Warracknabeal and Brim Flood Investigation – Final Report

July 2016

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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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- ***Recommendation 1:*** Update the planning scheme LSIO and FO layers using the mapping products from this investigation.
- ***Recommendation 2:*** Adopt the flood intelligence information produced as part of this project in the YSC MFEP.
- ***Recommendation 3:*** Provide readily available details to local communities of their flood risk through the Wimmera CMA website, Section 32 certificates (via planning scheme) and ongoing community education.
- ***Recommendation 5:*** Educate the communities in the study area about aspects of the TFWS including their flood risk, local flood warning triggers for action and the warnings that they will receive if a flood is imminent.
- ***Recommendation 6:*** Combine the old Jung gauge rating (for low flows) with new modelled rating (for flood flows). DELWP and BoM to adopt this rating curve for flood forecasting and streamflow monitoring.
- ***Recommendation 7:*** A new streamflow gauge with telemetry be installed at the Ailsa Road crossing of Yarriambiack Creek. Consideration should be given to whether this gauge is a permanent or temporary unit but it must be specific to the site. This gauge should be tied to AHD and the flood mapping outputs of this study.
- ***Recommendation 8:*** BOM provide flood forecasting at the Jung gauges and, in the interim, provide detailed information to all agencies to determine flood forecasting using charts that relate stream height to AEP, and timing of flood flows to AEP.
- ***Recommendation 9:*** Further develop the community flood observers crowdsourcing program to enable people to provide real-time flood height observations to the ICC.
- ***Recommendation 10:*** Establish a 'phone tree' or similar localised communication method for isolated properties in the vicinity and downstream of Brim.
- ***Recommendation 11:*** Explore the possible uptake of a localised smartphone flood warning app for the study area.
- ***Recommendation 12:*** Move the gauge boards at Lah to a location that can be viewed during time of flood.
- ***Recommendation 13:*** Ensure that all people requiring assistance in Yarriambiack Shire are in the Vulnerable Persons Register.
- ***Recommendation 14:*** Engage (e.g. by doorknocking) with all people in the Brim community if a flood is imminent.
- ***Recommendation 15:*** Identify and implement ways for community members in the study area to participate in the establishment, operation and review of the TFWS.
- ***Recommendation 17:*** Ensure that the integration of the TFWS is included as part of future TFWS reviews in the study area.
- ***Recommendation 18:*** Further investigate the potential to upgrade drainage under the Borung Highway east of Warracknabeal
- ***Recommendation 19:*** Further investigate improved drainage under the Henty Highway at Brim
- ***Recommendation 20:*** Contact landholders in Thomas and Molyneaux Streets (between Gardiner and Woolcock) and Arnold, Milbourne, Franklin, Lyle and Shank Streets (between the Henty Highway and Devereux Street) to discuss stormwater issue and impacts during January 2011
- ***Recommendation 20:*** Apply for funding to construct the levee design proposed as part of this project.

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 a large number of properties were protected from above floor inundation. 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 was 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.

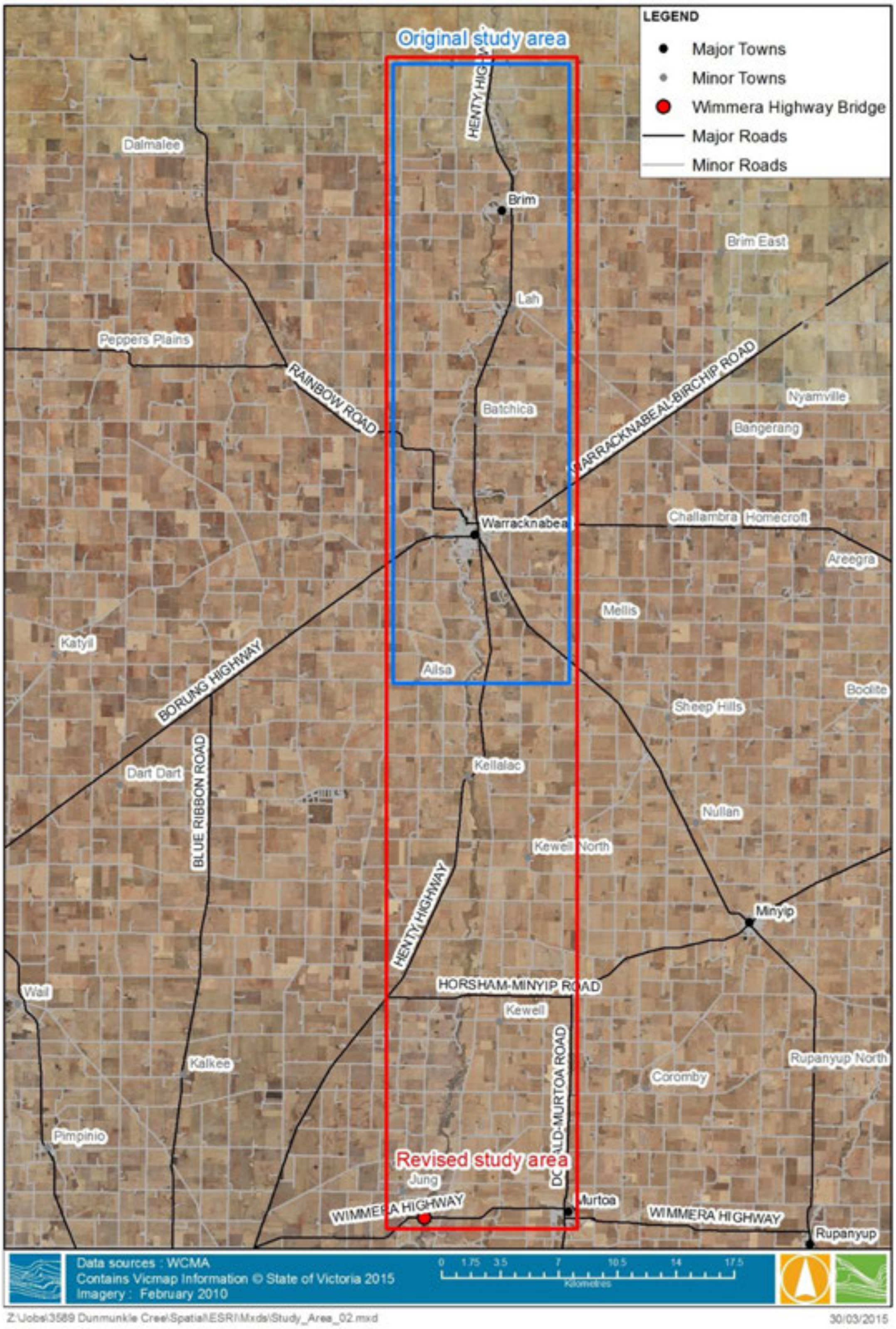


Figure 2-1 Original and extended study area extents

3. REPORTING STRUCTURE

This Report is the final Warracknabeal and Brim Flood Investigation Report, it covers all aspects of the Warracknabeal and Brim Flood Investigation. There were a number of reporting stages throughout the project to allow review from Wimmera CMA, DELWP, Yarriambiack Shire Council and the community, these reporting stages were as follows:

- Site Visit, Inception and Data Collation Report
- LiDAR Verification Memo
- Design Modelling - Remnant Levee Memo
- Hydrology and Hydraulics Report
- *Flood Warning Assessment Report (Molino Stuart)*
- Flood Mitigation Report
- *Levee Engineering Design and Costing Memo (Price Merrett)*
- Flood Intelligence Report
- *Planning Scheme Amendment Report (Planning and Environmental Design)*

The reports listed in *italics* were produced by or in collaboration with other consultants. These reports are summarised in this study report, for full detail see the reports individually.

4. SITE VISIT

A site visit was undertaken on Friday 5th September, 2014 by Clare Wilson (Wimmera CMA), Ben Tate and Ben Hughes (Water Technology). The site visit began at the Yarriambiack Creek Offtake from the Wimmera River and ended in Brim. During the inspection of Warracknabeal and immediate surrounds Bernie Naylor and James Magee (Yarriambiack Shire Council) also attended, while James McFarlane (community member) attended for inspection in and around the Brim township.

The sites visited during inspection are listed below with reference to photographs in Appendix C:

- Yarriambiack Creek Offtake at the Wimmera River (Photos 1, 3 and 3)
- Yarriambiack Creek at the Wimmera Highway Bridge (Photos 4 and 5)
- Warracknabeal township
  - Reconstructed Warracknabeal Primary School Levee (Photo 6 and 7)
  - Several one way stormwater pipes (Photo 8 and 9)
  - Several levee locations adjacent to Yarriambiack Creek
  - Potential levee location along Yarriambiack Creek behind the bowls club (Photo 10)
  - Craig Avenue bridge (Photo 11)
  - Warracknabeal Weir Pool (Photos 12, 13,14 and 15)
  - Gardiner Street
- Warracknabeal Immediate surrounds
  - Earthen embankment downstream of Warracknabeal
  - Borung Highway/Warracknabeal Birchip Road
    - Previous GWMWater channel and culvert infrastructure (Photos 16, 17, 18, 19 and 20)
    - Several drainage channels
    - Wilken grain silos (Photo 21)
- Brim township
  - Earthen levee at King Street (Photo 22)
  - Brim Weir (Photos 23 and 24)
  - US and DS ends of the Brim Weir (Photos 30 and 31)

- Levee constructed along a private landholders property boundary south east of the weir pool (Photos 25 and 26)
- Private properties which may have been impacted by flood water if no levees were constructed on King Street and Swan Street
- Brim Recreation Reserve (Photos 27 and 28)
- Henty Highway adjacent to the Brim Silos (Photo 29)
- Henty Highway bridge over Yarriambiack Creek (Photo 32)

5. TOPOGRAPHIC DATA VERIFICATION

5.1 LiDAR Data Availability

Three LiDAR datasets were available within the study area, two datasets 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, Land, Water and Planning (DELWP) captured LiDAR as part of the Index of Stream Conditions (ISC) project, this data was limited to waterways and some floodplain areas. The available LiDAR dataset details were as follows:

- 2005 Warracknabeal LiDAR – Coverage of the Warracknabeal township. Provided as a 2 m resolution grid, 0.15 m vertical accuracy, 0.55 m 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 1 m resolution grid, 0.2m vertical accuracy, 0.3 m horizontal accuracy.

