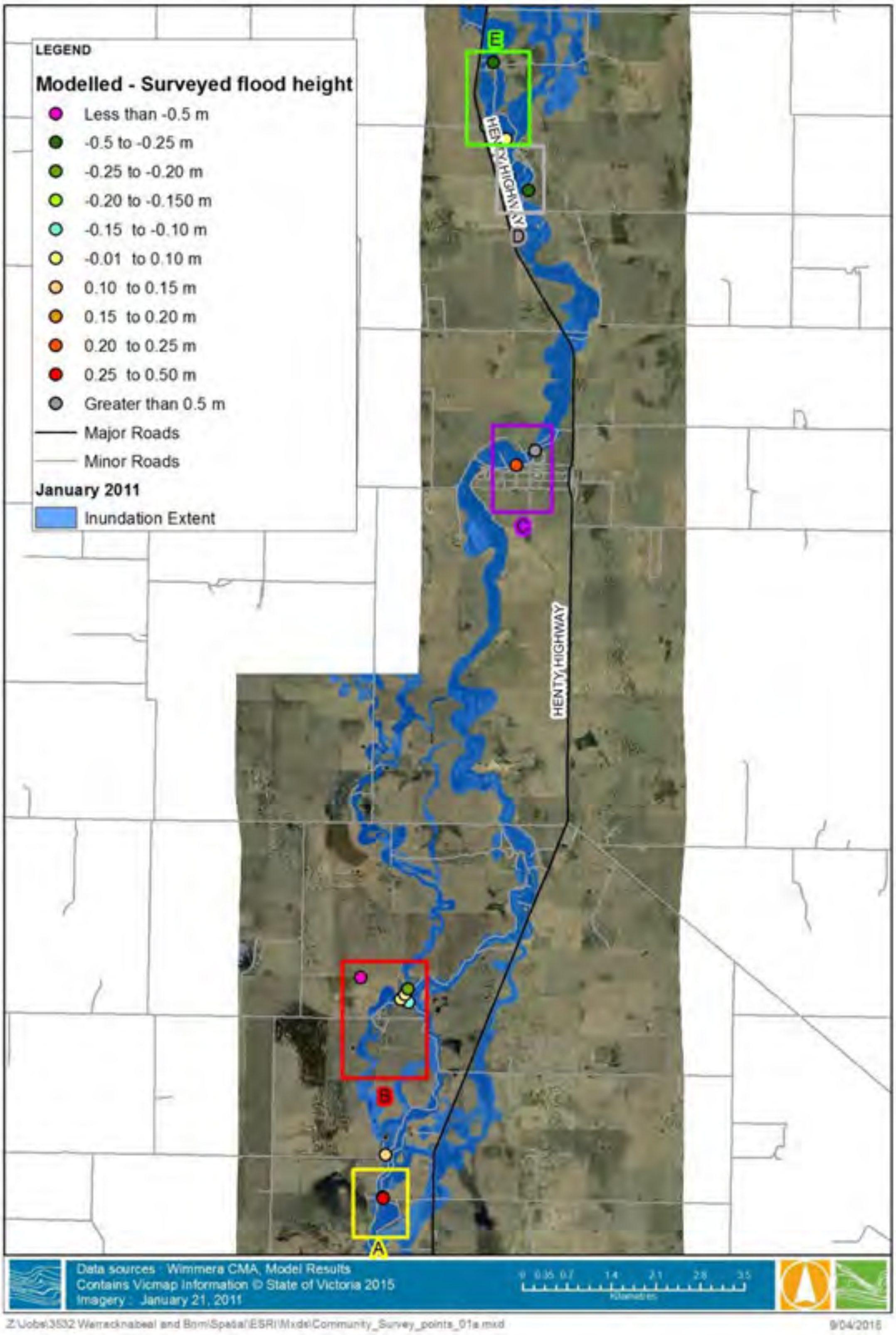


Figure 7-11 January 2011 – Community Collected Surveying peak flood height comparison

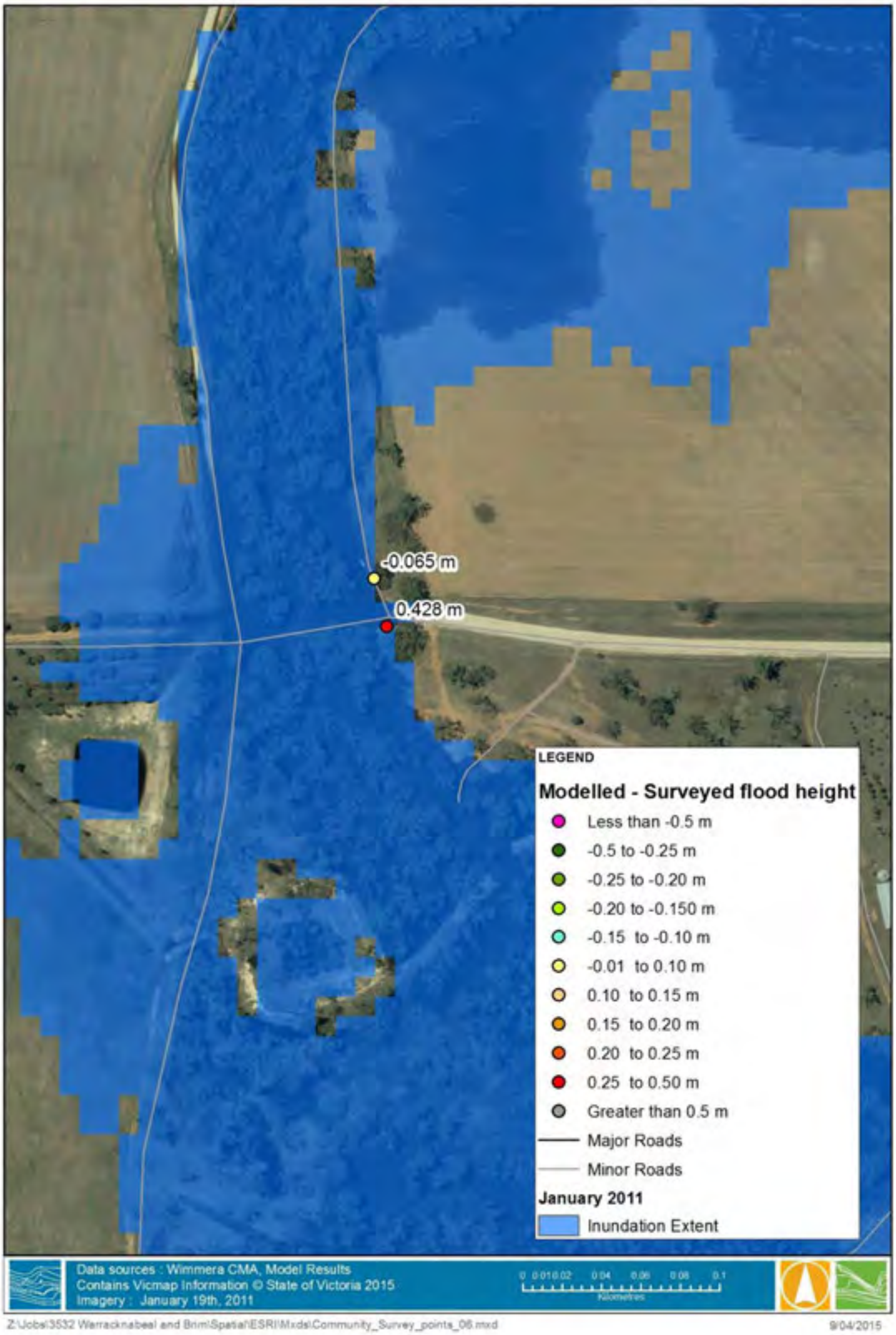


Figure 7-12 January 2011 – Community Collected Surveying peak flood height comparison – A

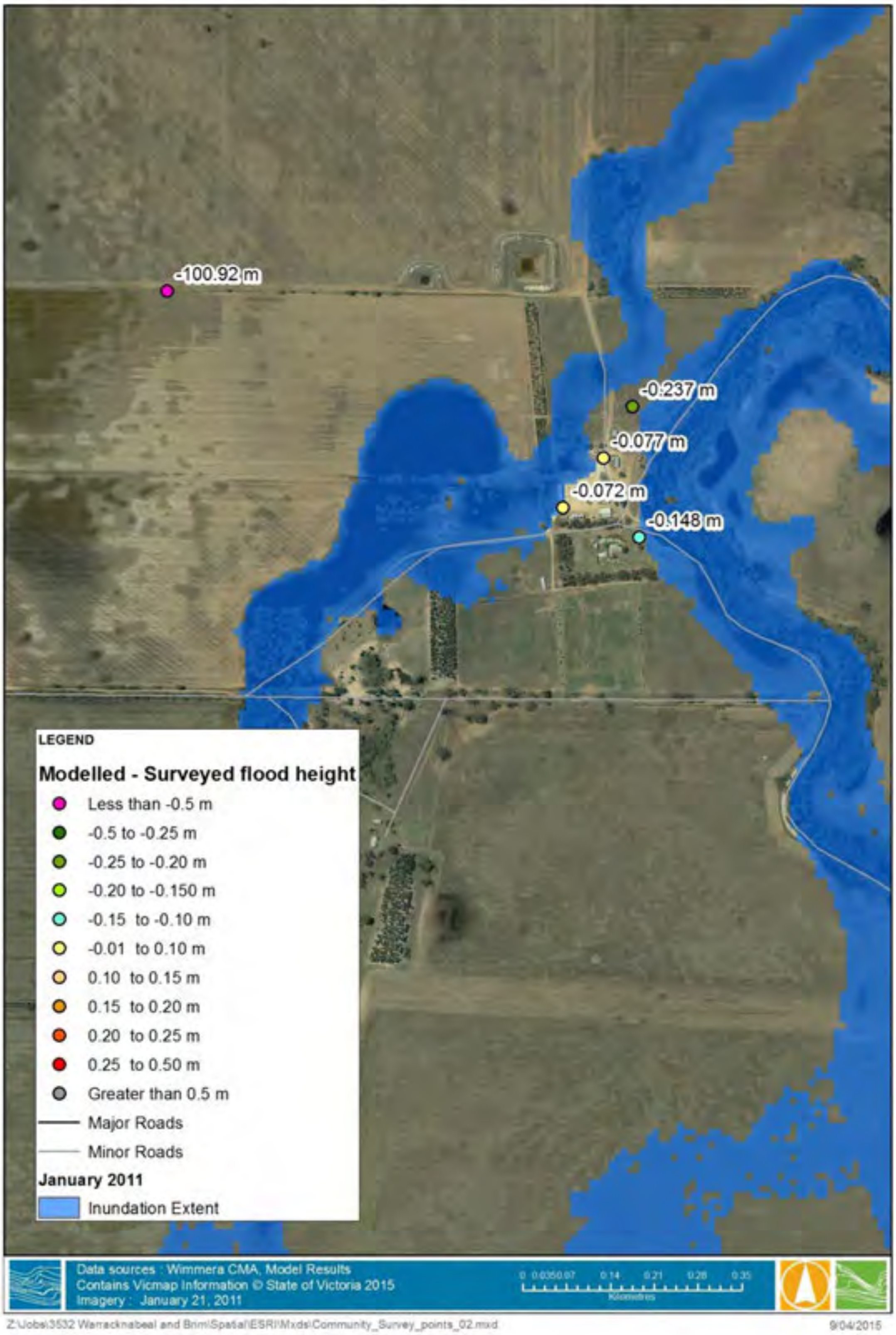


Figure 7-13 January 2011 – Community Collected Surveying peak flood height comparison – B

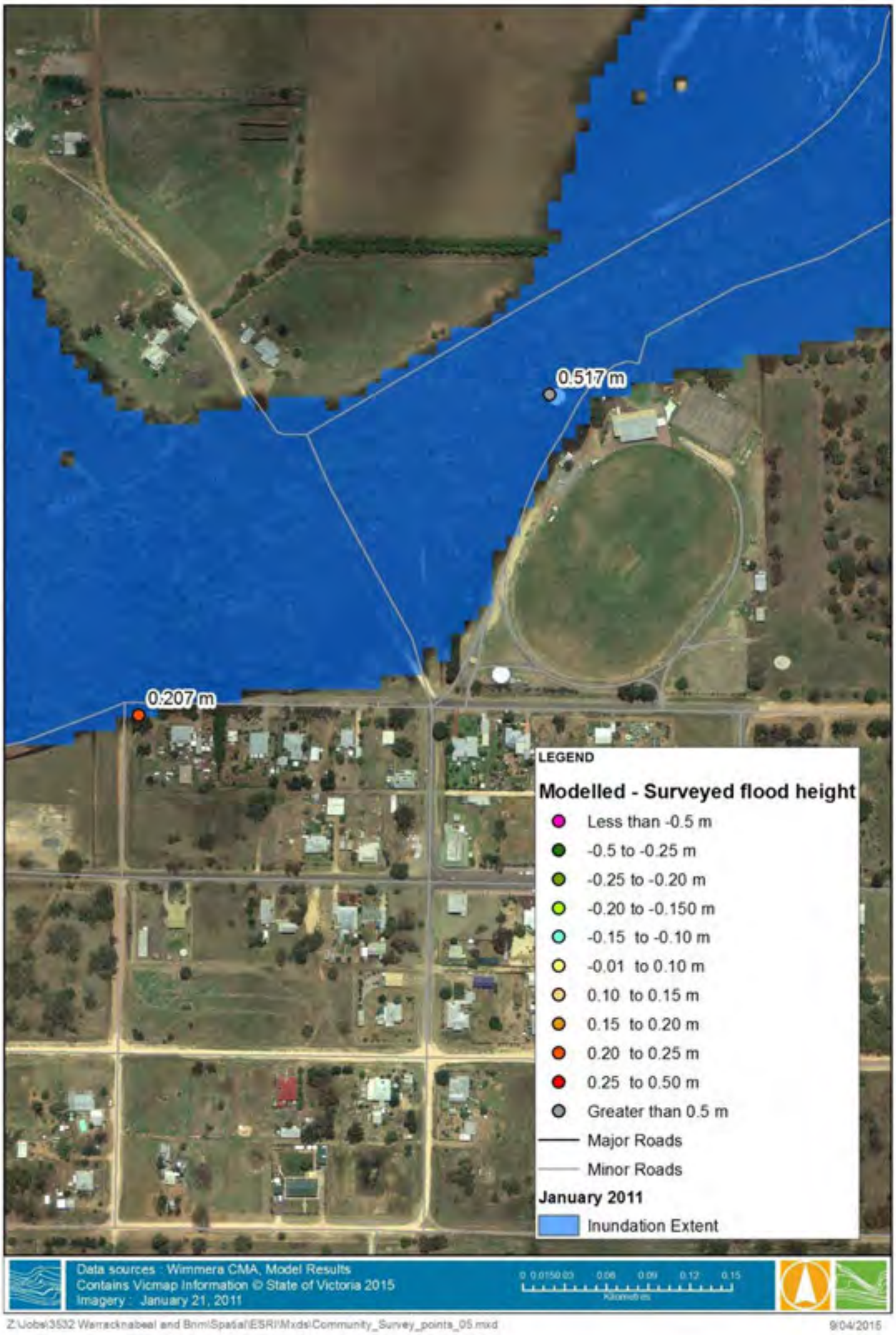


Figure 7-14 January 2011 – Community Collected Surveying peak flood height comparison – C

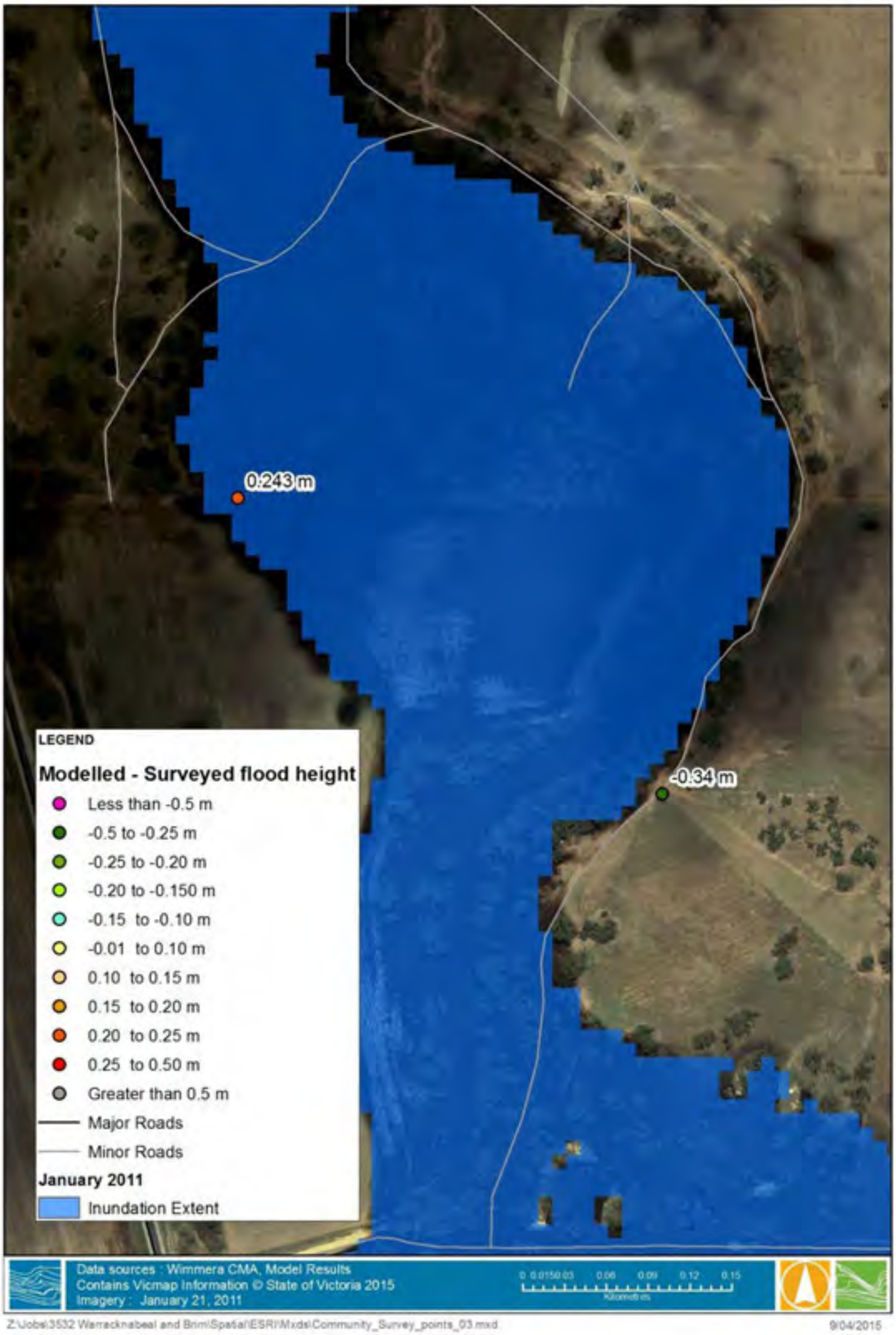


Figure 7-15 January 2011 – Community Collected Surveying peak flood height comparison – D

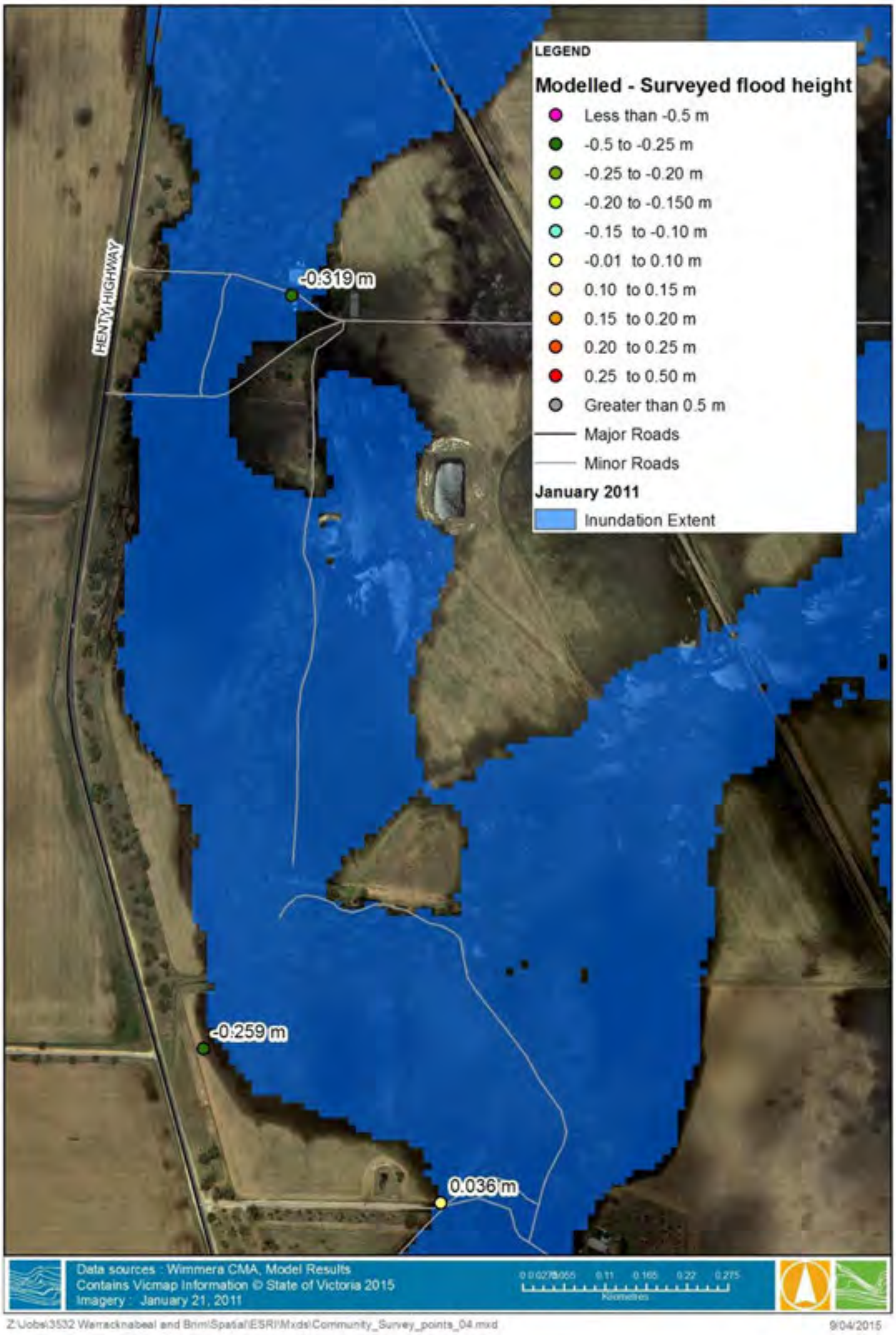


Figure 7-16 January 2011 – Community Collected Surveying peak flood height comparison - E

Discussion

The revised rating curve for the Yarriambiack Creek at Wimmera Highway gauge was able to better represent the January 2011 peak flow, this was shown by the general match to the observed flood extents and surveyed peak flood heights during the January 2011 event. This was also verified using the Wimmera River and Yarriambiack model simulation of the January 2011 event. Given the current Wimmera Highway rating is based on only a limited number of flow observations the last of which was completed in 1988, the revised rating curve is considered to give a more accurate representation of high flows. This is reinforced by the reality that significant topographic changes have occurred in direct proximity to the gauge since the last rating.

The hydraulic model is accurately modelling the January 2011 levels and extents covering the entire study area. This is best shown by comparison to the Ferguson and Perry Surveyed levels. The community collected survey points showed an inconsistent match to modelled levels. This is likely to be due to the error surrounding some points. However, the accuracy of these points will be discussed with Wimmera CMA.

In general the hydraulic model is considered to represent the January 2011 flows, water levels and extents closely.

7.4.3 September 2010

Overview

The September 2010 event was recorded at the Yarriambiack Creek at Wimmera Highway gauge. It was the fourth highest peak level recorded behind 2011, 1983 and 1981. The gauge recorded a level of 1.467 m and a flow of 11.0 m^3/s (1,035 ML/d using the current rating curve) at 11:15 pm on the 5th September. The revised rating curve determined during the January 2011 calibration estimated a peak flow 26.2 m^3/s (2,264 ML/d). Rainfall in Warracknabeal occurred in the 24 hrs prior to 9am on the 4th September, with 37.4 mm recorded at the Warracknabeal Museum Gauge.

There were 22 peak flood heights surveyed along Yarriambiack Creek post the September 2010 event, their locations are shown in Figure 7-17. All of the points are located between Warracknabeal and Kellalac.

Figure 7-17 September 2010 surveyed peak flood heights

Upstream of Kellalac a series of point based aerial photos were captured in the morning of the 8th September 2010. These photos give a reference for how well the model results are representing the observed flooding in this area. The photo locations available are shown in Figure 7-18

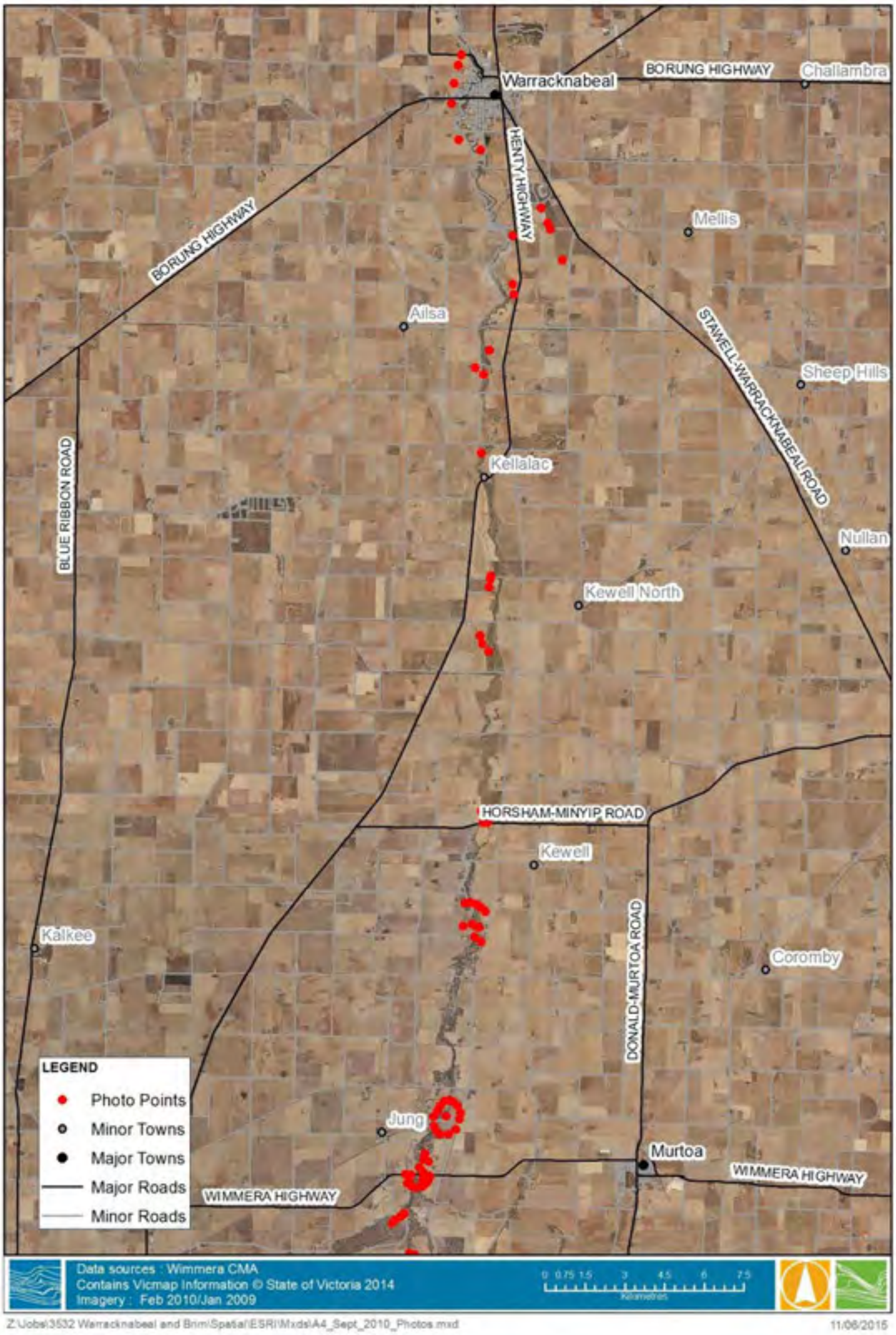


Figure 7-18 September 2010 – Aerial photograph locations

The exact timing of the Main Western channel decommissioning is unknown but it did occur prior to the September 2010 event, as shown in Figure 7-19. This confirms the revised rating curve can be used to estimate the September 2010 flows.

Figure 7-19 September 2010 – Aerial photography captured at the Wimmera Highway Bridge

Calibration

During the model calibration process the hydraulic model was run using both the recorded hydrograph (current rating) and revised hydrograph (revised rating). The two hydrographs are shown below in Figure 7-20.

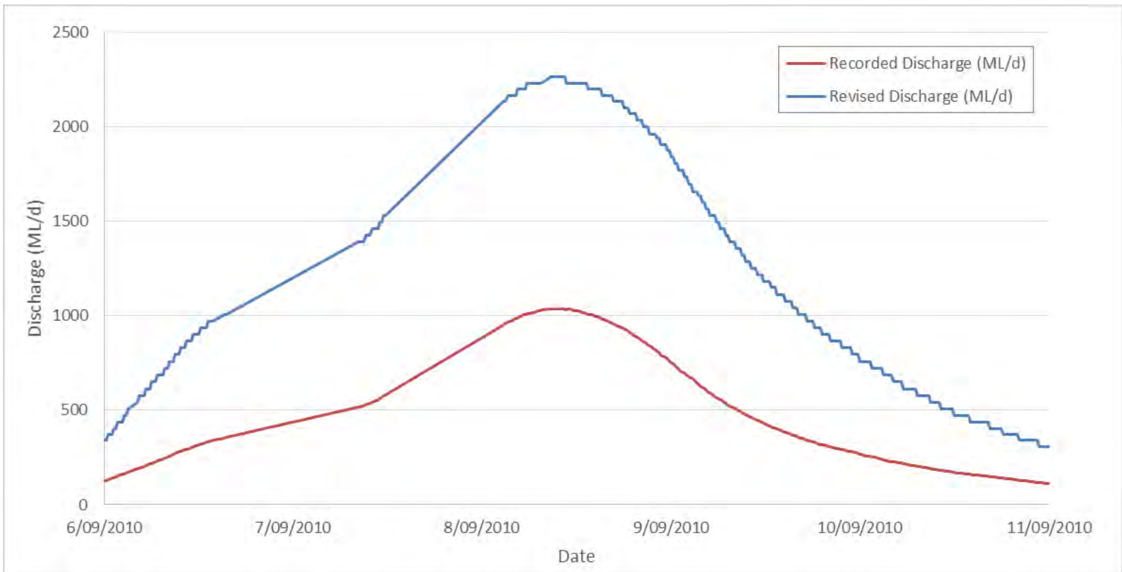


Figure 7-20 September 2010 recorded and revised hydrographs

The modelled extents and water levels using the recorded hydrograph were consistently lower than that observed. Of the 22 surveyed points available the modelled results were lower than the surveyed levels in 16 instances. The average difference between modelled and surveyed levels was -0.17 m.

The difference in the observed and modelled survey heights is shown in Figure 7-21, levels match well around Kellalac but are low in the Warracknabeal township.

When modelling was completed using the September 2010 hydrograph generated from the revised rating curve the model results were consistently higher than that observed. With the modelled results higher than that surveyed at all locations with an average difference between the surveyed and modelled levels of 0.25 m. The difference in modelled and observed maximum flood heights is shown in Figure 7-22.

Given the recorded flows (current rating) and revised flows (revised rating) are generally not matching the surveyed levels with a bias to being too low and too high respectively downstream of Kellalac, a comparison of the modelled extents was made against aerial photography. The comparison was made in close proximity to the model upstream boundary in two locations shown in Figure 7-23 and Figure 7-24.

The model extents generated using the revised rating inflows match the aerial photography better than the current rating at the model's upstream end. They do not exceed the observed extents as would be expected given the overestimate of levels in the Warracknabeal area.

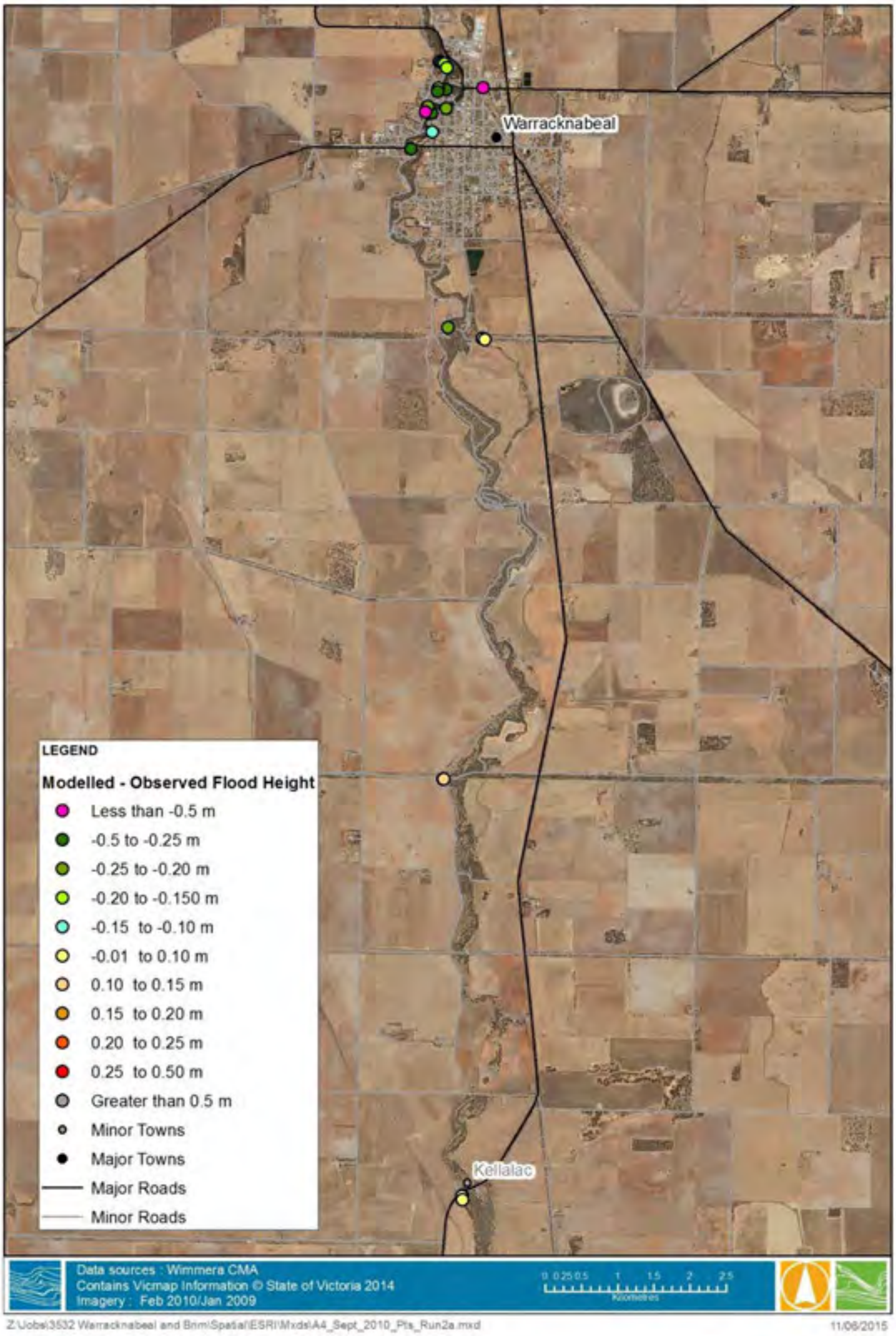


Figure 7-21 September 2010 modelled and observed flood heights using the current rating curve