5.2 Methodology

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

- Verification against feature survey, comparing feature survey heights to those captured in the LiDAR date. This was completed at the following locations:
    - 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 covering the overlapping areas.

The focus of the topographic verification was to determine which dataset or combination of datasets was most appropriate for use in this project.

Generally, feature survey is considered to be the most accurate method to record and represent ground surface. Feature survey of a number of road crests was compared to LiDAR data, road crests were chosen due to the flat surface they provide, which should be well represented in the LiDAR data. Road crest transects also enable a graphical comparison as well as being able to calculate statistics on a point by point basis such as mean, max and minimum difference.

Comparison of the 2005 and 2010 LiDAR datasets was completed across the entire overlapping area. This highlighted any spatial topographic inconsistences such as large earth works, changes to agricultural management (removal of irrigation channels, drainage improvements, etc.) as well as areas which may have had consistent thick vegetation (mature crops or windrows) which may have led to the ground surface being misrepresented in the LiDAR. It also highlighted any misrepresentations within the LiDAR datasets including "banding" where inconsistent elevations are present at the edge of LiDAR flight runs.

5.2.1 Feature Survey Comparison

Overview

Road crest feature survey was captured in four locations around Warracknabeal and three locations between Jung and Warracknabeal. Emphasis was placed on the Warracknabeal township as this is the most populated area and where mitigation designs are proposed (See Section 10). The chosen locations were straight roads with low camber. The road crests surveyed in Warracknabeal were Dimboola Road, Anderson Street, Rainbow Road and Devereux Street, as shown in Figure 6-1. The road crests waterway cross section survey between Jung and Warracknabeal was captured at the Wimmera Highway, the Henty Highway and Ailsa Road, as shown in Figure 5-2.

Figure 5-1 Verification survey locations in Warracknabeal

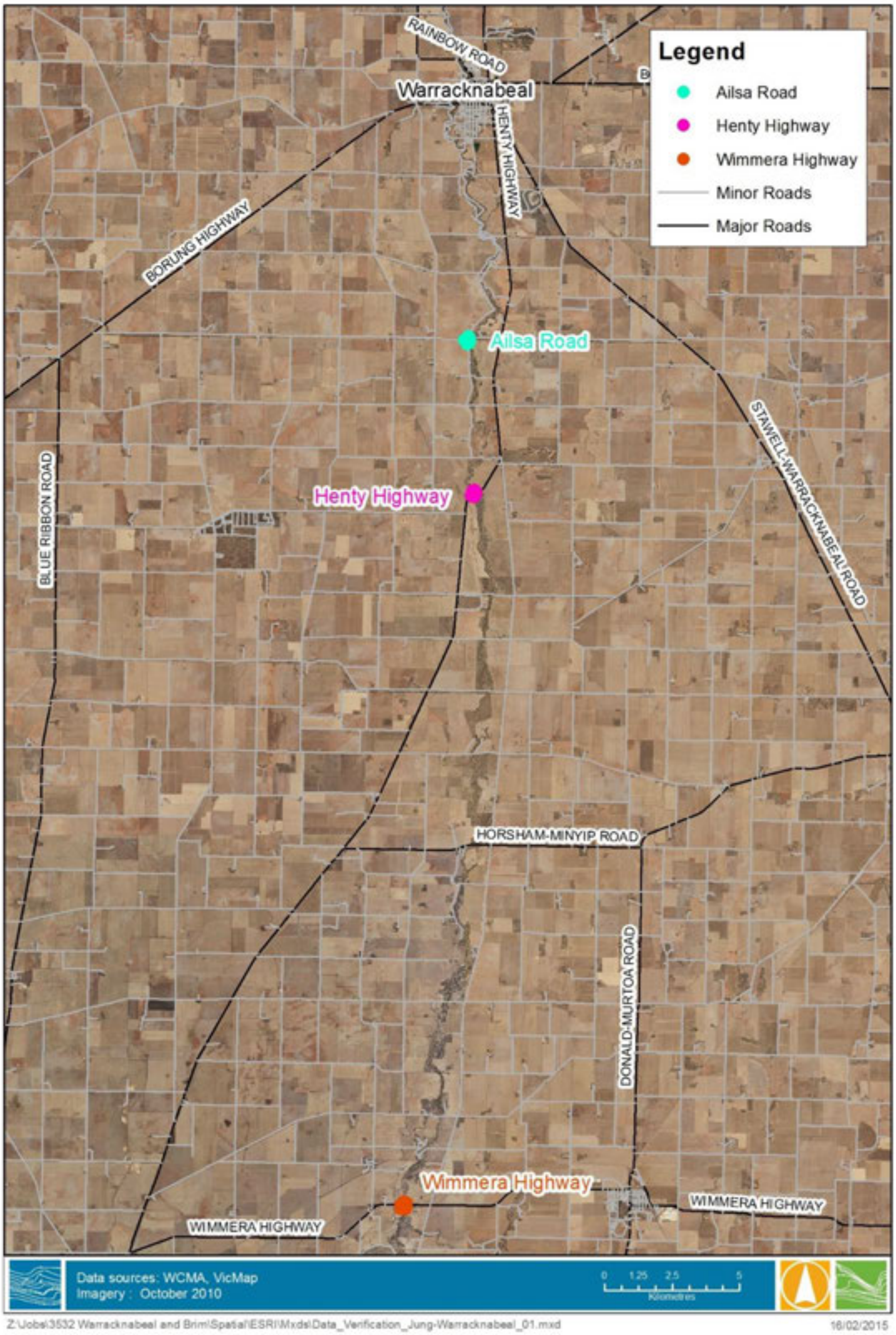


Figure 5-2 Verification survey locations between Jung and Warracknabeal

Warracknabeal – Road crest survey

Road crests surveyed in Warracknabeal were compared against both the 2005 Warracknabeal and 2010 ISC LiDAR datasets for Dimboola Road, Anderson Street, Devereux Street and Rainbow Road are shown in Figure 5-3, Figure 5-4, Figure 5-5 and Figure 5-6 respectively.