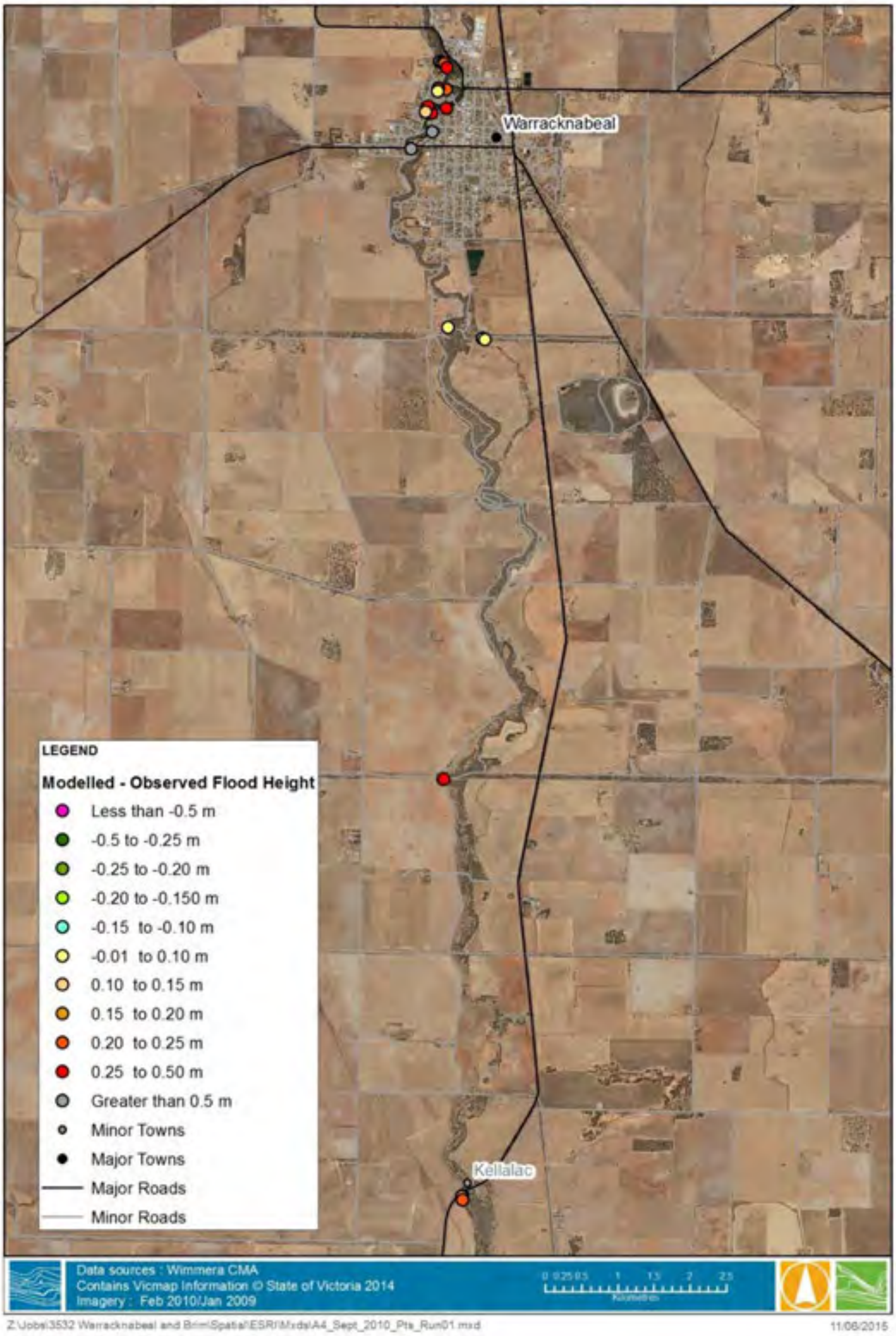


Figure 7-22 September 2010 modelled and observed flood heights using the revised rating curve

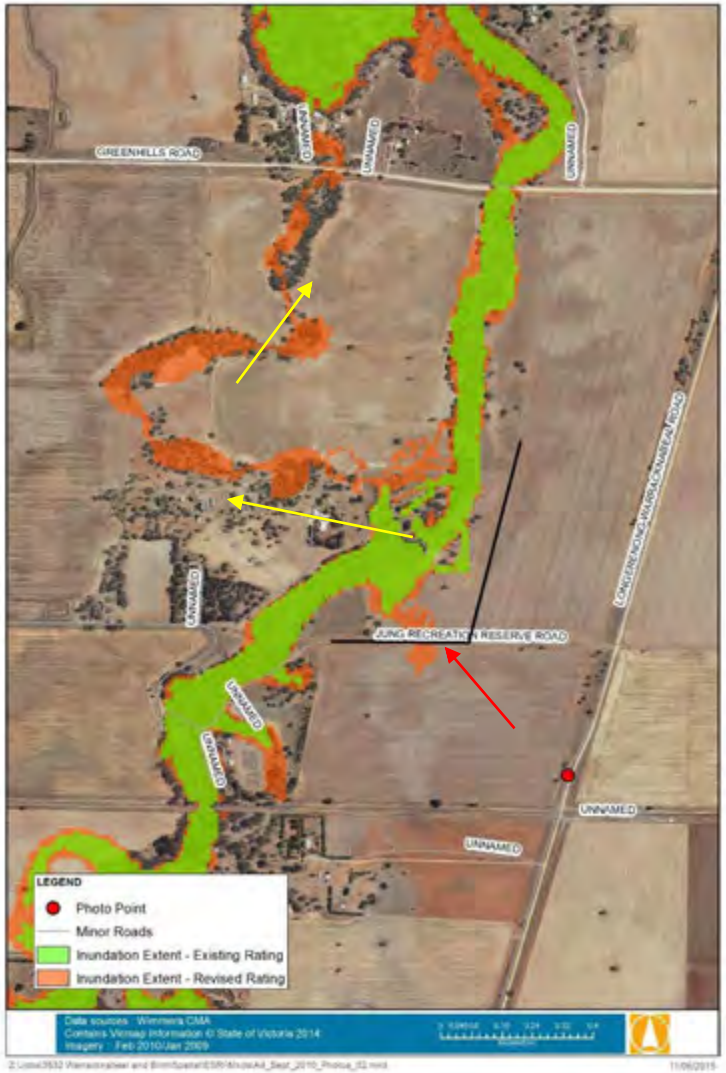


Figure 7-23 September 2010 modelled extent and captured aerial photography – Location 01

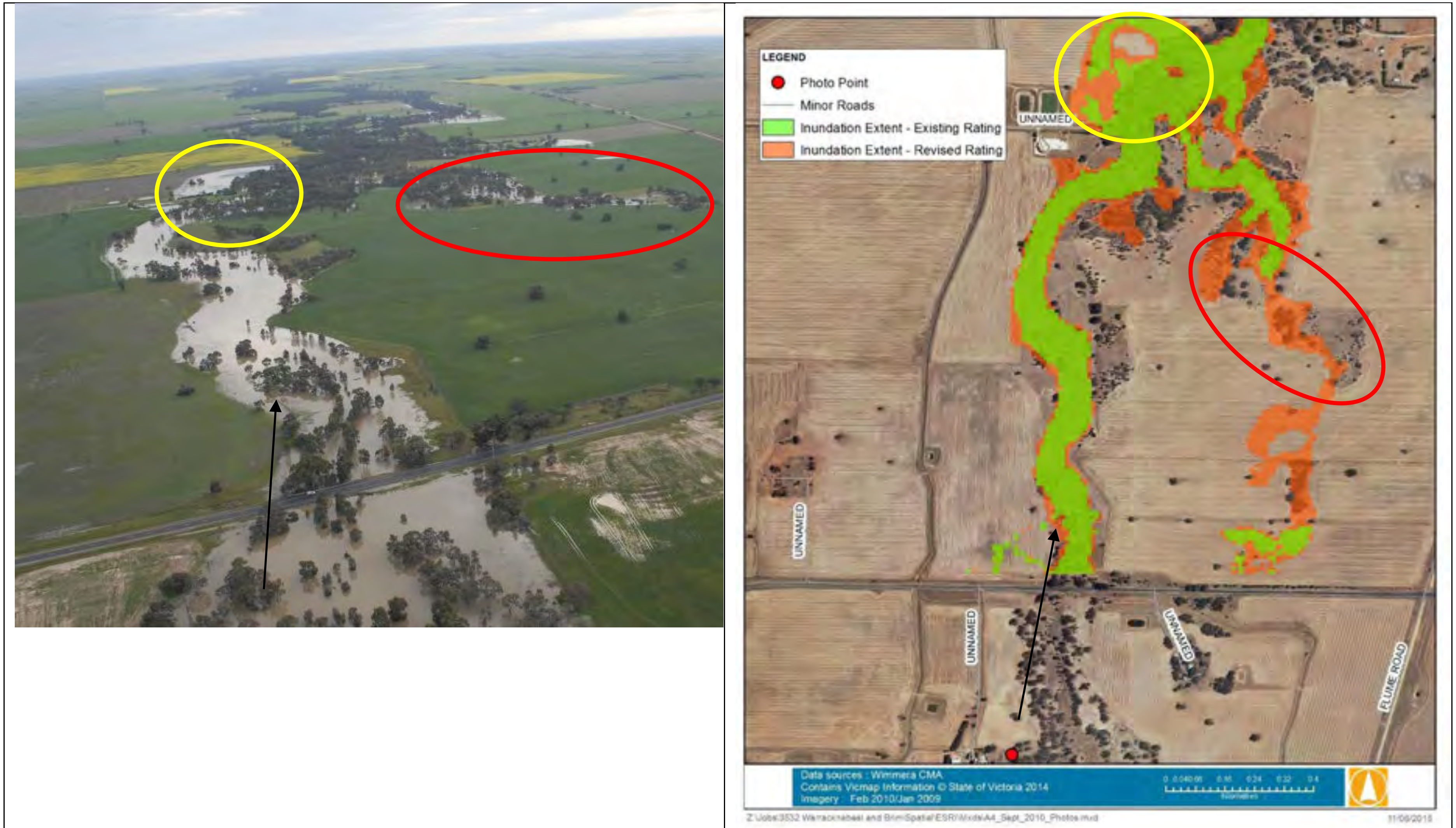


Figure 7-24 September 2010 modelled extent and captured aerial photography – Location 02

7.4.4 Discussion

The September 2010 hydrograph generated from the revised rating curve matched the aerial photographs better in the upper sections of Yarriambiack Creek, close to the upstream end of the model area beginning at the Wimmera Highway. However, the model was over predicting water levels at the surveyed flood heights in Warracknabeal.

The reasonable match upstream and overestimate downstream indicates the peak flow/volume in Yarriambiack Creek is not attenuating sufficiently along the reach.

Given the long period of time since a reasonable flow in Yarriambiack Creek prior to September 2010 and the warm conditions it is expected some evaporation/infiltration would have been occurring during the event.

To test the impact of evaporation/infiltration on the modelled water levels a 3mm/day loss was applied to the hydraulic model. The loss reduced the peak water levels at the survey point locations downstream of Kellalac but maintained a good match with the aerial photographs in the upstream sections. Of the 22 surveyed flood heights 18 were within 0.2 m and 9 were within 0.1 m. The average difference between the modelled and observed flood heights was 0.02 m. The difference between the modelled and observed flood heights is shown in Figure 7-25. There are still some outstanding differences in modelled and surveyed water levels, however a number appear to be errors in the survey points.

The calibration of the January 2011 event showed tightly matching observed and modelled flood heights with a revised rating curve. This was not able to be achieved using the revised rating for the September 2010 event, with losses required to be applied to the model to reproduce observed levels. The losses incorporated are not beyond that which could be reasonably assumed for a sandy floodplain north of Horsham. A possible explanation as to why losses were required to be applied to the September 2010 event and not January 2011 event may be due to the relative rainfall of the two events and resulting hydrograph volume. In the September 2010 event, where the Yarriambiack Creek and floodplain were reasonably dry prior to the event high losses could be expected as the flood wave first propagated down the system. On the smaller flood event these losses would have a larger proportional impact on the resulting flood levels. In January 2011, with significantly more rainfall in the days preceding the flood event and a much larger hydrograph volume the losses would likely have been less and the impact on the resulting flood levels less. I tis possible that if the January 2011 flood event was rerun with the same losses used in September 2010 event, that the modelled levels would not be much different to that modelled without loss applied.

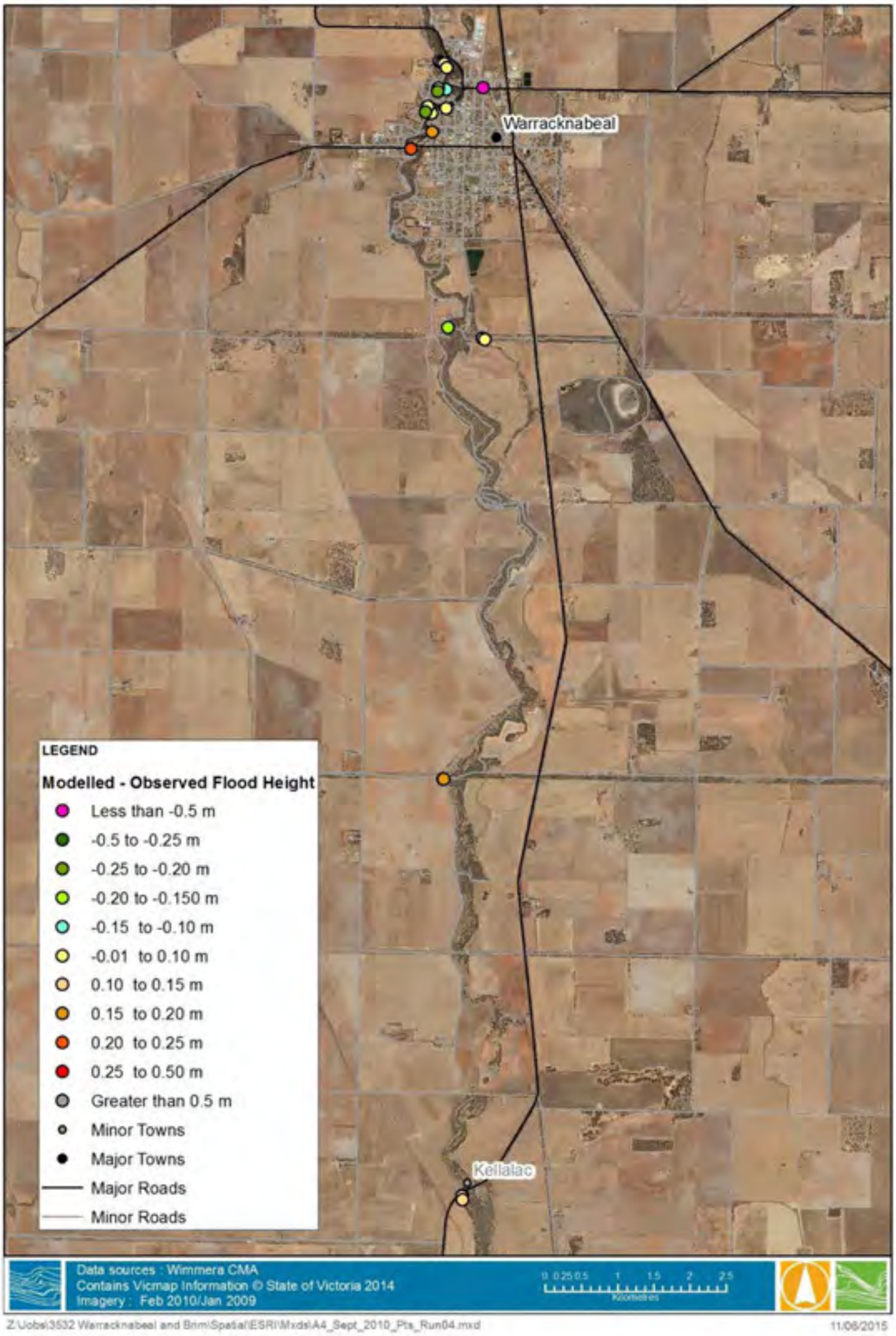


Figure 7-25 September 2010 modelled and observed flood heights using the revised rating curve and a infiltration loss of 3 mm/d

7.5 Design Flow Estimation

7.5.1 Overview

The Warracknabeal and Beulah Flood Investigation[1] and the Wimmera River and Yarriambiack Creek Flows Study[8] determined very different design flows for the Yarriambiack Creek gauge at the Wimmera Highway, as shown in Table 11 in Section 5.2.1.

As discussed previously, the period of gauge record at the Wimmera Highway gauge was not sufficient for the completion of a flood frequency analysis and could not be used for the determination of peak design flows. Large flows in Yarriambiack Creek are primarily driven by flow in the Wimmera River and Mt William Creek. Design flow distributions to Yarriambiack Creek were determined using the following methodology:

- Flood frequency analysis completed at the Wimmera River at Glenorchy gauge based on maximum daily flows to determine peak design flows.
- Flood frequency analysis completed at the Wimmera River at Glenorchy gauge based on four day accumulated volume to determine design event volumes.
- A ratio of design event peak flow to design event four day volume determined.
- A historic event chosen with a peak flow four day volume ratio similar to that determined across the design events to be used as the basis for hydrograph shape.
- Design events were modelled in the hydraulic model of the Wimmera River/Yarriambiack Creek offtake developed during the Wimmera River and Yarriambiack Creek Flows Study. This was completed using Mt William Creek inflows determined during Wimmera River and Yarriambiack Creek Flows Study[8] and the Mt William Creek Flood Investigation[12] to determine the most appropriate flow combination.

7.5.2 Glenorchy Design Flows

Peak flow analysis

The Wimmera River at Glenorchy stream gauge had peak design flow estimates completed during Glenorchy Flood Study[10] and the Wimmera River and Yarriambiack Creek and Wimmera River Flows Study[8]. Flows were determined using FFA and a URBS runoff routing model respectively. These analyses were completed prior to the September 2010 and January 2011 events.

A comparison of the design flow estimates determined at the Glenorchy stream gauge during each study is shown in Table 15.

Table 15 FFA results for all distributions and annual series

Design event	Wimmera River and Yarriambiack Creek Flows Study (URBS Model)		Glenorchy Flood Study (FFA)	
	ML/d	m^3/s	ML/d	m^3/s
5	8,726	101	14,100	163
10	14,861	172	19,000	220
20	22,982	266	23,500	272
50	30,067	348	29,000	336
100	37,584	435	32,800	380
200	43,459	503	36,400	421

An annual series FFA was completed at the Glenorchy gauge as part of this study to determine revised design flow estimates at the gauge. The available period of instantaneous record at Glenorchy included 1965-2013 with the period of mean daily flow extending to 1951. In general, mean daily flow records are lower than instantaneously recorded flows due to the peak flow being captured in the instantaneous record, whereas the mean daily flow is the average flow rate over the preceding 24 hour period. To translate each recorded peak annual mean daily flow into an instantaneous peak flow, a ratio of mean daily flow to instantaneous peak flow was determined for the period of instantaneous record for each gauge. The annual maximum mean daily flow was then scaled up as an estimate for the instantaneous peak flow and the instantaneous peak flow series was extended. The instantaneous gauge record extension was completed by applying a multiplier of 1.28 to the recorded mean daily flow. The correlation between mean daily flow and instantaneous flow was determined by an R^2 value, which was 0.9927 in this instance.

The extended period of gauge record was used to complete an annual series FFA in Flike[14], using the expected quantile output. The analysis was completed on raw annual peaks and a modified annual series with low flow years removed using the Multiple Grubbs Beck test. The determined low flow threshold was 6,600 ML/d, removing 31 years from the 63 year record.

The following distributions were tested:

- Log Pearson Type 3 (LP3)
- Generalised Extreme Value (GEV)
- Generalised Pareto (GP)
- Gumbel
- Log-normal

Of these distributions the LP3 and Gumbel matched well for both the raw and censored annual series, while GEV and GP matched better using the censored annual series. The Log-normal distribution didn't match well for either series.

A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table 16.

[14] University of Newcastle - Flike Flood Frequency Analysis

Table 16 FFA results for all distributions and annual series

AEP (%)	LP3		Gumbel		GEV		GP	
	Raw Data	Low Flow Censoring	Raw Data	Low Flow Censoring	Raw Data	Low Flow Censoring	Raw Data	Low Flow Censoring
5	14,437	14,182	10,550	14,531	9,550	14,655	10,275	14,903
10	21,558	20,140	14,294	19,884	18,392	20,271	16,286	20,835
20	28,011	26,125	17,885	25,020	33,588	25,719	23,555	26,809
50	35,224	33,967	22,534	31,667	71,857	32,864	35,545	34,769
100	39,681	39,781	26,017	36,648	126,124	38,286	46,839	40,840
200	43,359	45,450	29,488	41,611	220,203	43,747	60,494	46,954

The tested FFA distributions and annual series that matched the observed data are plotted in Figure 7-26, showing the confidence limits around the 1% AEP design peak flow. The plot shows the Gumbel Raw and low flow censored data have the narrowest confidence limits, followed by the LP3 Raw FFA.

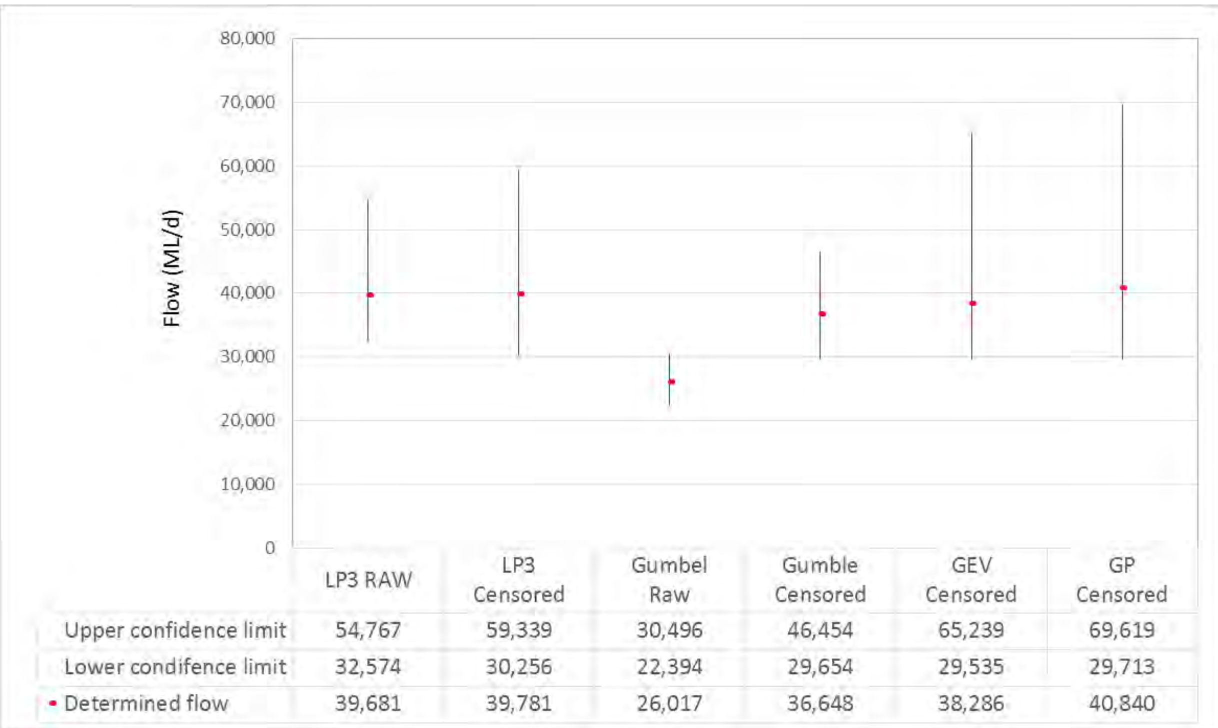


Figure 7-26 1% AEP FFA design flow estimates and confidence limits

The FFA analysis distributions for the Gumbel Raw, Gumbel low flow censored and LP3 censored have the smallest error bounds with their distributions shown in Figure 7-27, Figure 7-28 and Figure 7-29 respectively. The remainder are shown in Appendix A.

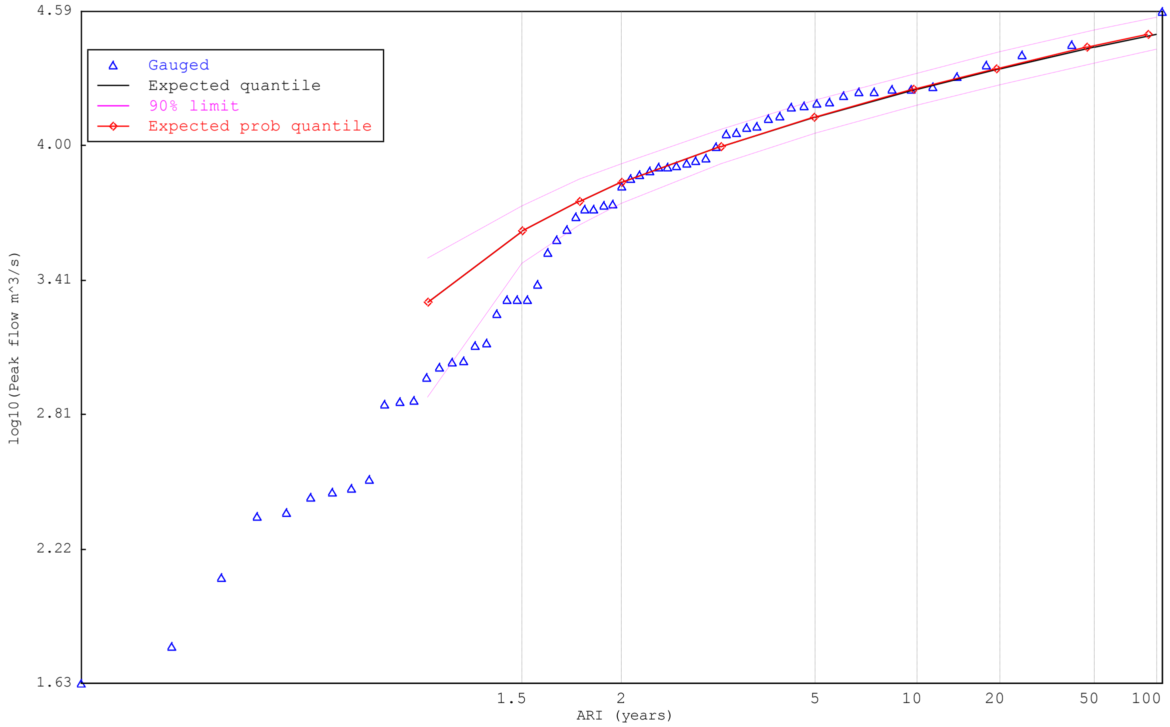


Figure 7-27 Gumbel Distribution – Raw annual series

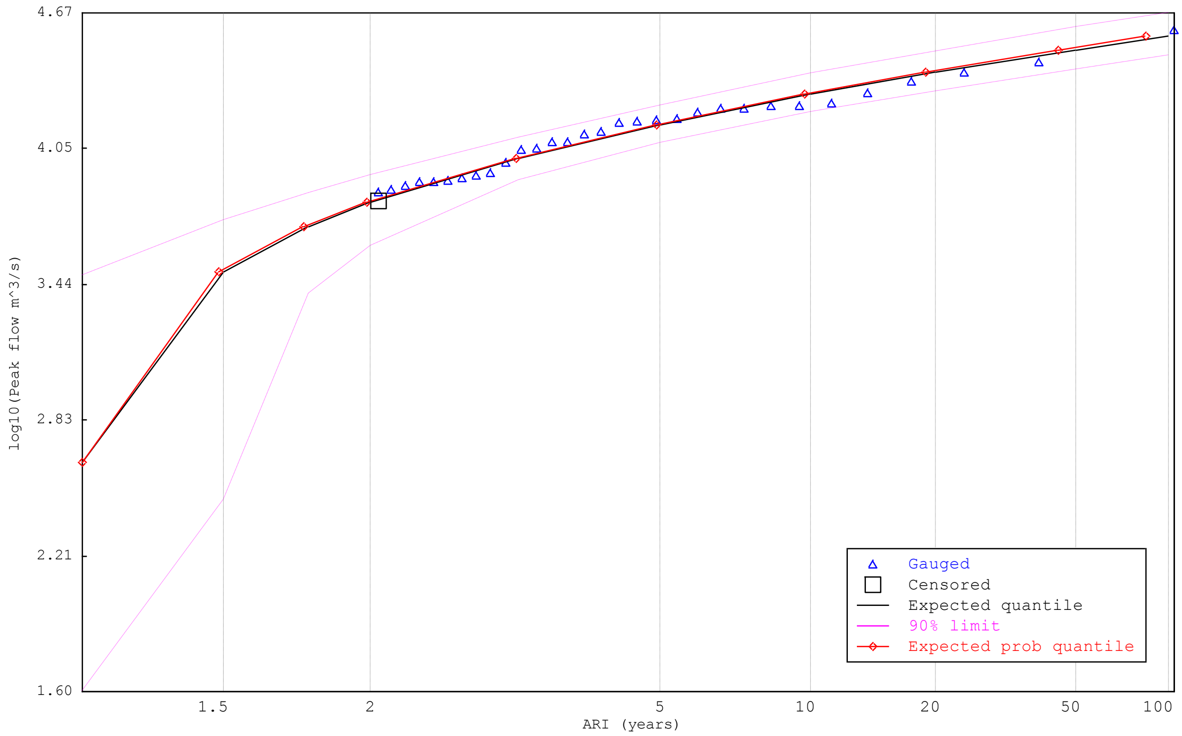


Figure 7-28 Gumbel distribution – Censored annual series

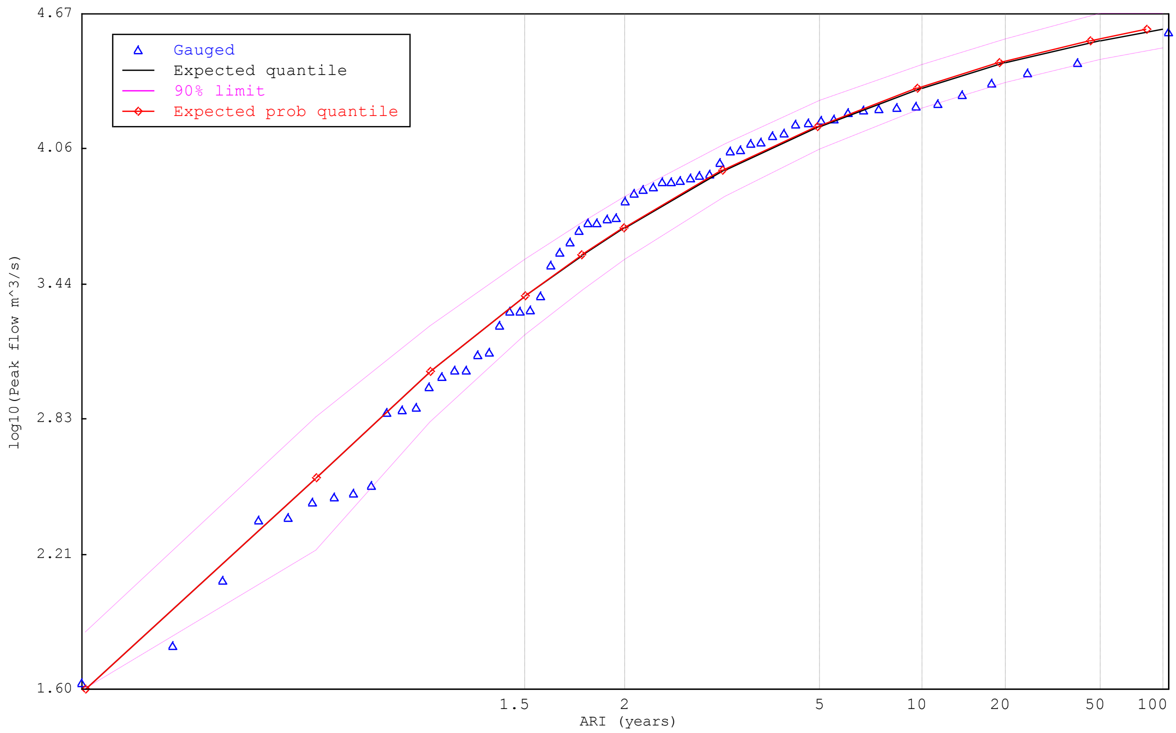


Figure 7-29 LP3 Distribution – Raw annual series

The Gumbel distribution with a raw annual series has the smallest error bounds, however the distribution clearly shows the series is under predicting the observed peak flows with historic peaks nearing the upper error bound. There are also a number of annual peak flows outside the error bounds in the 50-20% AEP range.

The Gumbel distribution with a low flow censoring showed a higher 1% AEP peak flow estimate than the raw data series. The error bounds for events less than a 50% AEP are quite large, however this is not considered important to this study as the focus is on events larger than 20% AEP.

The LP3 distribution with a raw annual series shows a good match. The largest event on record (January 2011) does influence the distribution significantly at the upper end of the curve where it departs from the observed high flow events ranging from 10 to 2 % AEP.

Discussion

The Gumbel distribution with low flow censoring using the Multiple Grubbs Beck Test was determined as the best fit to the Glenorchy extended annual series. The distribution had best graphical match to the data in the flow range of interest (20% to 0.5% AEP) and the second lowest error bounds.

The chosen flood frequency distribution and modified annual series match relatively closely with the flows determined by URBS modelling in the Wimmera River and Yarriambiack Creek Flows Study[8] at high flows. The design estimates for small events are larger than those estimated by URBS in the earlier study. The design estimates are also larger than that determined in the Glenorchy Flood Study[10] at high flows but match more closely at lower flows. A comparison of the peak flows is shown in Table 17.

Table 17 Gumbel distribution with low flow censoring FFA results and previous design flows

AEP (%)	Gumbel with Low Flow Censoring		Wimmera River and Yarriambiack Creek Flows Study[8] (URBS Model)		Glenorchy Flood Study[10] (FFA)	
	ML/d	m^3/s	ML/d	m^3/s	ML/d	m^3/s
20	14,531	168	8,726	101	14,100	163
10	19,884	230	14,861	172	19,000	220
5	25,020	290	22,982	266	23,500	272
2	31,667	367	30,067	348	29,000	336
1	36,648	424	37,584	435	32,800	380
0.5	41,611	482	43,459	503	36,400	421

Hydrograph shape

Similar to peak flows, design hydrographs were determined at the Glenorchy streamflow gauge during the Yarriambiack Creek and Wimmera River Flows Investigation[8] and Glenorchy Flood Study[10].

The Yarriambiack Creek and Wimmera River Flows Study[8] used the BoM developed URBS model of the upper Wimmera River catchment to determine the shape of the inflow hydrographs.

This project used the ratio of event peak flow to event volume determined by a FFA, then matched the ratio to a historic event which could be used for the shape of the design hydrographs.

The three largest events recorded at the Glenorchy gauge (January 2011, September 2010, October 1983 and September 1988) are shown overlayed in Figure 7-30. The events occurred over a 3-4 day period. The January 2011, September 2010 and October 1983 events all have a very similar shape.

Based on these hydrographs it was determined a four day volume FFA would be completed.