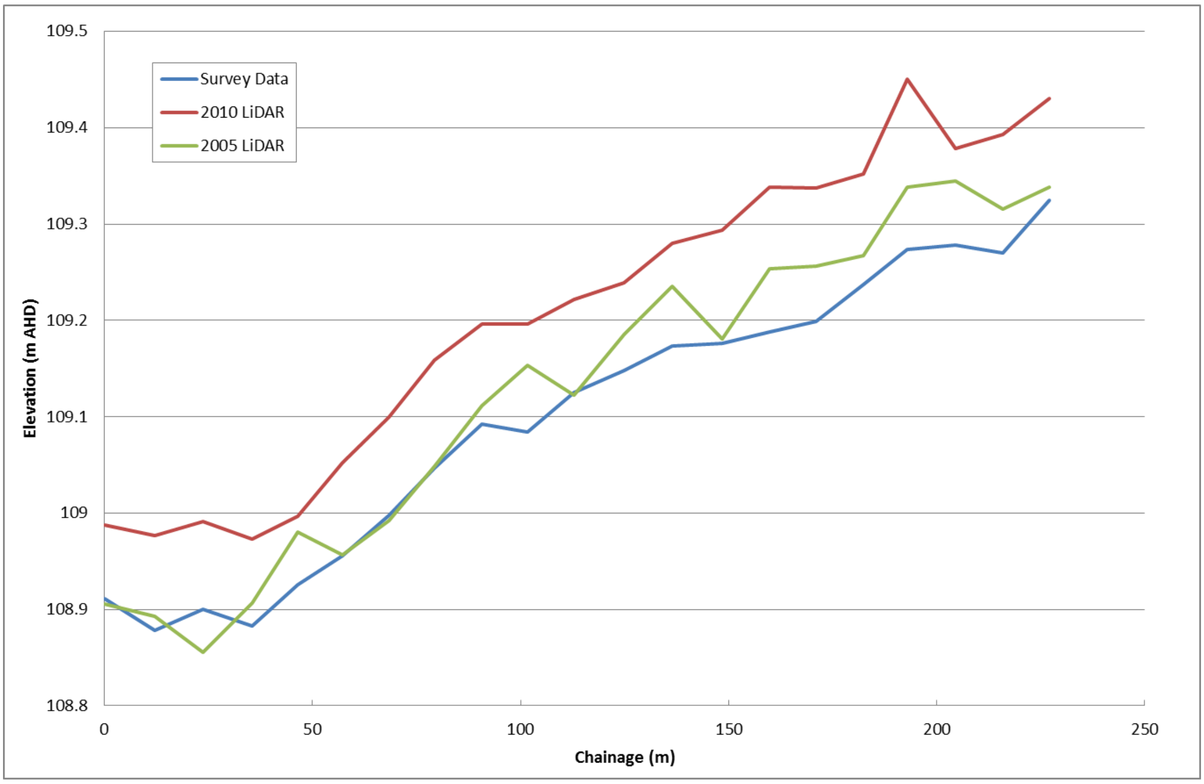


Figure 5-3 Dimboola Road - Survey and LiDAR Data comparison

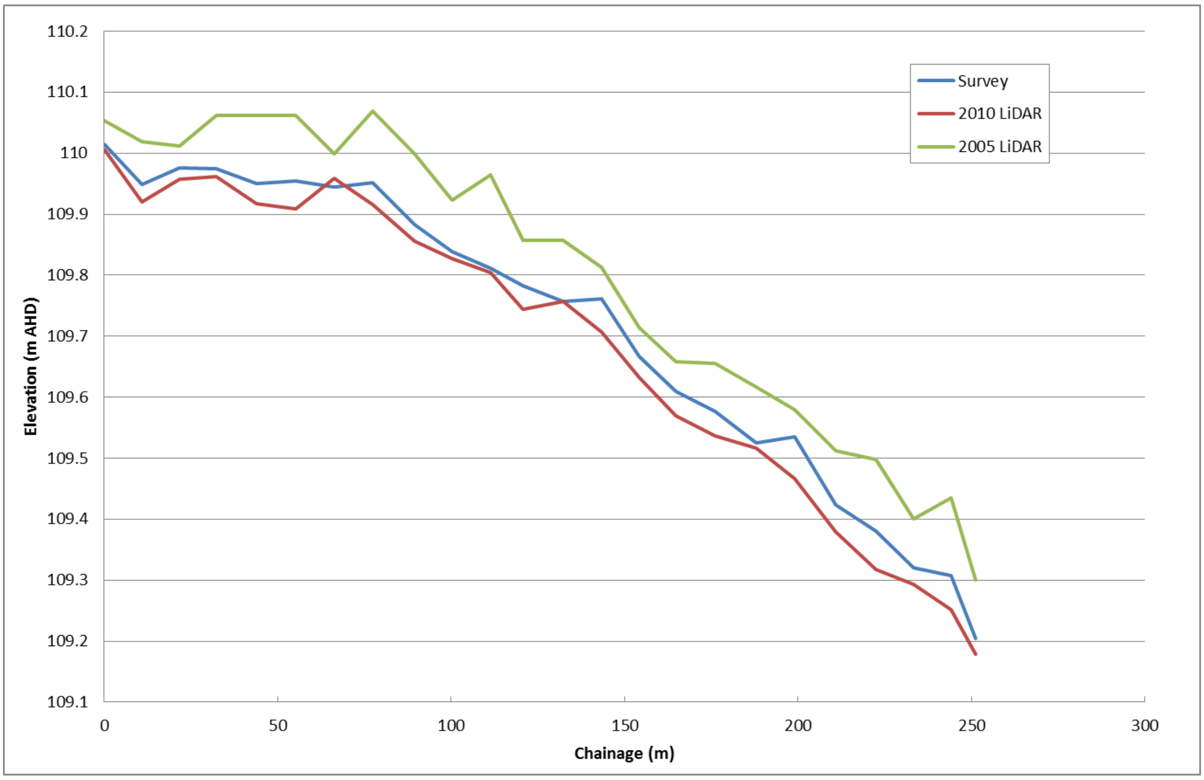


Figure 5-4 Anderson Street - Survey and LiDAR Data comparison

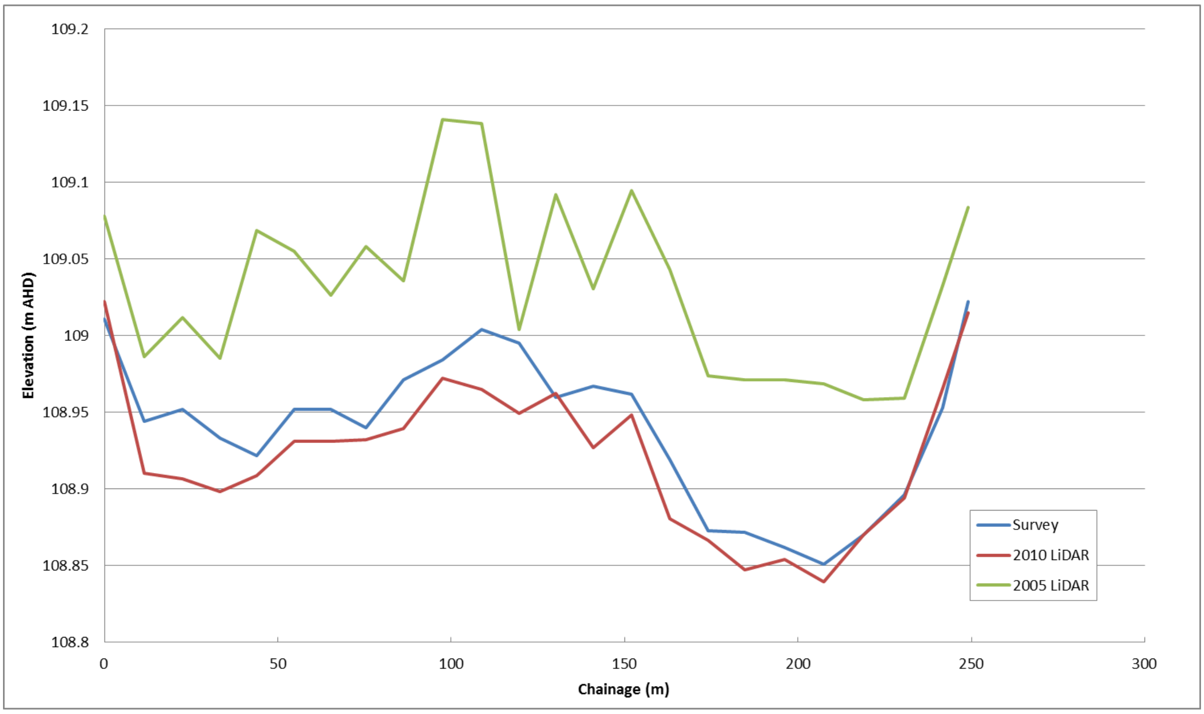


Figure 5-5 Devereux Street - Survey and LiDAR Data comparison

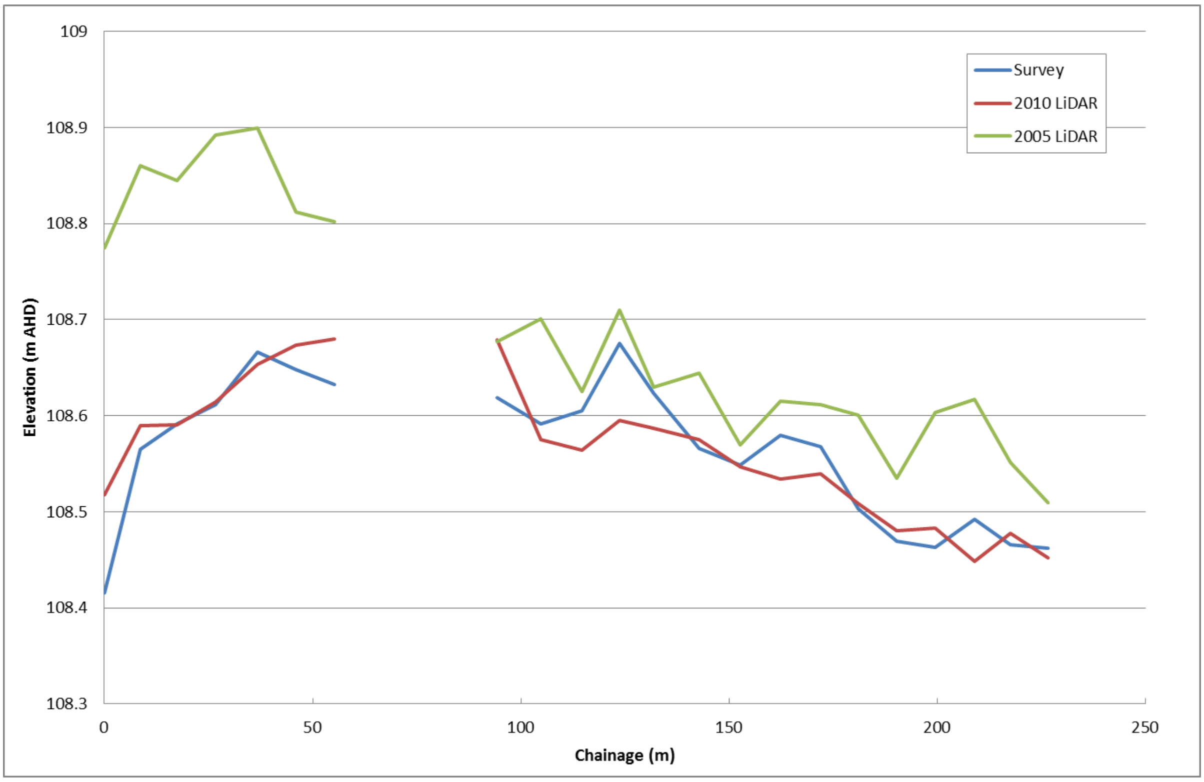


Figure 5-6 Rainbow Road - Survey and LiDAR Data comparison

The comparison along Rainbow Road (Figure 5-6) contains a gap in the transect between chainage 50 m and 100 m. This is the Yarriambiack Creek Bridge, which was removed from the analysis. The LiDAR datasets had the bridge removed as part of the data processing and no data was available for the bridge deck.