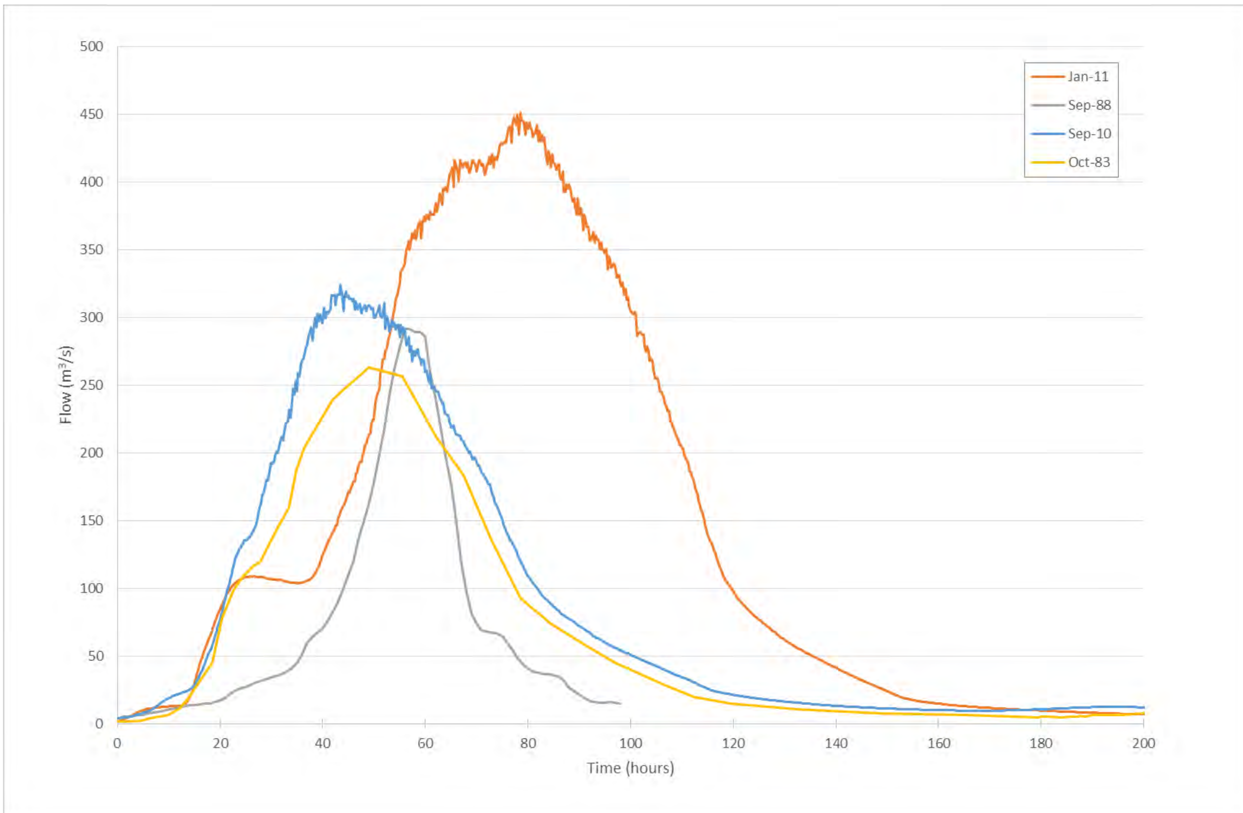


Figure 7-30 LP3 Distribution – Raw annual series

The four day volume FFA was completed using the same set of flood frequency distributions as completed in the peak flow analysis. The LP3 distribution showed to be the best match for the recorded data. Given the four day volume FFA distribution used was LP3 while the peak flow distribution was completed using a Gumbel distribution the peak flow : four day volume ratio was completed using both distributions as a sensitivity test, comparison to the four largest historic events was also made. The four day volume FFA results and comparisons for the design events are shown in Table 18, with the January 2011, September 2010, October 1988 and September 1983 events shown in Table 19.

Table 18 Design four day volume and peak flow FFA results and ratios

AEP	4 Day volume	Peak flow (Gumbel)	Peak Flow (LP3)	Ratio (Gumbel)	Ratio (LP3)
20	29409	14531	14437	2.02	2.04
10	46241	19884	21558	2.33	2.14
5	62419	25020	28011	2.49	2.23
2	81526	31667	35224	2.57	2.31
1	93910	36648	39681	2.56	2.37
0.5	104504	41611	43359	2.51	2.41
Average				**2.42**	**2.25**

Table 19 Historic event four day volume and peak flow FFA results and ratios

	4 Day Volume	Peak flow	Ratio
January 2011	95298	38995	2.44
September 2010	55486	28002	1.98
October 1988	51568	25172	2.05
September 1983	47249	17698	2.67

The January 2011 hydrograph's peak flow : four day volume matches that shown in the FFA results closely using the four day volume LP3 distribution and the Gumbel peak flow distribution. Given the similarities between the historic hydrograph shapes it was determined the January 2011 event would be used as the basis for hydrograph shape at Glenorchy with design hydrographs scaled to match each design peak flow.

Discussion

Using the above peak flow, volume and hydrograph shape a suite of design hydrographs were determined at Glenorchy. The 1% AEP event hydrograph is shown overlayed on 1% AEP hydrographs determined in the Glenorchy Flood Study[10] and Wimmera River and Yarriambiack Creek Flows Study[8] in Figure 7-31. Comparison between the other AEP events and previous studies is shown in Appendix B. The full set of design flow hydrographs at Glenorchy are shown in Figure 7-32, including comparison to the January 2011 event. As can be seen the hydrograph shapes are all reasonably similar with the Glenorchy Flood Study[10] comprising a shorter duration event peaking earlier, with the study using the observed 1983 event a basis for hydrograph shape.

Similar hydrograph shapes at Glenorchy across historic events is indicative of the catchment's size and typical flood rainfall pattern required to generate high flows in the Wimmera River. A close comparison between the URBS model results and historic events indicate the model schematisation is matching the actual catchment well.

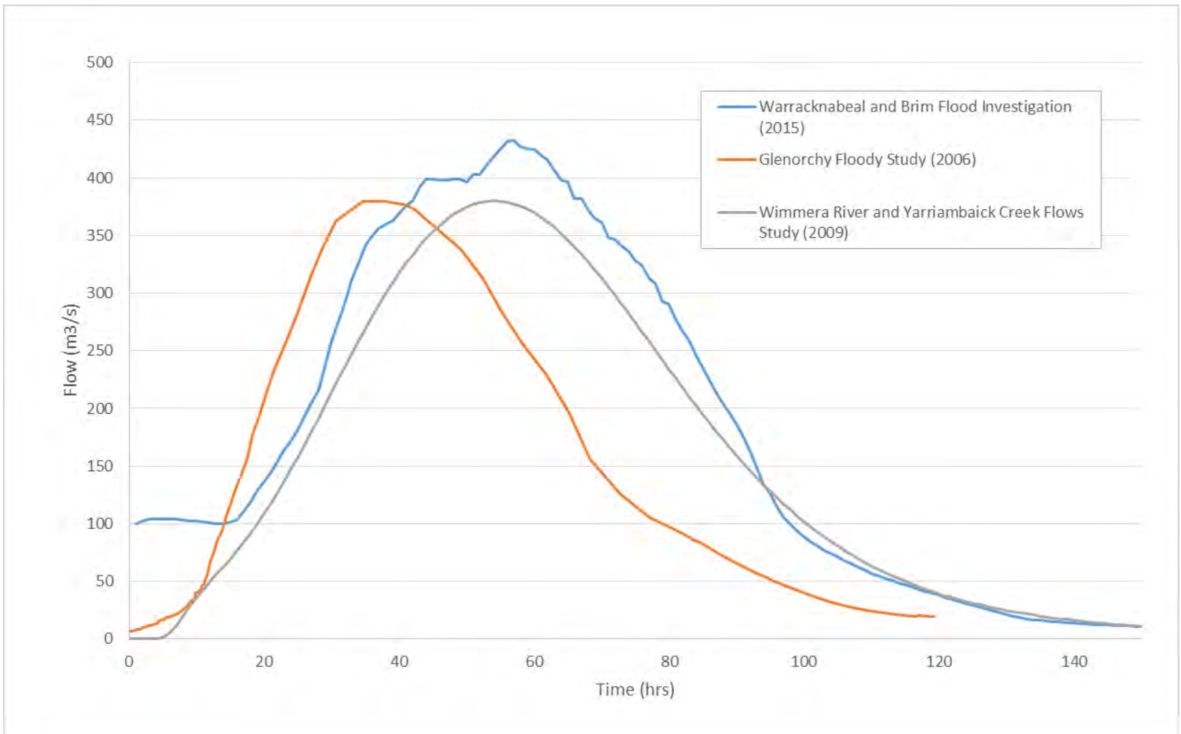


Figure 7-31 1% AEP hydrograph overlayed on hydrographs used in the Glenorchy Flood Study and Wimmera Rivera and Yarriambiack Creel Flows Study

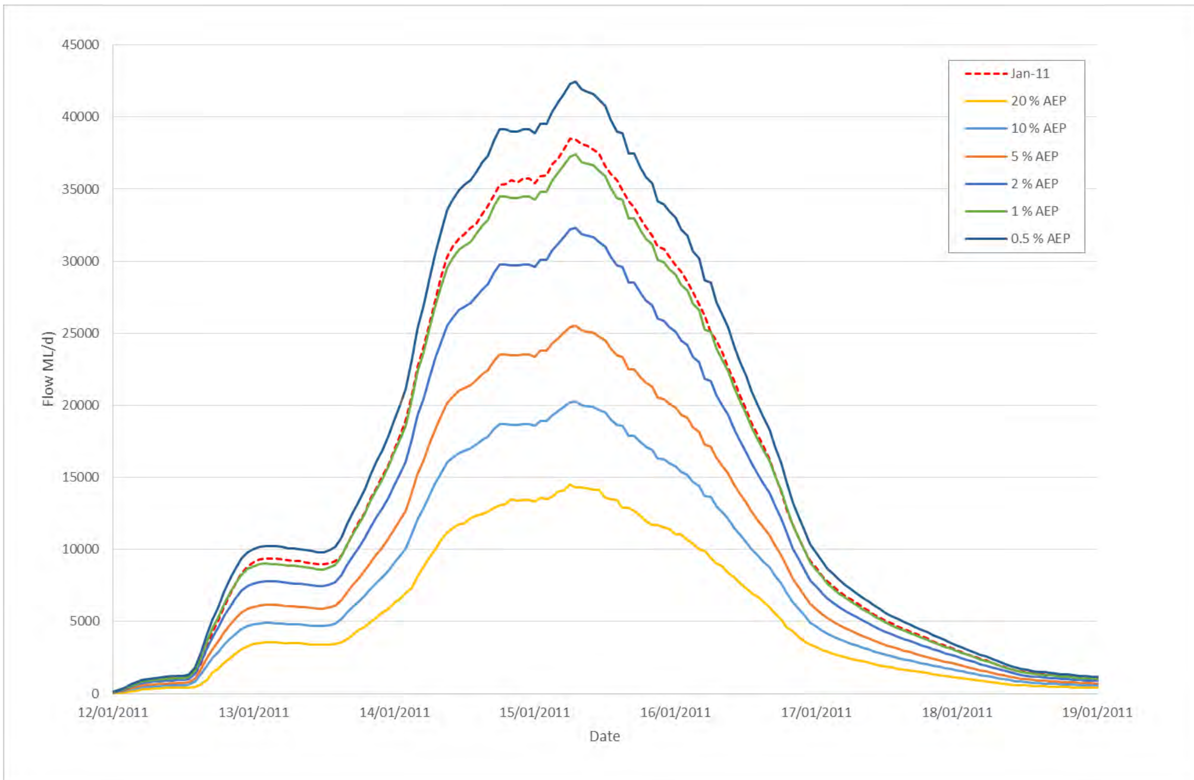


Figure 7-32 Glenorchy design flow hydrographs

The FFA and design flow hydrographs show the January 2011 event to be between a 0.5 % to 1 % AEP event at Glenorchy. This matches with regional estimates made soon after the January 2011 flood event.

7.5.3 Mt William Creek Design Flows

Analysis

Design inflows from Mt William Creek impact on the Wimmera River distribution to Yarriambiack Creek. As discussed in Section 5.2 there has been two previous studies determining design flows for Mt William Creek at Dadswells Bridge; the Wimmera River and Yarriambiack Creek Flows Study and the Mt William Creek Flood Investigation. The peak flows estimated for each of the design events is shown in

Table 20, with a comparison of the 1% AEP event shown in Figure 7-33.

Table 20 Dadswells Bridge peak flows

Event	Peak Flow (m^3/s)		
	Wimmera River and Yarriambiack Creek Flows Study (2009)	Mt William Creek Flood Investigation (2014)	% Difference
20% AEP	14.3 (1,236 ML/d)	14.9 (1,287 ML/d)	4.0%
10% AEP	32.8 (2,834 ML/d)	46.6 (4,026 ML/d)	29.6%
5% AEP	65.4 (5,651 ML/d)	128.0 (11,059 ML/d)	48.9%
2% AEP	107.0 (9,245 ML/d)	244.8 (21,151 ML/d)	56.3%
1% AEP	147.5 (12,744 ML/d)	346.5 (29,938 ML/d)	57.4%
0.5% AEP	196.3 (16,960 ML/d)	466.3 (40,288 ML/d)	57.9%

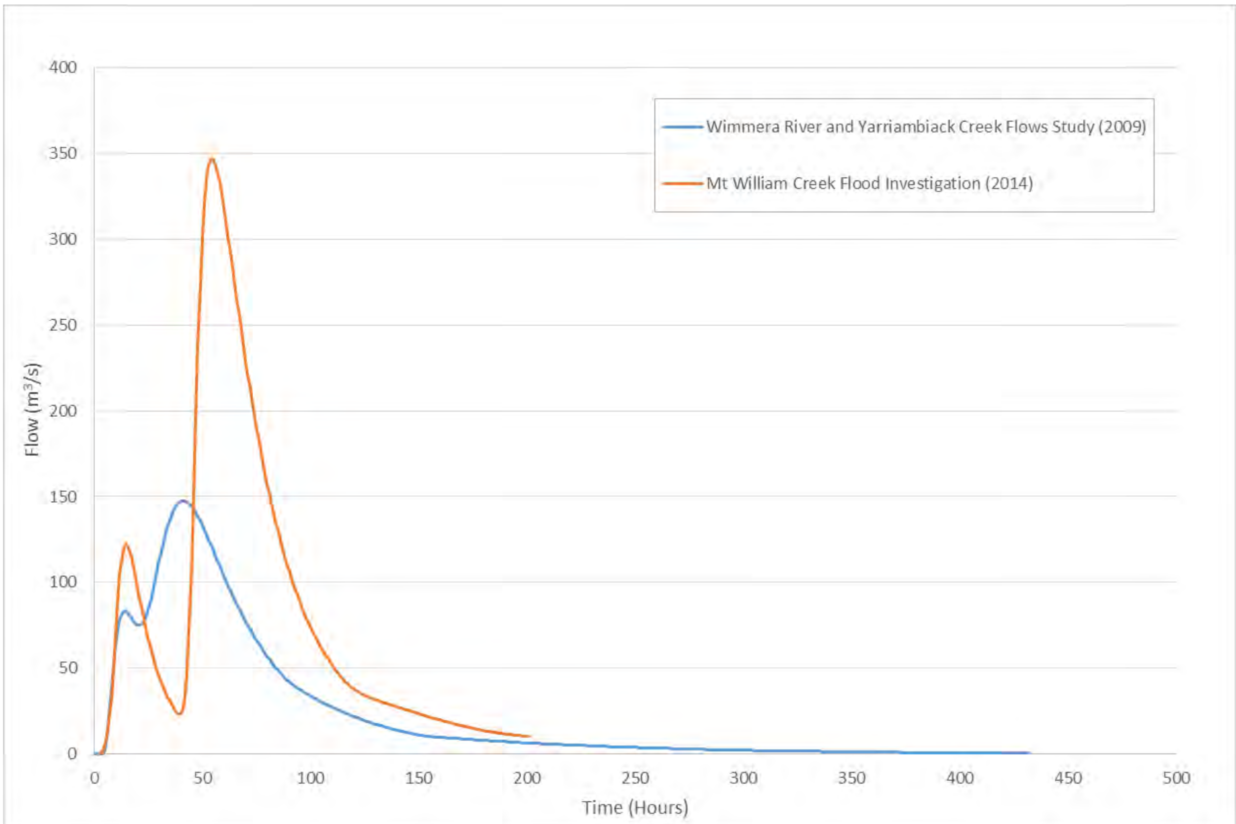


Figure 7-33 1% AEP hydrograph comparison – Wimmera River and Yarriambiack Creek Flows Study/Mt William Creek Flood Investigation

The Wimmera River and Yarriambiack Creek Flows Study[8] used the BoM developed URBS model to determine inflows from Mt William Creek into the Wimmera River, while the RORB model used in the Mt William Creek Flood Investigation[12] covers the Mt William Creek catchment alone.

The BoM URBS model was separated into two model subareas, the Upper Wimmera, upstream of Glenorchy and the Lower Wimmera downstream. The model was recalibrated during the Wimmera

River and Yarriambiack Creek Flows Study using the August 1981, September 1983, September 1988 and October 1996 events. The URBS model used an initial and continuing loss model to represent rainfall losses.

The calibration across the four events for the Upper and Lower Wimmera subareas is shown in Table 21 and Table 22 respectively.

Table 21 Wimmera River and Yarriambiack Creek Flows Investigation[8] URBBS model calibration – Upper Wimmera River subarea

Event	Routing Parameters		Rainfall losses		Wimmera River at Glenorchy	
	α	β	IL (mm)	CL (mm/hr)	Recorded Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)
August 1981	0.45	3.0	10	1.0	198 (17,110 ML/d)	204 (17,625 ML/d)
September 1983	0.4	3.0	10	1.0	206 (17,800 ML/d)	211 (18,230 ML/d)
September 1988	0.4	3.0	20	1.5	316 (27,300 ML/d)	344 (29,720 ML/d)
October 1996	0.4	3.0	5	0.9	171 (14,780 ML/d)	175 (15,120 ML/d)

Table 22 Wimmera River and Yarriambiack Creek Flows Investigation[8] URBBS model calibration –Lower Wimmera River subarea

Event	Routing Parameters		Rainfall losses		Wimmera River at Faux Bridge		Wimmera River at Horsham	
	α	β	IL (mm)	CL (mm/hr)	Recorded Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)	Recorded Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)
August 1981	0.3	3.0	15	1.0	184 (15,900 ML/d)	195 (16,850 ML/d)	262 (22,640 ML/d)	276 (23,850 ML/d)
September 1983	0.3	3.0	20	1.0	217 (18,750 ML/d)	207 (17,890 ML/d)	296 (25,580 ML/d)	287 (23,850 ML/d)
September 1988	0.36	3.0	20	2.0	NA	316 (27,300 ML/d)	244 (21,080 ML/d)	262 (22,640 ML/d)
October 1996	0.4	3.0	10	1.4	NA	172 (14,860 ML/d)	227 (19,610 ML/d)	226 (19,530 ML/d)

The URBS model calibration is considered of sufficient accuracy for use in this project.

A comparison of the two parameters used in the RORB and URBS models are shown below in Table 23.

The hydrograph and peak flow comparisons show the flow estimates generated in the Mt William Flood Investigation are significantly larger than those determined during the Wimmera River and Yarriambiack Creek Flows Study. The general hydrograph shape remains the same with a double peak.

Given the large disparities between the Mt William Creek hydrographs at Dadswells Bridge it was decided to run both sets of design flows with the Glenorchy design flow estimates in the hydraulic models constructed as part of the Wimmera River and Yarriambiack Creek Flows Investigation[8] to determine their impact on the flow distribution to Yarriambiack Creek. Table 24 shows the flow distribution to Yarriambiack Creek at the Wimmera Highway gauge for the modelled design events using the Glenorchy design flow hydrographs determined during this study (as discussed in Section 7.5.2) and the two different design hydrographs for Mt William Creek at Dadswells Bridge. Two different hydrographs were used as inflows on Mt William Creek to test their impact on the distribution to Yarriambiack Creek. Flows originating from the Mt William Flood Investigation[12] are representative of the peak 1% AEP flow for Mt William Creek flows extracted from the Wimmera River and Yarriambiack Creek Flow Modelling Study[8] are representative of peak flows in the Wimmera River.

Table 23 Mt William Creek Flood Investigation[12] RORB model/Wimmera River and Yarriambiack Creek Flows Investigation[8] runoff routing comparison

Parameter	Wimmera River and Yarriambiack Creek Flows Study (2009)[8]	Mt William Creek Flood Investigation[12] (2014)
Initial Loss	20 mm	20-25 mm
Continuing Loss	2.5 mm/hr	1.5-2.5 mm
Temporal Pattern	Zone 2	Zone 2
Spatial Pattern	Uniform	Uniform
Calibration Factor	Alfa = 0.3, Beta = 3.0	Kc = 12-70
‘m’ Value	0.8	0.8
Areal Reduction Factors	Siriwardena and Weinmann	Siriwardena and Weinmann
Modelled durations and depths		
20%	60.08 mm (30 hour)	84.45 mm (72 hour)
10%	77.06 mm (36 hour)	79.43 mm (30 hour)
5%	101.8 mm (72 hour)	111.74 mm (72 hour)
2%	122.3 mm (72 hour)	98.87 mm (18 hour)
1%	139.0 mm (72 hour)	113.24 mm (18 hour)
0.5%	-	122.01 mm (24 hour)

Table 24 Wimmera River and Yarriambiack Creek Flows model – Design flow distribution to Yarriambiack Creek

Design Event (AEP)	Peak Flow (m^3/s)		
	Mt William Creek Flood Investigation[12] - Mt William Creek inflow	Wimmera River and Yarriambiack Creek Flows Study[8] -- Mt William Creek inflow	% Difference
20 %	10.6 (916 ML/d)	10.5 (907 ML/d)	1.0%
10 %	16.4 (1,417 ML/d)	13.5 (1,166 ML/d)	21.5%
5 %	23.4 (2,022 ML/d)	20.2 (1,745 ML/d)	15.8%
2 %	60.5 (5,227 ML/d)	39.0 (3,370 ML/d)	55.2%
1 %	91.2 (7,880 ML/d)	58.2 (5,028 ML/d)	56.7%
0.5 %	126.4 (10,921 ML/d)	76.02 (6,568 ML/d)	66.3%
Jan 2011	63.4 (determined by the revised rating curve)		

Discussion

Inflows to the Wimmera River from Mt William Creek have a large impact on the flow distribution to Yarriambiack Creek. The Mt William Creek Flood Investigation inflows are significantly higher than those used in the Wimmera River and Yarriambiack Creek Flows Investigation and result in a significantly higher flow distribution to Yarriambiack Creek. However, these inflows were generated for the Mt William Creek catchment, where the primary focus was on inundation within that catchment. The critical duration determined for each event is focused on Dadswells Bridge. Flows generated in the Wimmera River and Yarriambiack Creek Flows Study were focused on flow along the Wimmera River with rainfall occurring catchment wide with the critical duration of the event focussed on the Wimmera River. From a design flow estimation perspective, if we were to adopt a 1% AEP flow at Glenorchy and combine it with a 1% AEP flow at Dadswells Bridge, then the resulting event downstream would have an AEP much rarer than 1%. It is suggested that using the Wimmera River and Yarriambiack Creek URBS model estimate is a more reasonable assumption.

The predicted flow distribution to Yarriambiack Creek during January 2011 is 63.4 m^3/s (5478 ML/d) based on the revised rating curve at the Wimmera Highway gauge. This places the event between a 1% and 0.5% AEP event when applying the Wimmera River and Yarriambiack Creek Flows Study Mt William Creek inflows. This AEP estimate is inline with the Glenorchy FFA completed as part of this study and AEP estimates for the Wimmera River downstream of the Two Mile Creek re-entry to the

Wimmera River[15]. Flooding on Mt William Creek at Dadswells Bridge was determined as slightly higher than a 0.5% AEP event.

The predicted flow at the Yarriambiack Creek at Wimmera Highway Bridge gauge was 26.2 m^3/s (2,264 ML/d) based on the revised rating curve. This places the event between a 5% and 2% AEP event when applying the Wimmera River and Yarriambiack Creek Flows Study Mt William Creek inflows. This is very similar to the AEP estimate at Glenorchy based on the completed FFA.

7.6 Model calibration and design summary

The process undertaken to determine reliable calibration and design flows with an inaccurate rating curve at the Wimmera Highway gauge was complex with many iterations and model revisions. The process undertaken has been summarised below as it was undertaken in the project:

- Model Calibration
    - Wimmera Highway gauge model was constructed and attempts we made to match the existing rating curve using a series of ramped flows. The match could not be made with reasonable assumptions.
    - Study area hydraulic model constructed and run for the current adopted rating curve, the modelled extents and water levels were far too low with no possible way to increase them based on the current model inflows.
    - Wimmera River and Yarriambiack Creek Flows Study model was run to test what ballpark distribution would be made to Yarriambiack Creek.
    - The numerous model runs completed in the Wimmera Highway gauge model were reviewed for the closest peak flow/level match to that shown in the Wimmera and Yarriambiack Creek Flows Study, this model was used to as the basis for a revised rating curve.
    - The revised rating curve was used to generate a revised January 2011 hydrograph based on the recorded water levels at the gauge
    - The revised January 2011 hydrograph was modelled in the study area hydraulic model and a general match to the aerial photography and surveyed flood marks was achieved.
    - Changes were made to the study area hydraulic model to refine the model calibration
    - Existing and revised model hydrographs were modelled for the September 2010 event
    - Losses were incorporated into the September 2010 event to improve calibration
- Design Flow Estimates
    - Peak flow Flood Frequency Analysis was under taken at Glenorchy to determine design peak flows
    - Four day Flood Frequency Analysis was under taken at Glenorchy to determine design event volume
    - The Flood Frequency Analysis peak flow to volume ration was determined and matched to a historic event for the basis for design hydrographs.
    - Previous Mt William Creek studies were assessed for model inflow hydrographs. It was determined both the Mt William Creek and Wimmera River and Yarriambiack Creek Flows Study flows would be modelled in the previously constructed hydraulic model with the Glenorchy design hydrographs as a sensitivity test.
    - It was determined the Wimmera River and Yarriambiack Creek Flows Study flows at Mt William Creek were the most appropriate for use in this project.

[15] Water Technology, East Horsham Flood Plan (2012), Water Technology, January 2011 Flood Report (2011), Water Technology, Horsham Bypass Hydrology and Hydraulics Investigation (2012).

- The design flow hydrographs for the study area were determined by the flow distribution in Yarriambiack Creek from the Wimmera River and Yarriambiack Creek Flows Study models.

7.7 Next Stages

7.7.1 Overview

The design events will be completed along with stormwater modelling of the Warracknabeal and Brim townships, this includes the Probable Maximum Flood (PMF) and climate change scenarios. This modelling will be incorporated into the Design Modelling Report.

7.7.2 Stormwater modelling

Stormwater modelling will be undertaken for the 1% AEP event only applying the ARR recommended rainfall intensities and Zone 2 temporal pattern across a 2 hour storm duration event. Rainfall will be directly applied to the Warracknabeal and Brim catchment areas as a rainfall on grid model.

7.7.3 Probable Maximum Flood

PMF flows will be generated using the rapid assessment method detailed by Nathan et al[16]. Nathan uses a prediction equation based on a sample of 56 catchments in South Eastern Australia, ranging in size from 1 km^2 to 10,000 km^2. The equation derived by Nathan et al (1994) was as follows:

$$Q_p = 129.1\ A^{0.616}$$

$$V = 497.7\ A^{0.984}$$

$$T_P = 1.062 \times 10^{-4}\ A^{-1.057}\ V^{1.446}$$

Where Q_p is the PMF peak flow (m^3/s), A is the catchment area (km^2), V is the hydrograph volume (ML) and T_P is the time to peak of the hydrograph (h).

This method was considered appropriate given the uncertainty associated with PMF estimates. Flows will be generated for both the Wimmera River at Glenorchy and Mt William Creek at Dadswells Bridge and comparisons will be made against previous studies.

7.7.4 Climate Change Scenarios

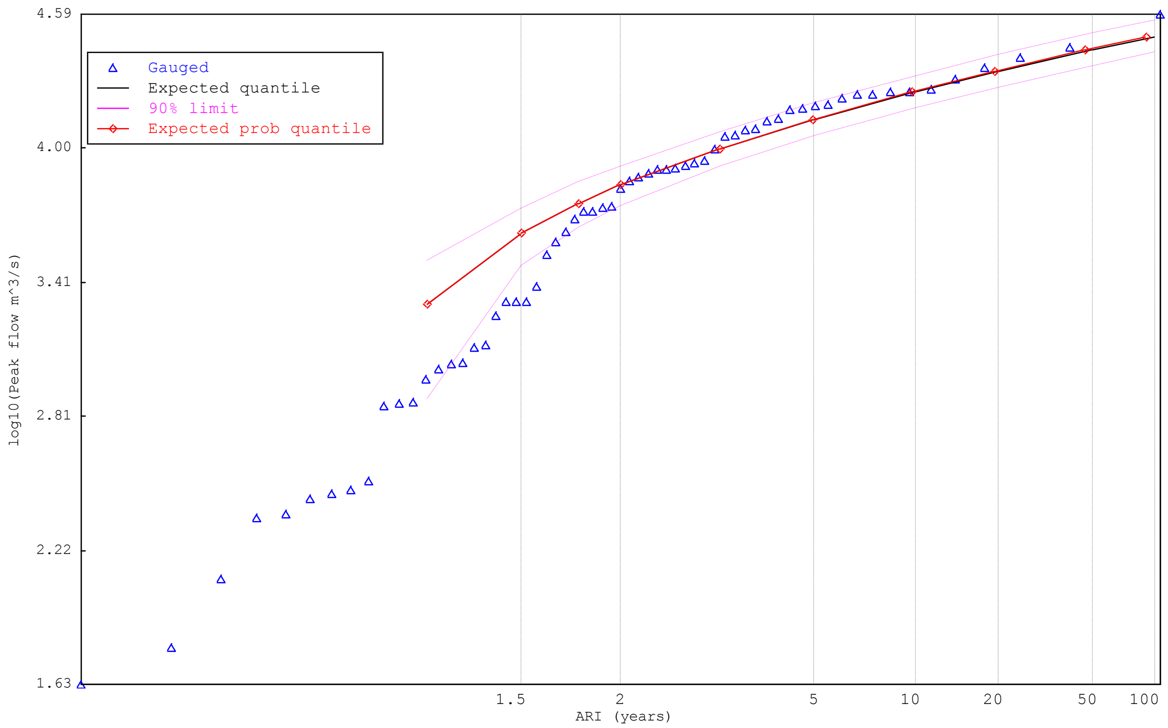
The current Australian Rainfall and Runoff rainfall climate change recommendation is for an increase of between 10 % and 30%[17]. This project will adopt a 30% increase in peak flow as a sensitivity test at both the Wimmera River and Mt William Creek inflow boundaries. Given the uncertainty in the climate change predictions this is considered appropriate.

[16] Nathan. R. J., Weinmann, P. E. and Gato, S. A. (1994), 'A Quick Method for Estimating Probable Maximum Flood in South Eastern Australia', Water Down Under 94 Conference Proc., Adelaide, November, 1994, pp. 229-234

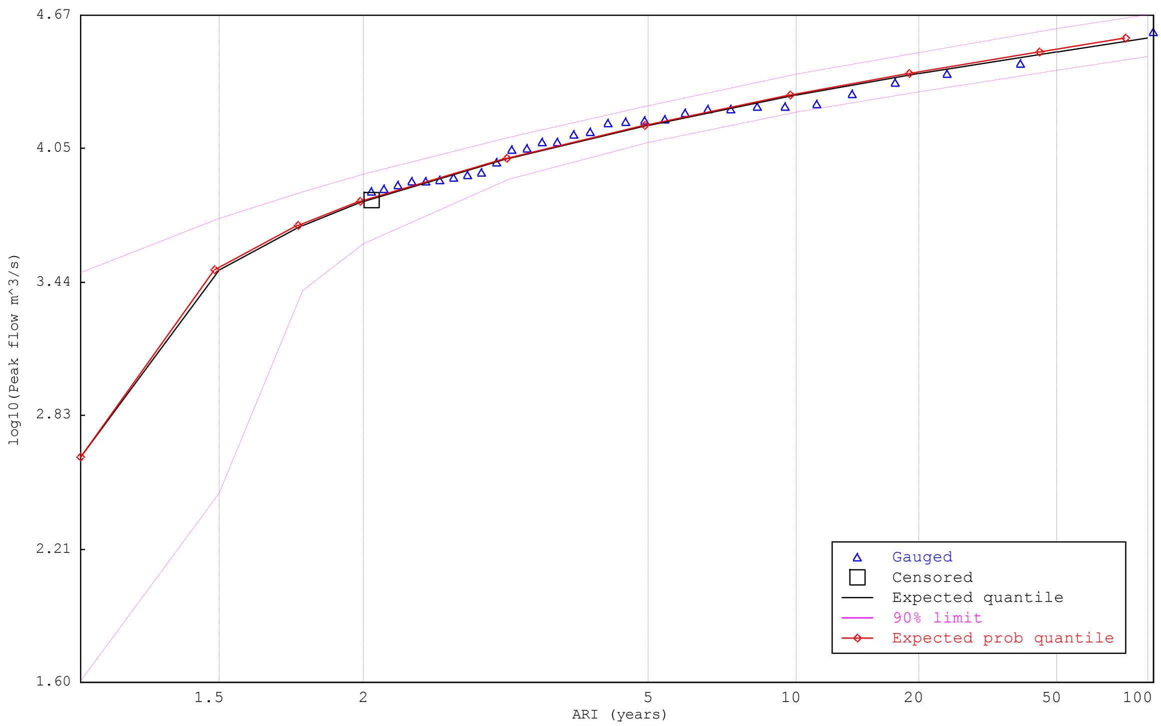
[17] ARR – Implications of Climate Chance on Flood Estimation. Discussion Paper for the Australian Rainfall and Runoff Climate Chance Workshop No.2, 2011