The difference between the survey and 2010 LiDAR survey levels was calculated for each survey point location. The difference in elevation along each transect was then averaged and the maximum and minimum difference calculated. These statistics are shown in Table 5-1.

Table 5-1 Mean, maximum, minimum and standard deviation differences between surveyed of LiDAR topography levels

Statistic	Elevation difference (LiDAR – Survey)							
	Dimboola Road		Anderson Street		Devereux Street		Rainbow Road	
	2010	2005	2010	2005	2010	2005	2010	2005
Average (m)	0.11	0.03	-0.03	0.11	-0.02	0.09	0.00	0.11
Max. (m)	0.18	0.07	0.01	0.36	0.01	0.16	0.10	0.36
Min. (m)	0.07	-0.04	-0.07	0.00	-0.05	0.01	-0.08	0.00
Standard Deviation (m)	0.02	0.03	0.02	0.10	0.02	0.04	0.04	0.10

Jung – Warracknabeal - Road crest and waterway survey

The surveyed levels captured between Jung and Warracknabeal were compared against both the 2005 Wimmera and 2010 ISC LiDAR. The survey locations were the Wimmera Highway, Henty Highway and Alisa Road. At each location the road crest was surveyed along with a minimum of two waterway cross sections upstream and downstream. Water way transects were captured for inclusion into the hydraulic model.

Wimmera Highway

The Wimmera Highway road crest and waterway transect locations are shown in Figure 5-7. The topographic comparisons for each transect at the Wimmera Highway are shown in Appendix D with Transect 01 and 04 (Road Crest) shown in Figure 5-8 and Figure 5-9. These transects are considered typical of the elevation differences at the Wimmera Highway.

The topographic comparison at the Wimmera Highway and the waterway transects show the 2010 LiDAR to be consistently higher than the survey and the 2005 LiDAR. It also shows a lack of Yarriambiack Creek channel definition in the 2010 LiDAR, indicating the presence of water when the LiDAR was flown. The 2005 LiDAR compares well to the survey.

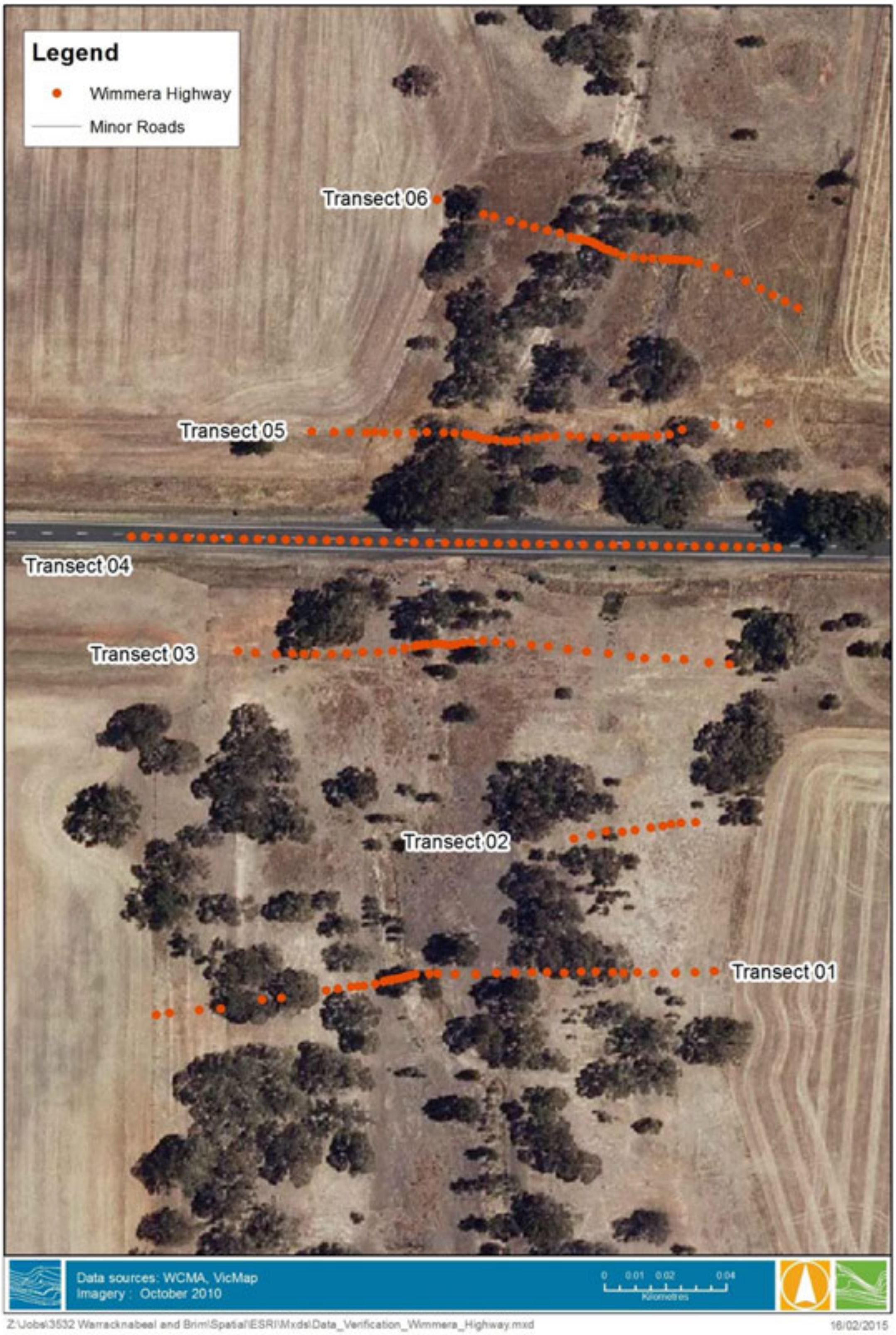


Figure 5-7 Wimmera Highway transect locations

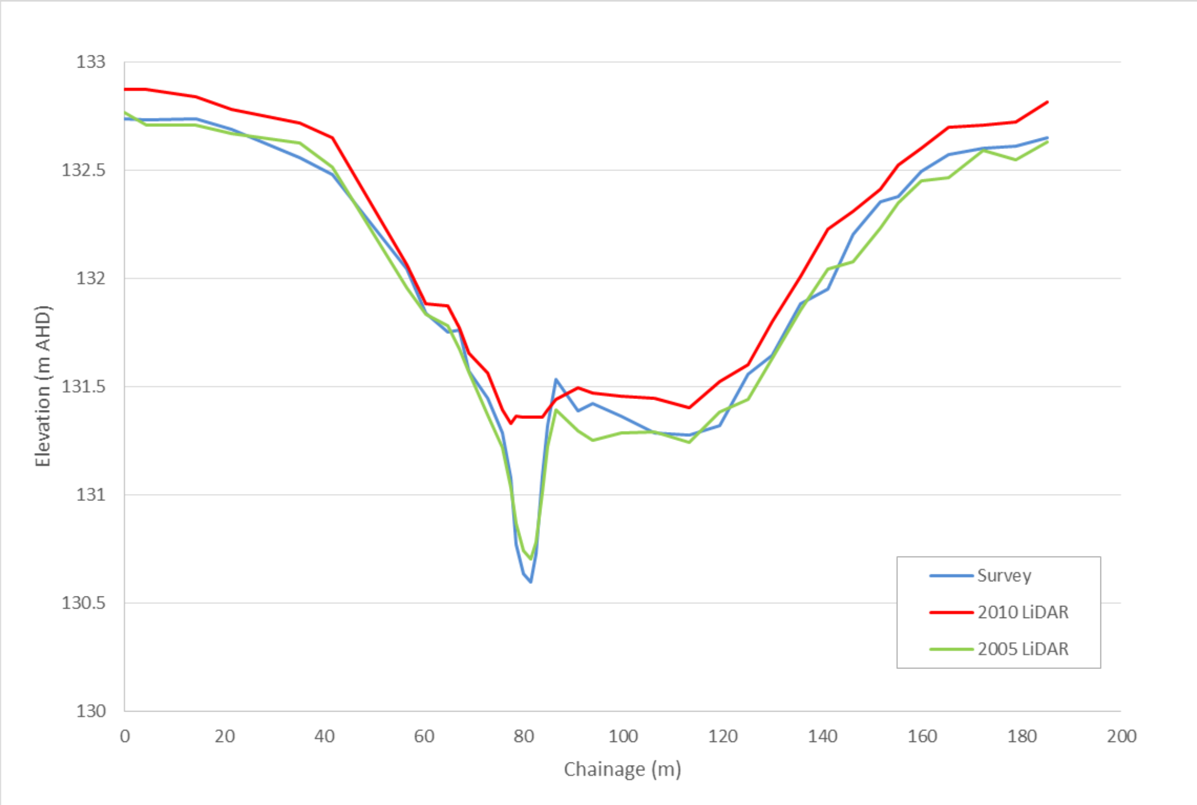


Figure 5-8 Wimmera Highway transect 01

Figure 5-9 Wimmera Highway transect 04 (Road Crest)

Henty Highway

The Henty Highway and waterway transects locations are shown in Figure 5-10. The topographic comparisons for each transect at the Henty Highway are shown in Appendix D with Transect 03 (Road Crest) and 05 shown in Figure 5-11 and Figure 5-12.

Similar to the Wimmera Highway transects, at Transect 05 of the Henty Highway the 2010 ISC LiDAR is consistently higher than the survey and 2005 LiDAR datasets. At Transect 03 the 2010 LiDAR shows a good match to survey, however, there were issues with the horizontal alignment of the survey. The road crest at this location has a degree of camber due to the highway having a bend over the waterway. Given all five transects at this location are showing the 2010 LiDAR data to be higher than both the 2005 LiDAR and the survey, the matching levels at Transect 03 is considered an anomaly, probably due to the horizontal alignment of the transect and camber.

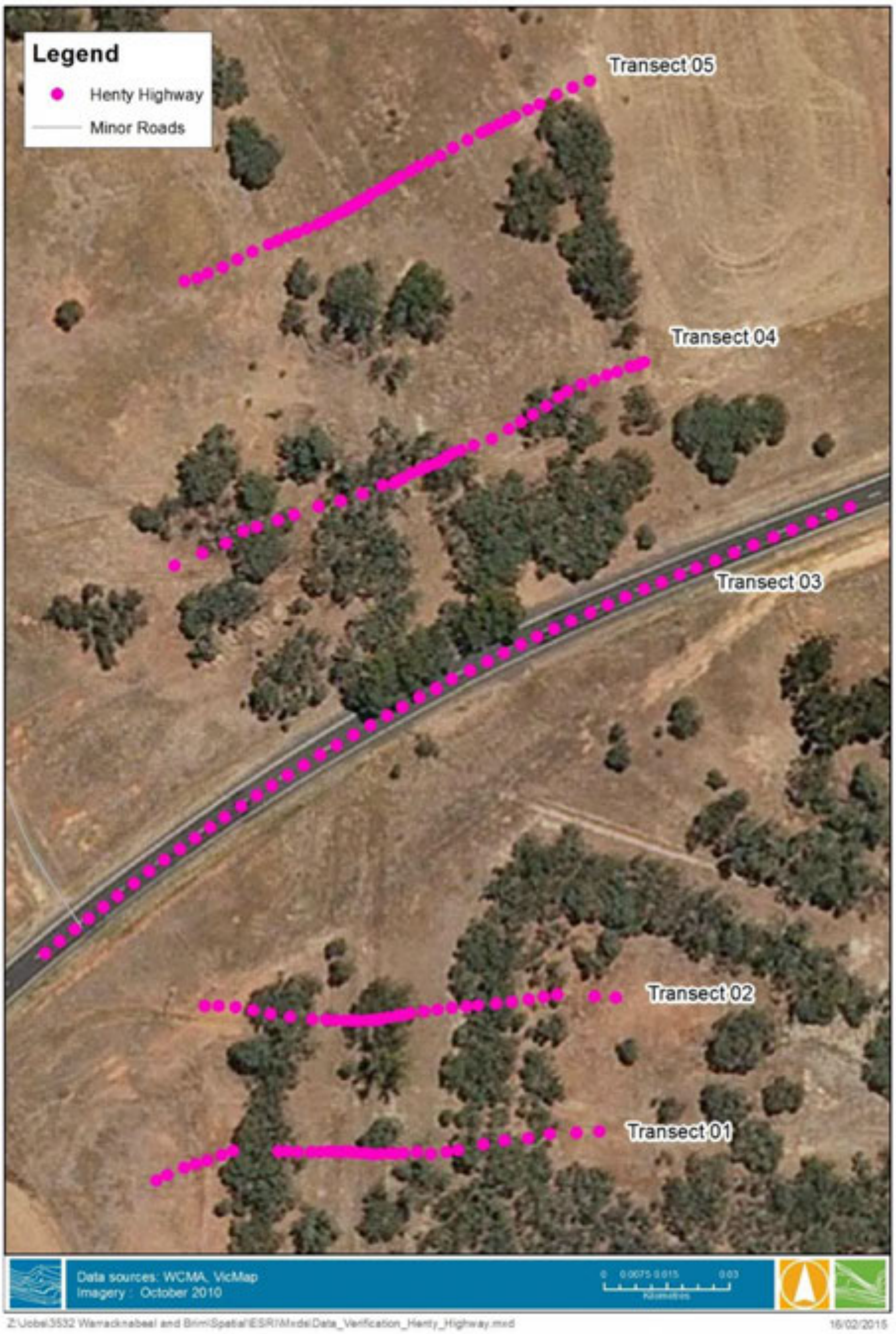


Figure 5-10 Henty Highway transect locations

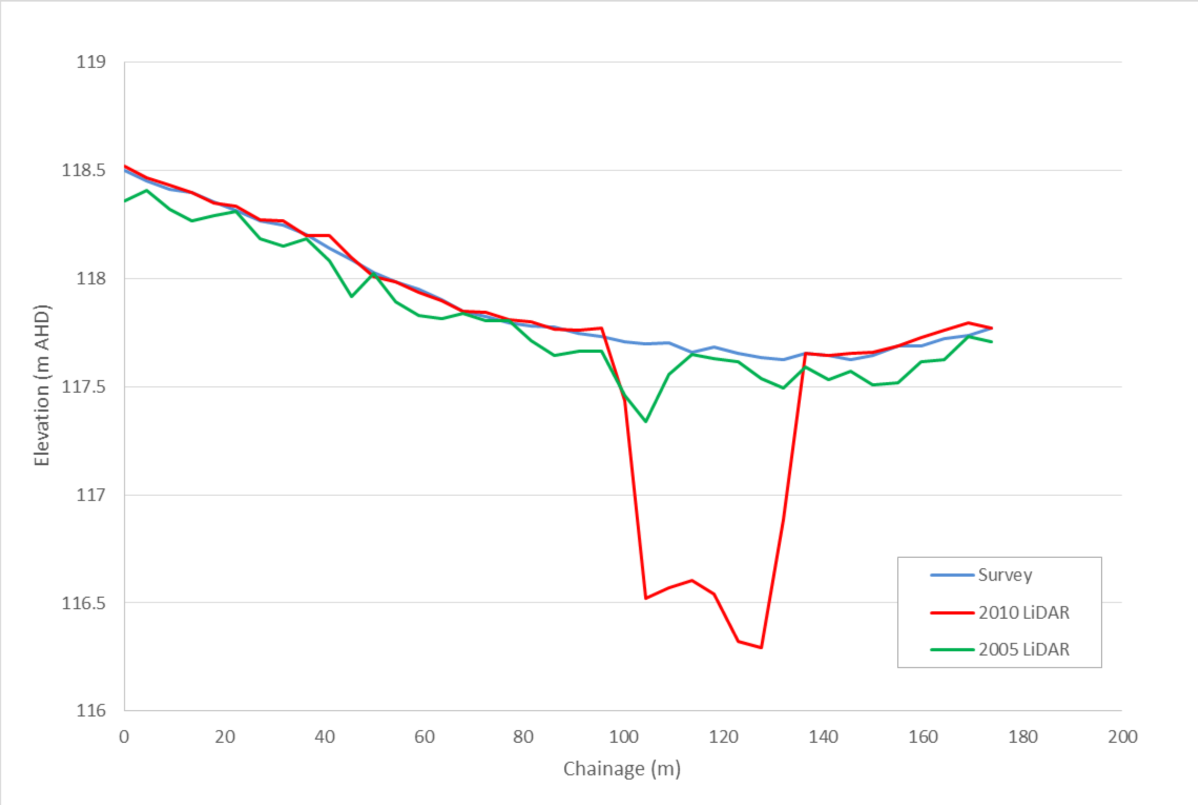


Figure 5-11 Henty Highway transect 03 (Road Crest)