APPENDIX A FFA DISTRIBUTIONS

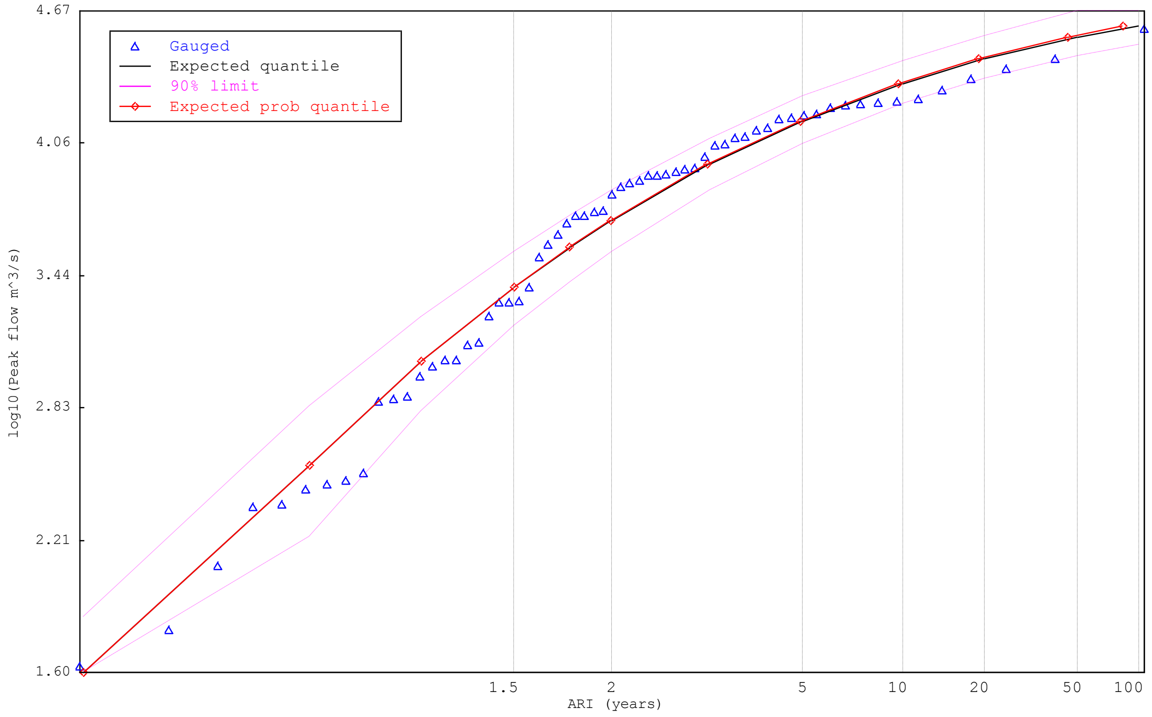
Gumbel – Raw Annual Series



Gumbel – Censored Annual Series



LP3 – Raw Annual Series



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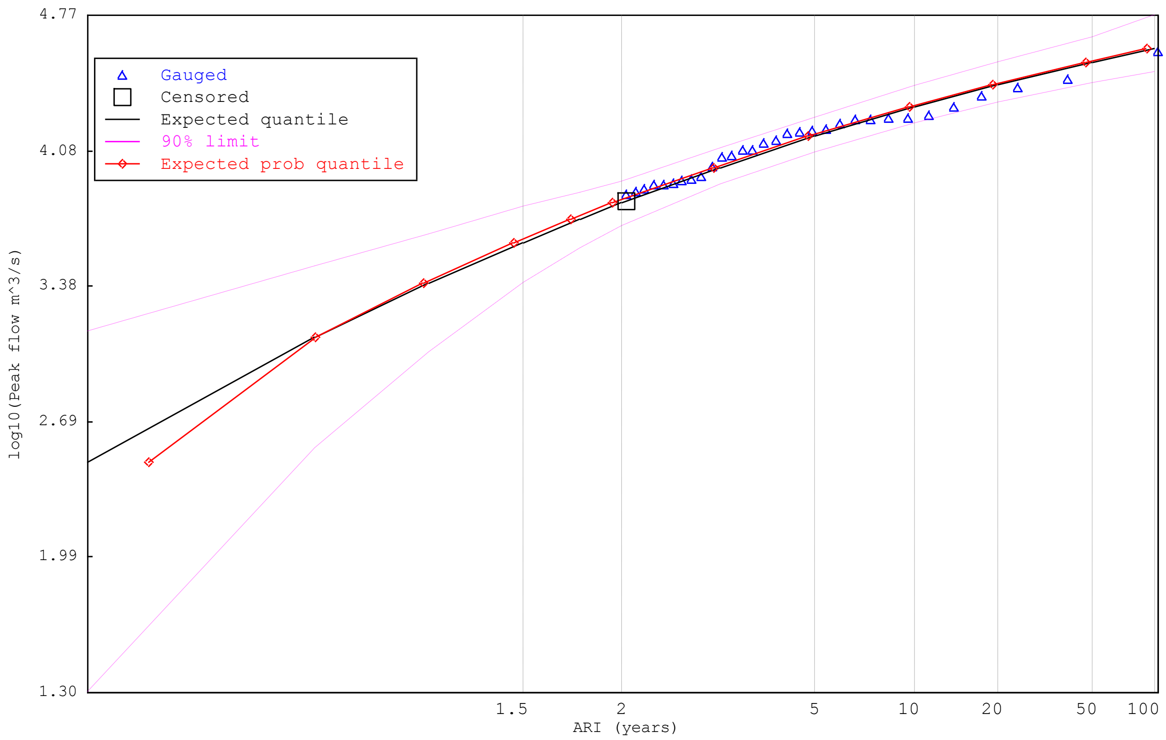
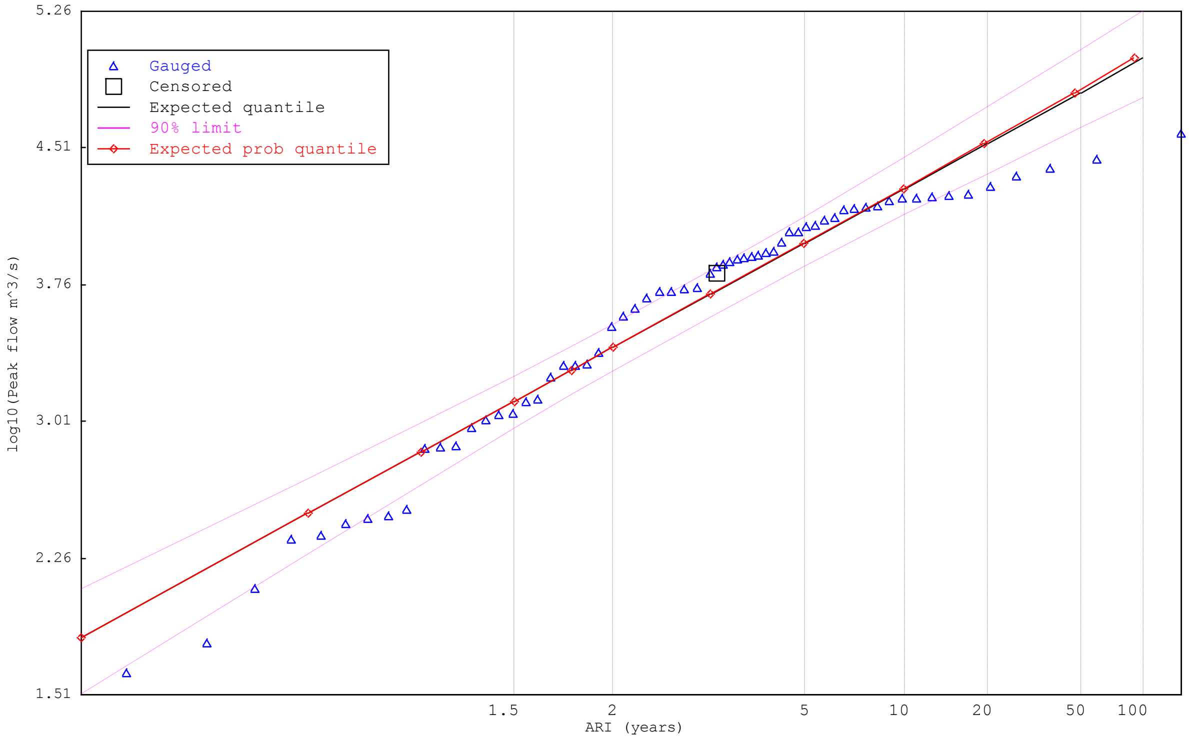
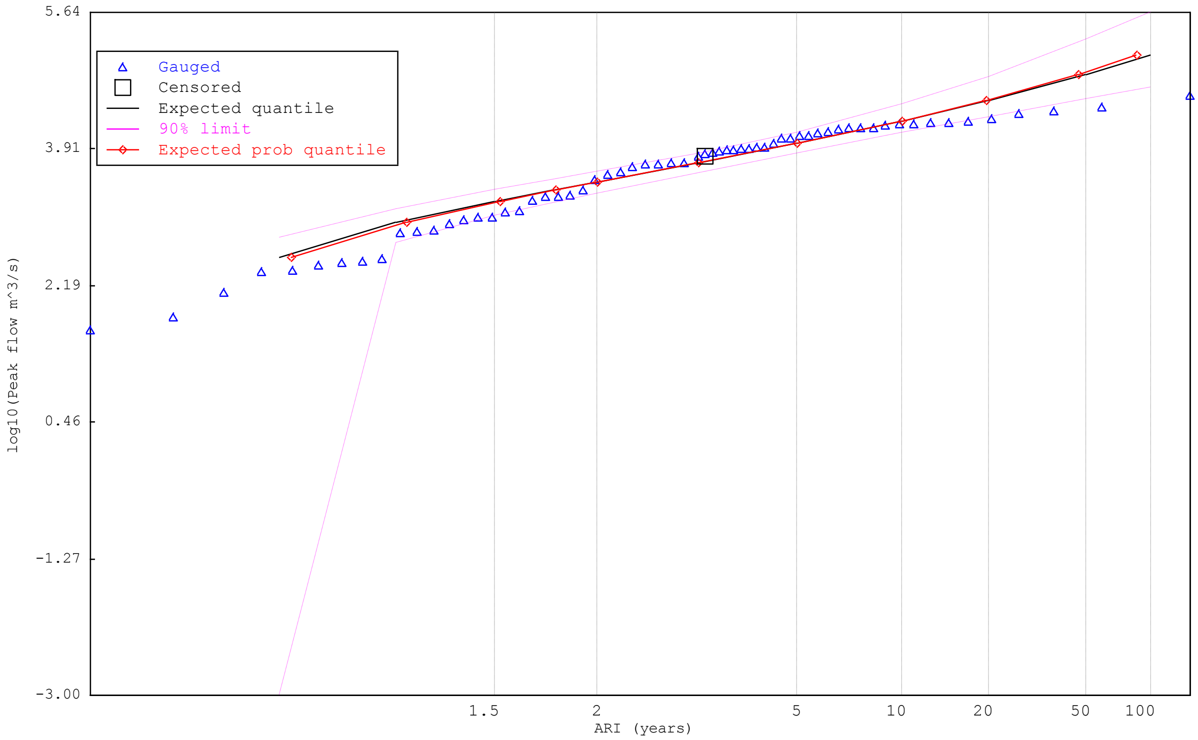


Log Normal – Raw Annual Series



GEV – Raw Annual Series



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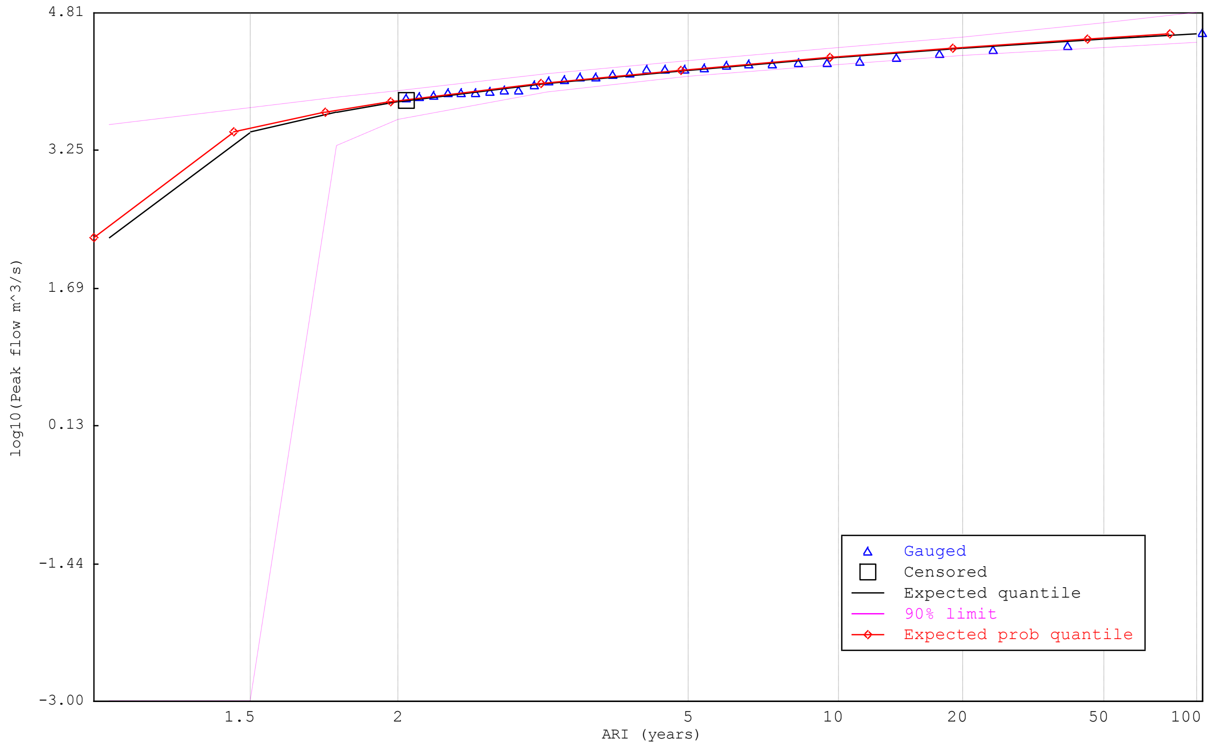
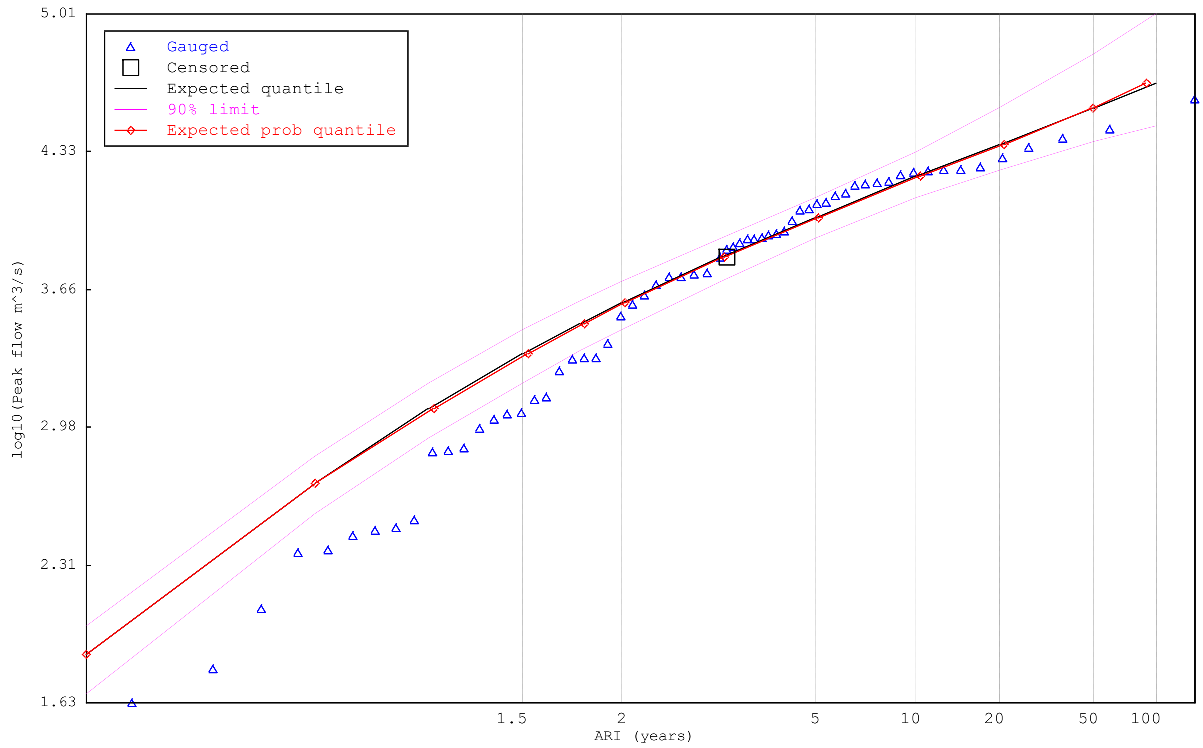