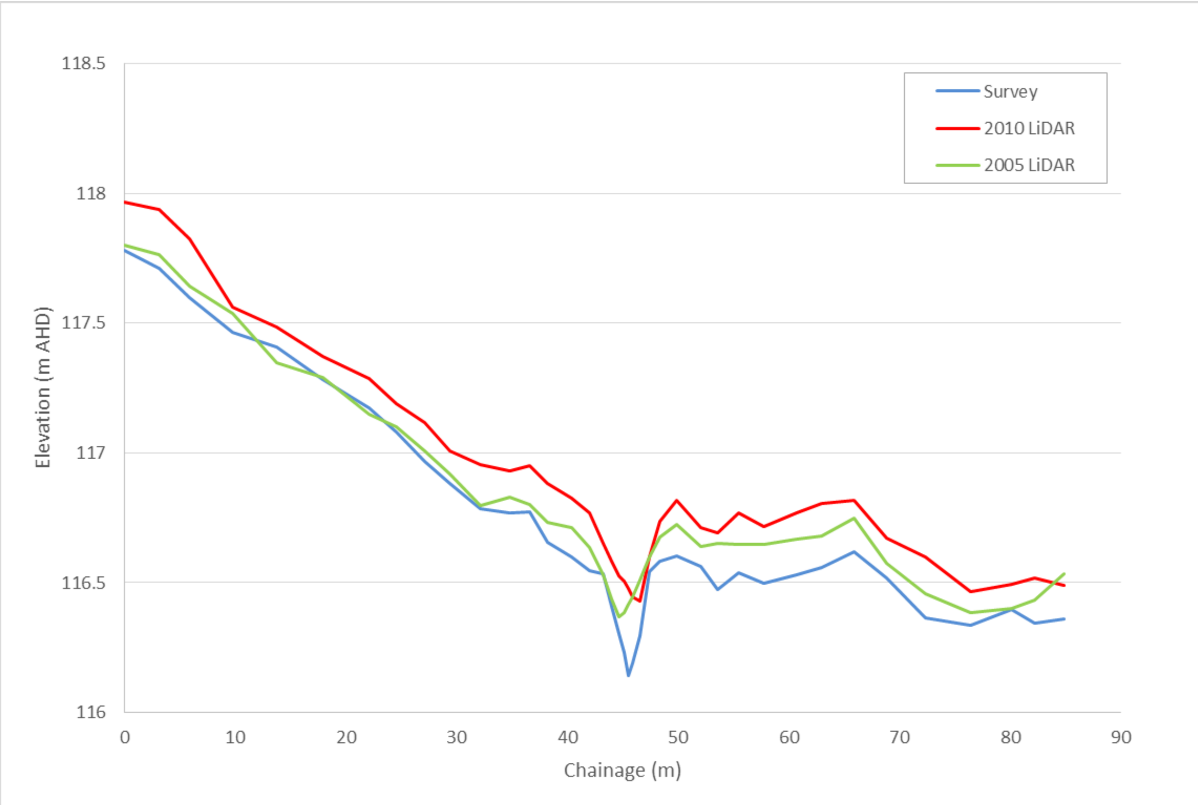


Figure 5-12 Henty Highway transect 05

Ailsa Road

The Ailsa Road and waterway transect locations are shown in Figure 5-13. The topographic comparisons for each transect at Ailsa Road are shown in Appendix D with Transect 01 and 03 (Road Crest) shown in Figure 5-14 and Figure 5-15.

The extracted transects at Ailsa Road show similar results to the Wimmera Highway and Henty Highway with the 2010 ISC LiDAR levels overestimating the surveyed levels and the 2005 LiDAR levels.

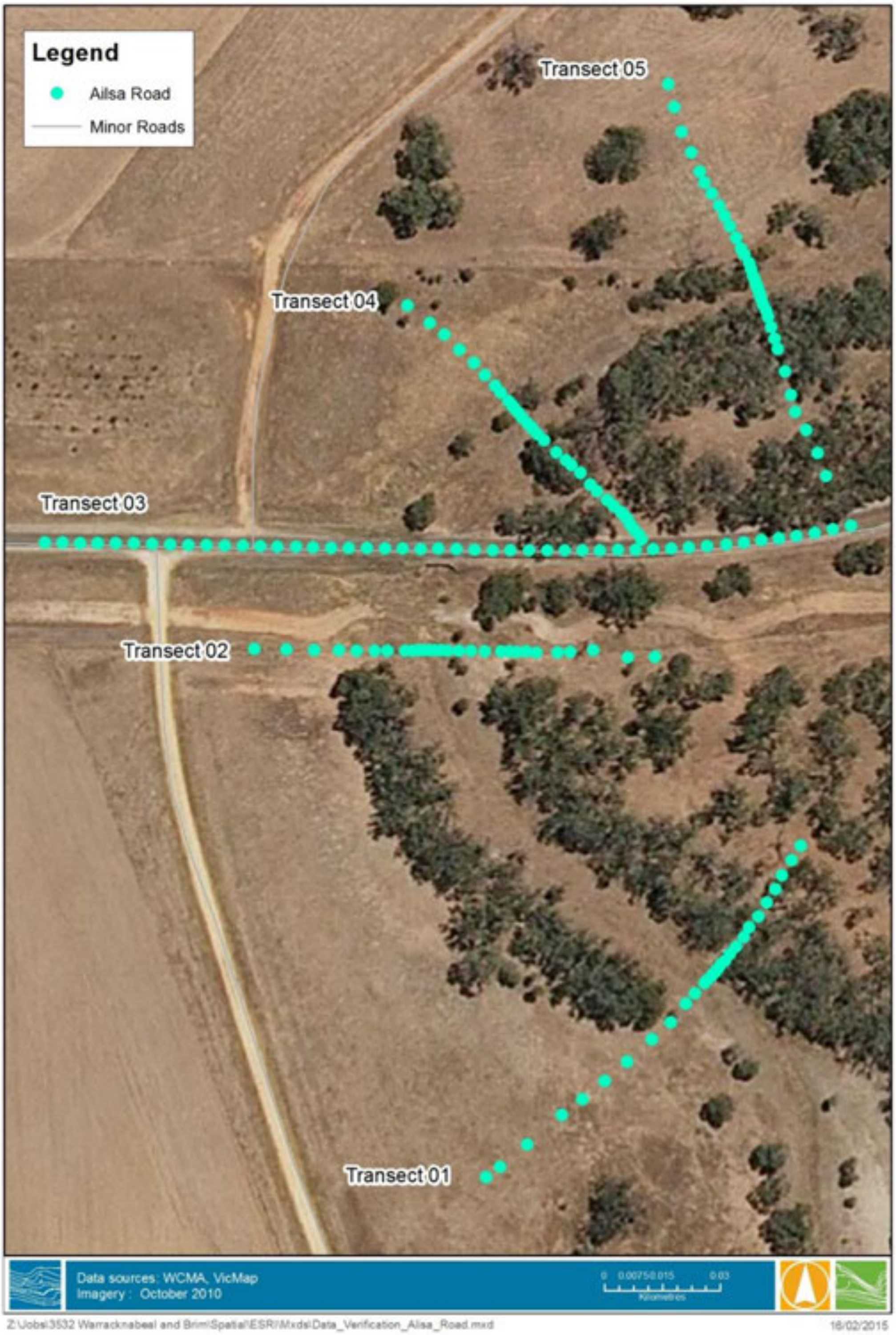


Figure 5-13 Ailsa Road transect locations

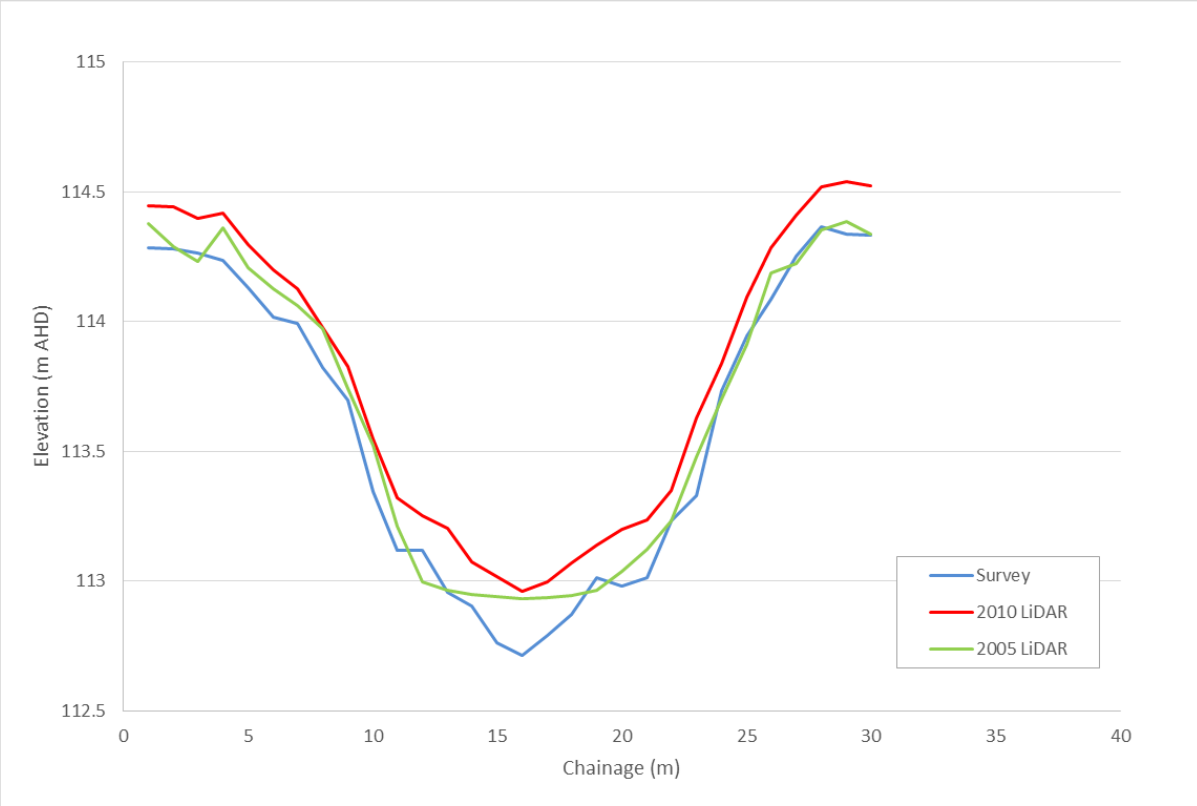


Figure 5-14 Ailsa Road transect 01

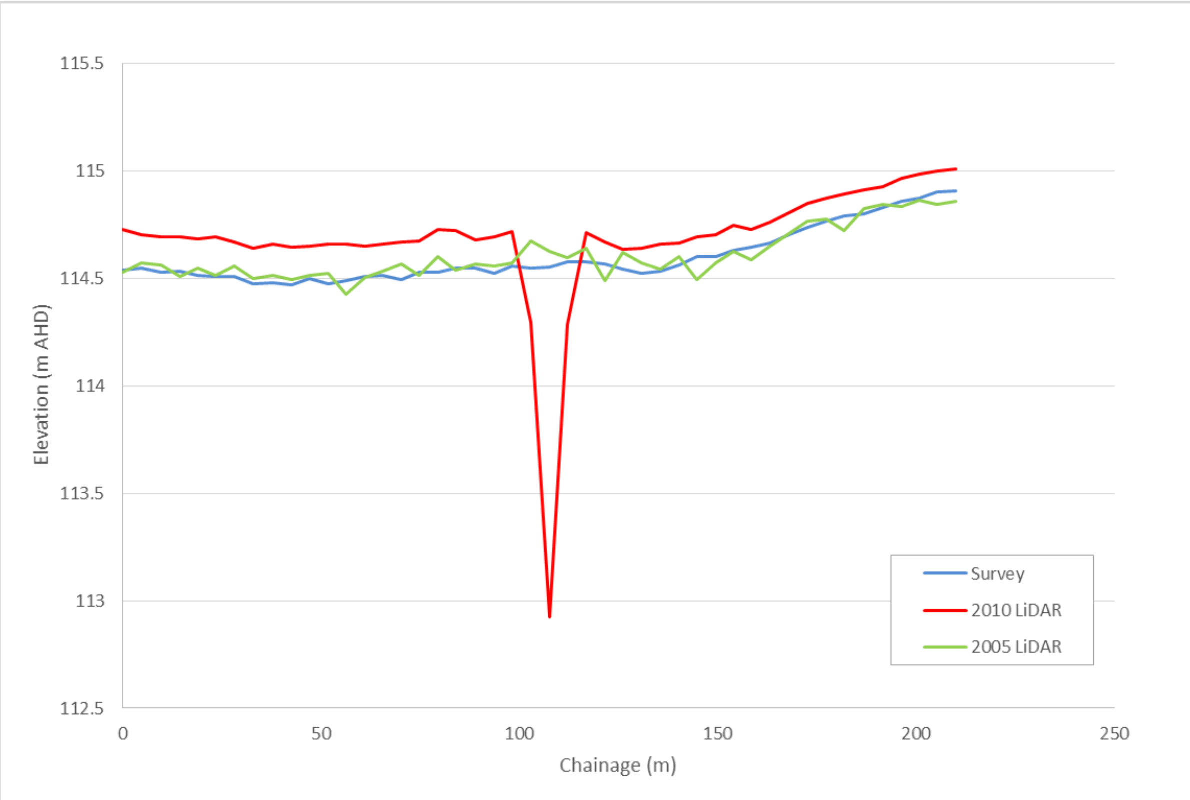


Figure 5-15 Ailsa Road transect 03

The difference between the survey and each LiDAR dataset was calculated at each survey point and the maximum, minimum and average difference for each location was calculated. These statistics were summarised into all road transects and the waterway transects at each location, this comparison was completed excluding data that recorded water in the Yarriambiack Creek channel. The statistics are shown in Table 5-2.

Table 5-2 Differences between surveyed and LiDAR topography at all road transects (across all three sites) and waterway cross-sections at each survey location.

Statistic	Elevation difference (LiDAR – Survey)							
	All Road Transects		Wimmera Highway		Henty Highway		Ailsa Road	
	2010	2005	2010	2005	2010	2005	2010	2005
Average (m)	0.04	-0.06	0.19	-0.07	0.12	0.03	0.19	0.06
Max. (m)	0.20	0.13	0.96	0.35	0.33	0.28	0.38	0.32
Min. (m)	-0.25	-1.00	-0.48	-1.00	-0.03	-0.27	-0.10	-0.34
Standard Deviation (m)	0.04	0.02	0.08	0.06	0.02	0.02	0.02	0.03

Discussion

Warracknabeal – Road Crest Survey

The transect comparison along Dimboola Road shows the 2010 LiDAR data to be consistently 0.1 m higher than the survey data. This was not true of the 2005 LiDAR which matched the surveyed levels much closer. This was also highlighted in the point comparison with the mean difference between the surveyed and 2010 LiDAR elevations being 0.11 m. The maximum difference along Dimboola Road was 0.18 m.

The remaining three transects at Anderson Street, Devereux Street and Rainbow Road all show relatively similar transect elevations with a slight bias to the 2010 LiDAR being marginally lower, but matching the survey very closely. This is confirmed by the average differences in elevation across each of the three transects ranging between -0.03 m and 0.00 m.

The 2005 LiDAR was shown to be consistently higher than the survey data for all transect comparisons. It was also higher than and the 2010 LiDAR for all transects except for the Dimboola Road transect where the 2010 data was around 0.1 m higher.

Jung – Warracknabeal Road Crest and Waterway Survey

The transect comparison at each road crest shows the 2010 LiDAR to be consistently higher at every location. It also shows the waterway invert is not well defined which is likely to be a result of water in Yarriambiack Creek at the time the LiDAR was flown.

The difference between the 2010 LiDAR and the surveyed levels appears to be approximately 0.1 to0.2 m. The Henty Highway road transect comparison is the exception with 2010 LiDAR closely matching the survey, however issues were encountered with the horizontal alignment against the road camber, creating a degree of uncertainty in the comparison.

Differences between the 2005 LiDAR and the surveyed levels were also observed, however they are not consistent with the average difference at each location (waterway transects only) varying from 0.07 to 0.06 m.

5.2.2 LiDAR Data Comparison

The 2005 Warracknabeal and 2005 WCMA region LiDAR datasets were compared to the 2010 ISC LiDAR. A comparison was made by subtracting each 2005 data set from the 2010 data, calculated as follows:

Difference = 2010 ISC LiDAR – 2005 LiDAR

This calculation results in a positive value when the 2010 ISC data is higher, and a negative value when it is lower. Figure 5-16 and Figure 5-17 show the difference between the 2010 ISC and 2005 Warracknabeal and 2005 WCMA region LiDAR datasets respectively.

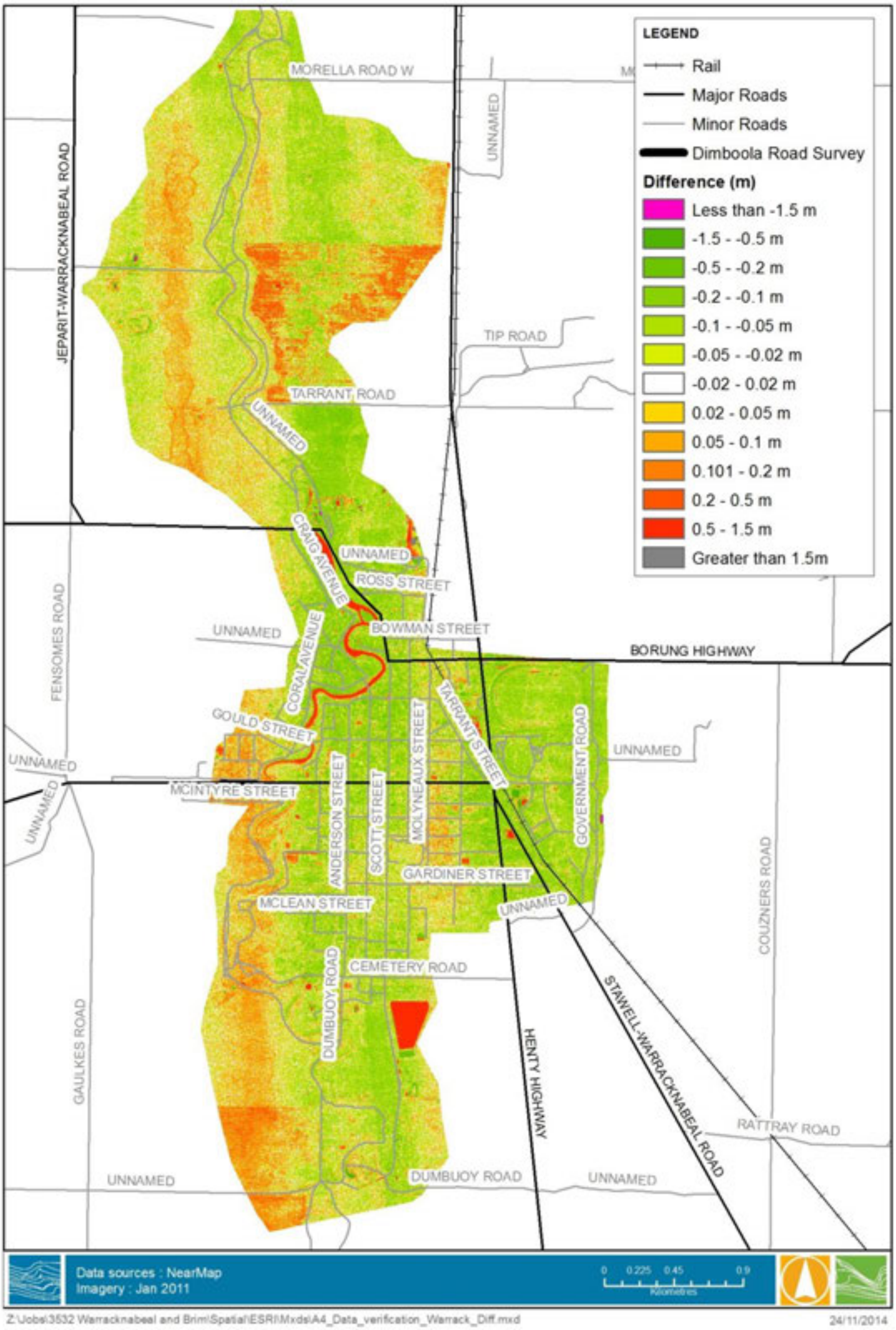


Figure 5-16 Differences between the 2010 ISC and 2005 Warracknabeal LiDAR (2010-2005)