GP – Raw Annual Series



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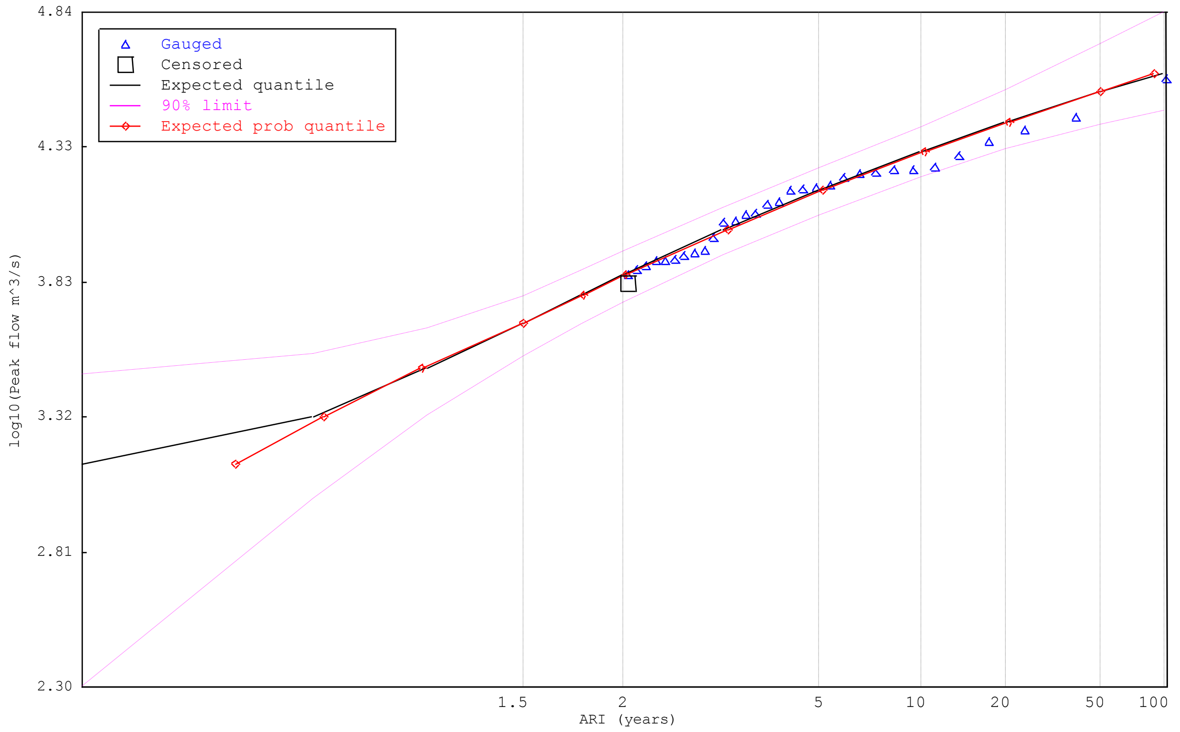
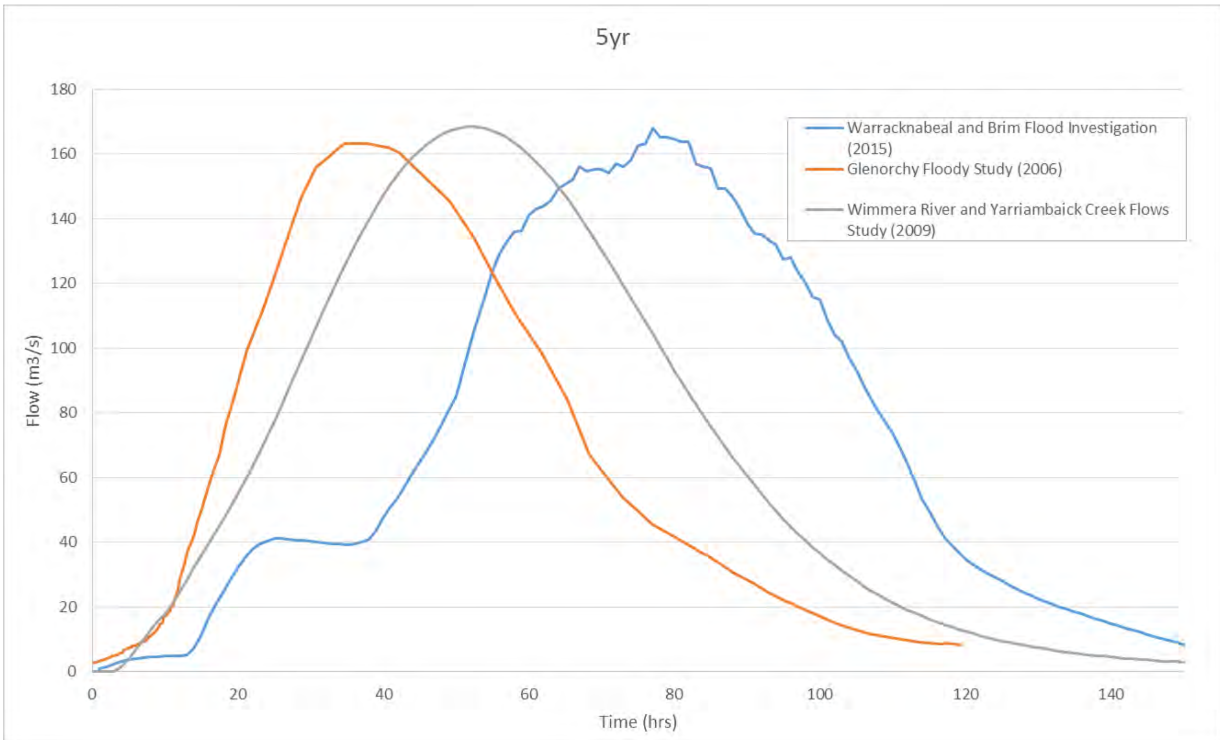
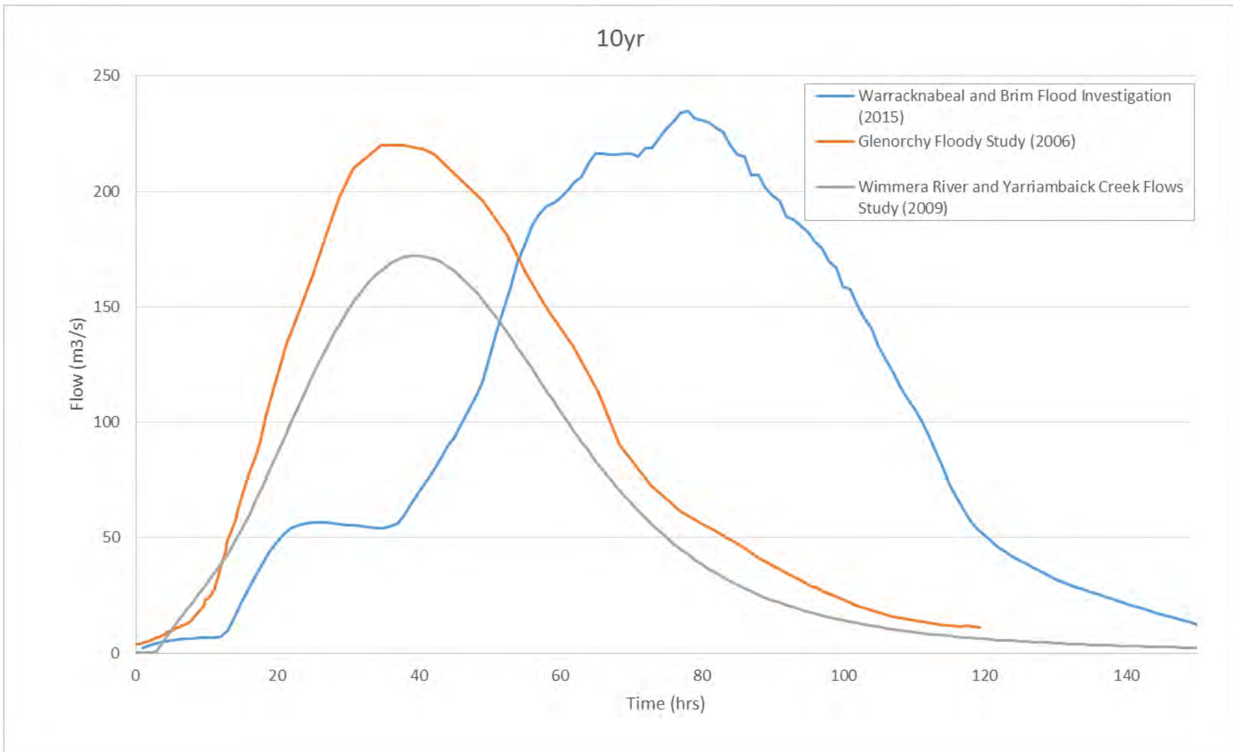
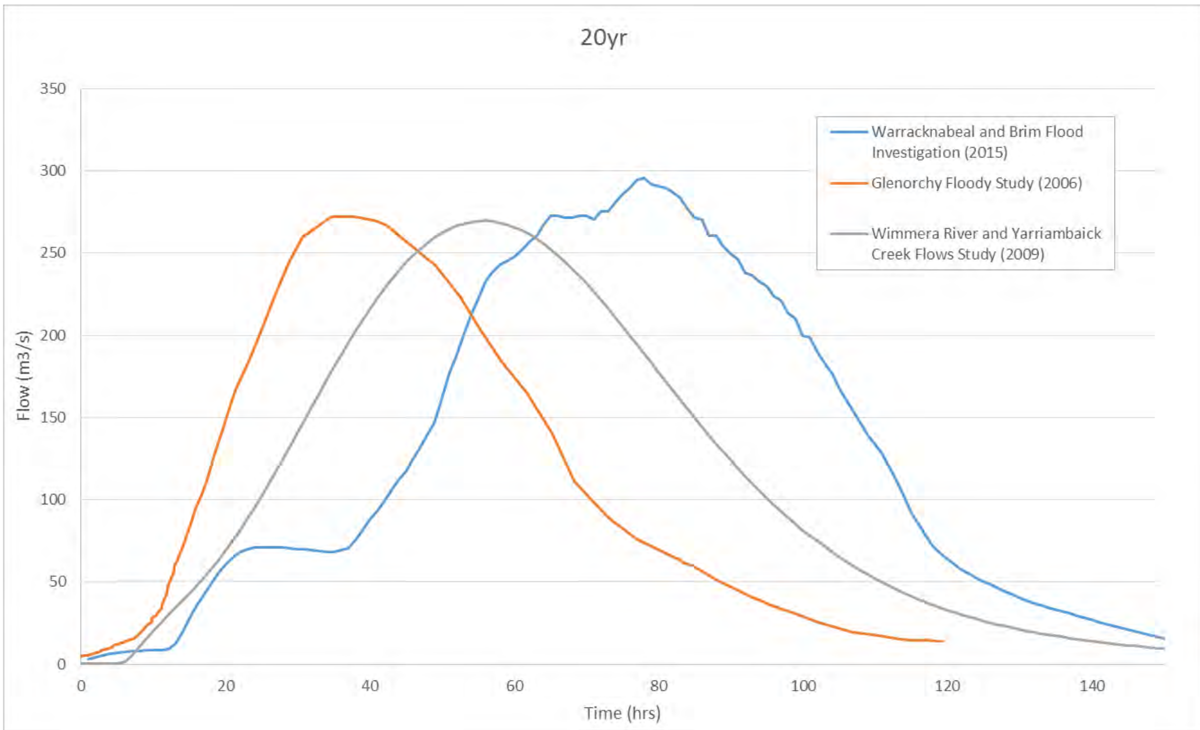
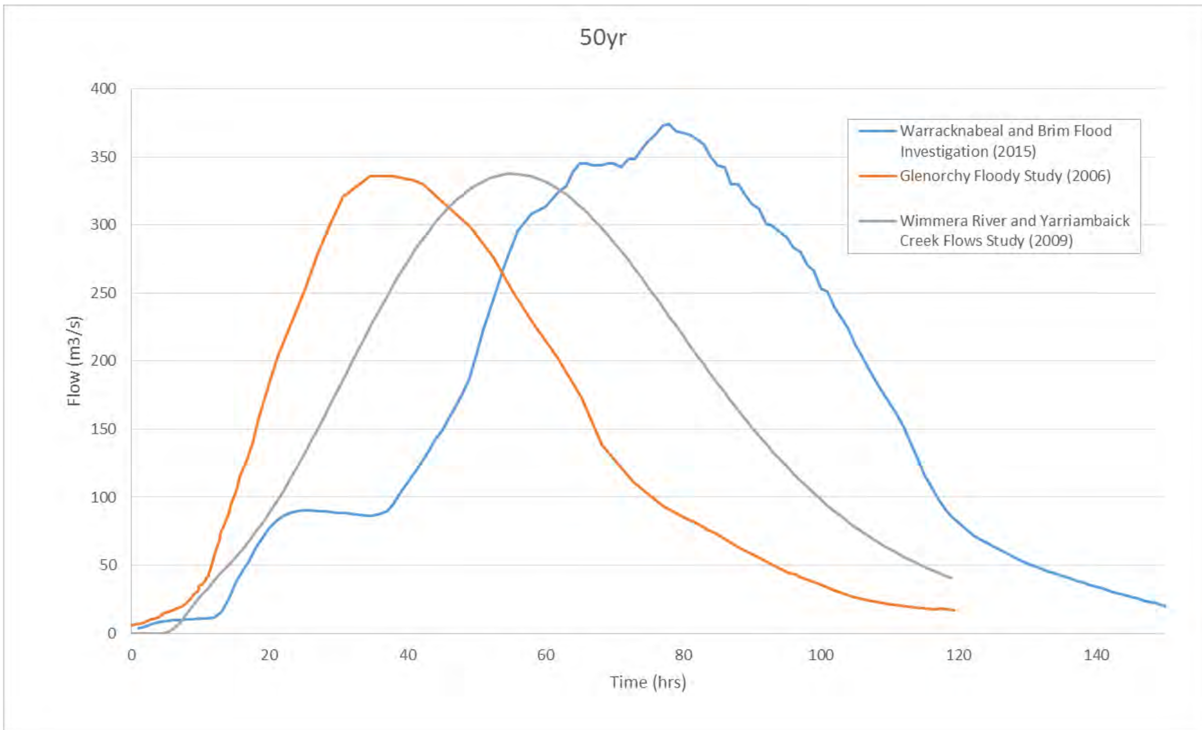


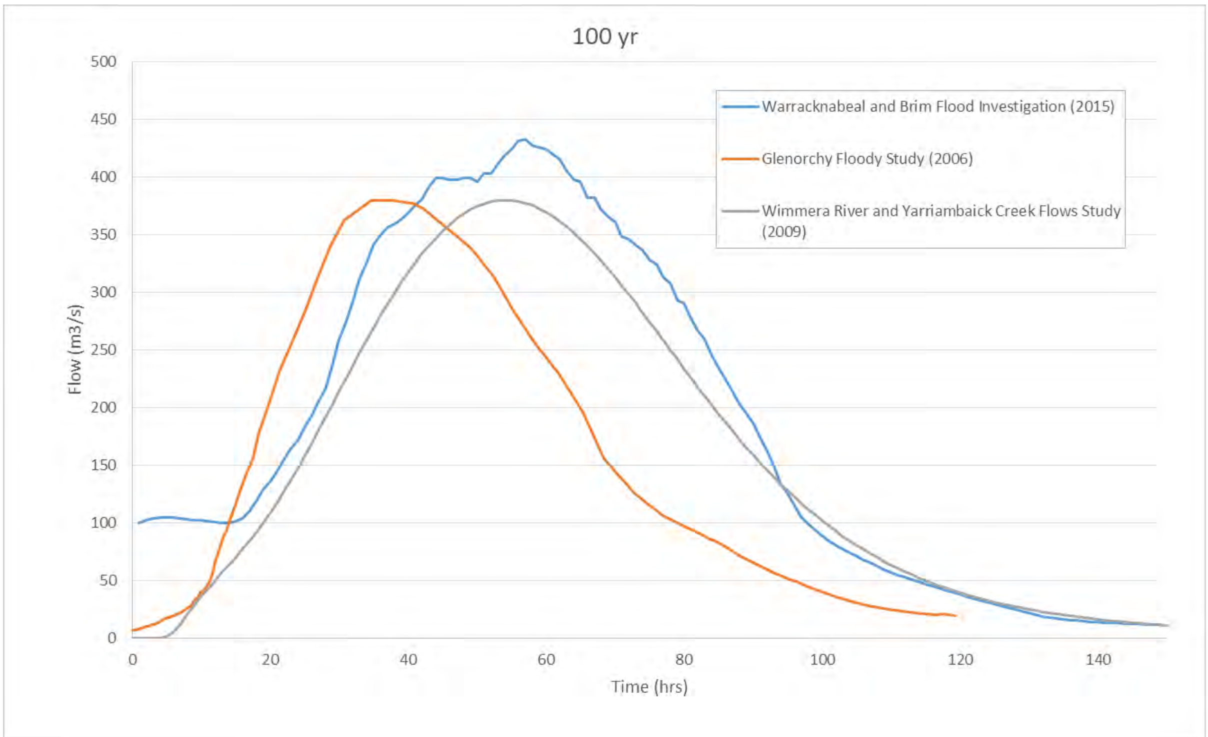
APPENDIX B GLENORCHY DESIGN FLOW HYDROGRAPH COMPARISONS

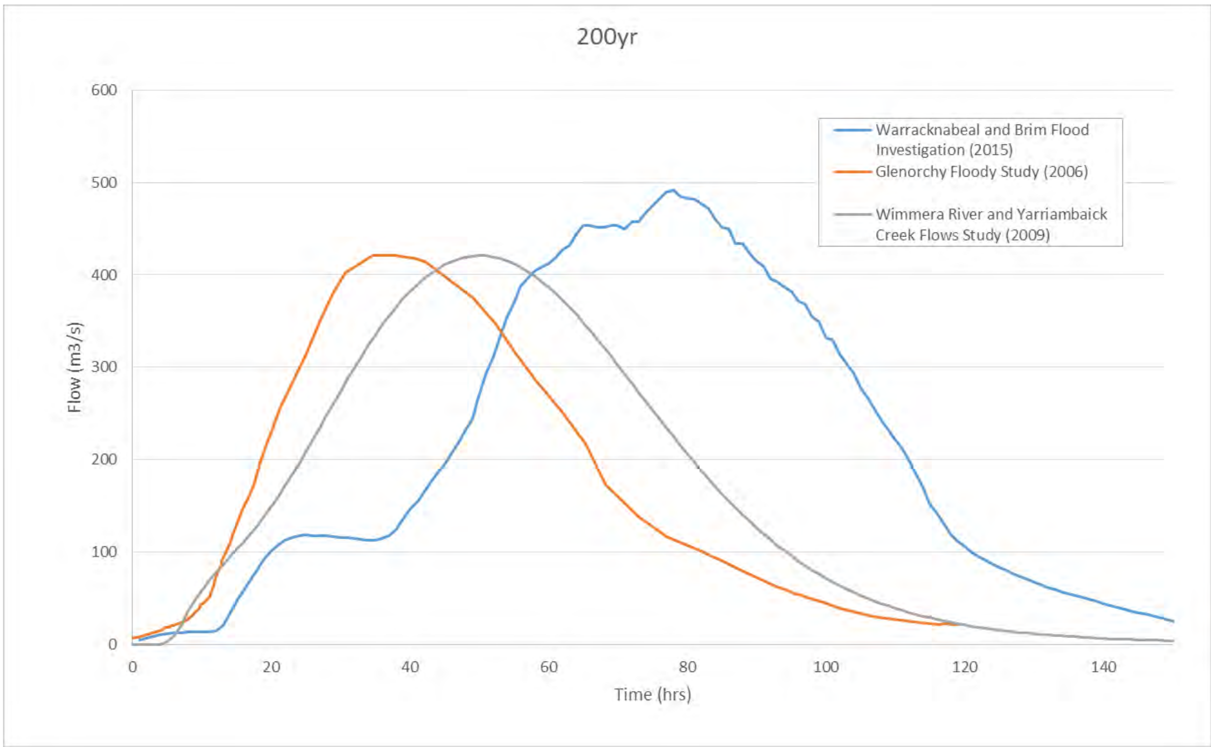

5yr
Flow (m3/s)
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time (hrs)
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)


10yr
Flow (m3/s)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Time (hrs)
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)


20yr
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)
Flow (m3/s)
Time (hrs)
0
50
100
150
200
250
300
350
20
40
60
80
100
120
140


50yr
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)
Flow (m3/s)
Time (hrs)
0
50
100
150
200
250
300
350
400
20
40
60
80
100
120
140


100 yr
500
450
400
350
300
250
200
150
100
50
0
Flow (m3/s)
0
20
40
60
80
100
120
140
Time (hrs)
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)


200yr
600
500
400
300
200
100
0
Flow (m3/s)
0
20
40
60
80
100
120
140
Time (hrs)
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)