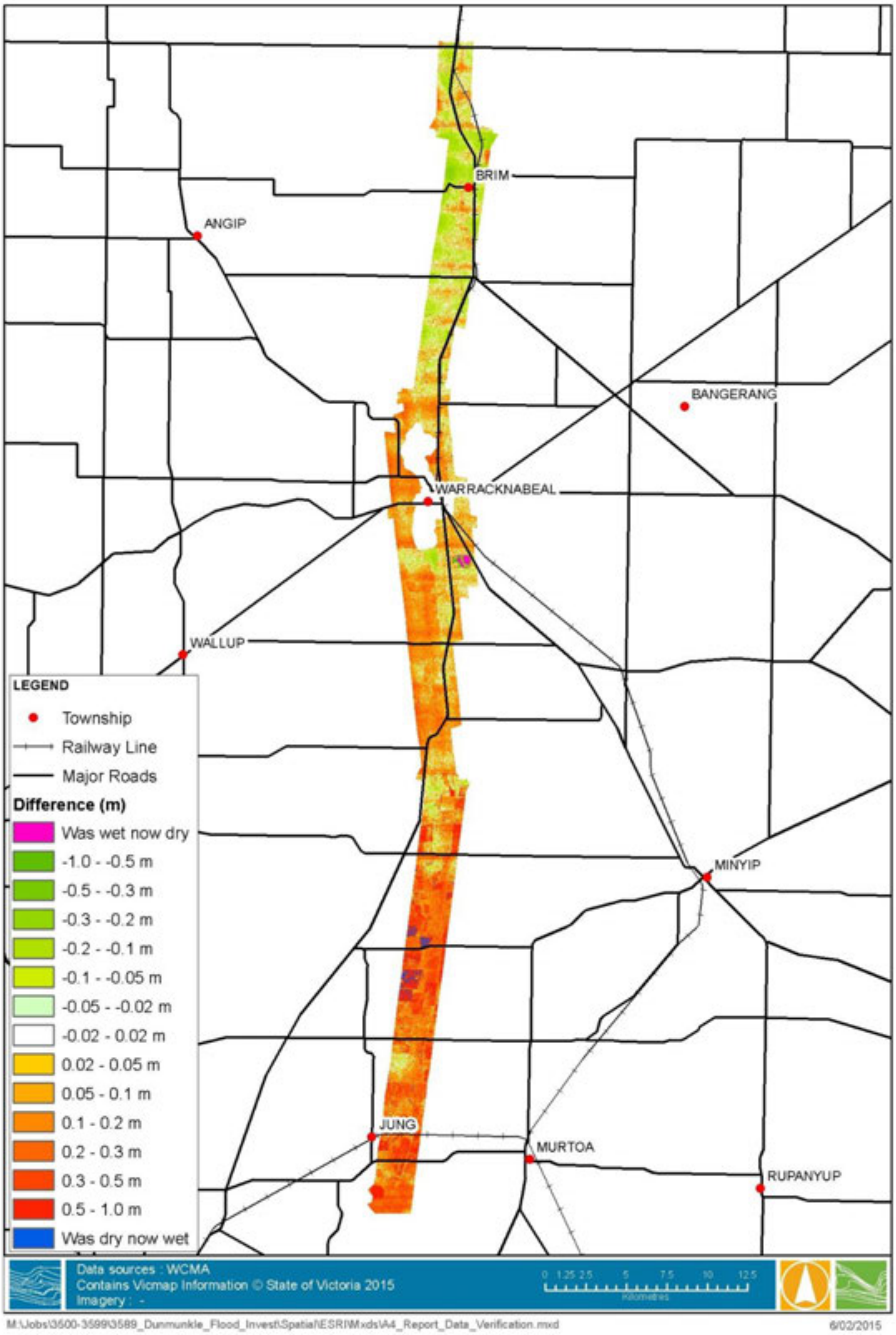


Figure 5-17 Differences between the 2010 ISC and 2005 WCMA Region LiDAR (2010-2005)

The 2005 Warracknabeal and 2010 ISC LiDAR comparison has several areas of significant difference including Yarriambiack Creek upstream of the weir pool and the waste water treatment plant water storage. In both instances the 2010 ISC LiDAR is higher, indicating a higher water level in both locations. North of Warracknabeal at Tarrant Road there is also a paddock which appears to have a higher representative ground surface in the 2010 ISC LiDAR. This may be due to a dense vegetation type misrepresenting the ground surface, most likely a mature monoculture agricultural crop given the time of year the data was captured (October). As well as isolated differences there is also the presence of bands running north-south where the topography is either higher or lower than the data captured as part of the 2005 Warracknabeal LiDAR dataset. These bands are most obvious in Figure 5-16 immediately west of the Warracknabeal township.

The 2005 WCMA Region and 2010 ISC LiDAR comparison also shows areas of significant difference related to water levels, most notably south east of the township at Lake Whitton. Areas in direct proximity to Warracknabeal are higher on average in the ISC LiDAR showing a range of orange and yellow colours in Figure 5-17. North of Warracknabeal regularly spaced bands where the elevation is higher than lower are present running east west across the Yarriambiack Creek direction of flow.

Statistics on each 2005 LiDAR comparison were calculated across the overlapping topography extent, these statistics are shown in Table 5-3.

Table 5-3 Differences between 2010 and 2005 LiDAR topography levels

Road transect	Elevation difference (m) [2010 LiDAR – 2005 LiDAR]	
	2005 Warracknabeal LiDAR	2005 WCMA LiDAR
Mean (m)	-0.028	-0.019
Max. (m)	7.641	7.130
Min. (m)	-2.794	-8.441
Standard Deviation (m)	0.151	0.188

The comparison of each 2005 LiDAR dataset to the 2010 LiDAR data showed relatively similar statistics. The Mean difference in topographic levels for the Warracknabeal and WCMA regional LiDAR data were -0.028 m and -0.019 m respectively. The maximum and minimum differences are generally due to man induced topographic changes or increased/decreased water levels in each dataset. In this case the 7 m plus maximums are due to the size of the grain silos north of Warracknabeal.

Comparison of the 2005 Warracknabeal and Regional datasets to the 2010 ISC LiDAR data has shown isolated differences in line with what would be expected. However, banding was present in both comparisons. Banding running north south was present in the 2005 Warracknabeal LiDAR data comparison and east west bands in the 2005 Regional WCMA LiDAR data.

The mean difference between the 2005 WCMA LiDAR and the 2010 ISC LiDAR is due to the areas south of Warracknabeal showing a positive difference, while the areas north of Warracknabeal are showing a negative difference, so when considering the averages they balance each other out.

5.2.3 Discussion

Warracknabeal

Comparison of the 2010 ISC LiDAR data to road transect feature survey has shown similar levels in Warracknabeal, with the exception of the Dimboola Road transect, where the LiDAR data was approximately 0.1 m higher than surveyed levels. The 2005 Warracknabeal LiDAR data at this location showed topographic levels similar to that surveyed. Yarriambiack Shire Council were contacted to confirm no road works were completed along the surveyed section of Dimboola Road had been carried out between 2010 (when the LiDAR was flown) and 2014 (when the survey was captured), explaining the uniform difference, however no changes to road height were undertaken during this time[1].

Comparison of the 2005 Warracknabeal and 2010 ISC LiDAR indicated a band of topography where the 2010 ISC data was higher than the 2005 Warracknabeal data running north south through the section of Dimboola Road surveyed. A closer perspective of this location is shown in Figure 5-18.

No bands could be observed in the 2010 ISC or 2005 Warracknabeal LiDAR by changing the colour display limits, this is likely due to the difference of 0.1 m being less than the local relative topographic changes. The band observed in the comparison between the 2005 Warracknabeal and the 2010 ISC LiDAR data shows the ISC LiDAR to be consistently higher, in the same location the ISC LiDAR is 0.1 m higher than the surveyed levels. However, it cannot be definitively stated which dataset contains the banding. Banding issues have been observed in many older datasets.

The captured survey transects are shown to cover both the higher band (at Dimboola Road) and an area where the 2010 ISC LiDAR is lower than the 2005 ISC LiDAR data (Anderson Street and Deveruex Street). However, transects in the areas where the 2010 ISC data is lower have shown to match the LiDAR levels accurately. This indicates the ISC data in this area is a good match.

The east west bands observed in the 2010 ISC and 2005 Wimmera CMA Region LiDAR comparison are likely to be present in the 2005 LiDAR. The ISC LiDAR was flown along Yarriambiack Creek (north south), given banding is observed in the opposite direction to the ISC data flight path it is most likely present in the 2005 Regional LiDAR data.

The difference between the surveyed and 2010 ISC LiDAR levels is approximately 0.1 m; this is still within the stated accuracy of the LiDAR data at 0.2 m.

[1] Pers. Comm. – Yarriambiack Shire Council – James Magee

Figure 5-18 Dimboola Road - Differences between the 2010 ISC and 2005 Warracknabeal LiDAR (2010-2005)

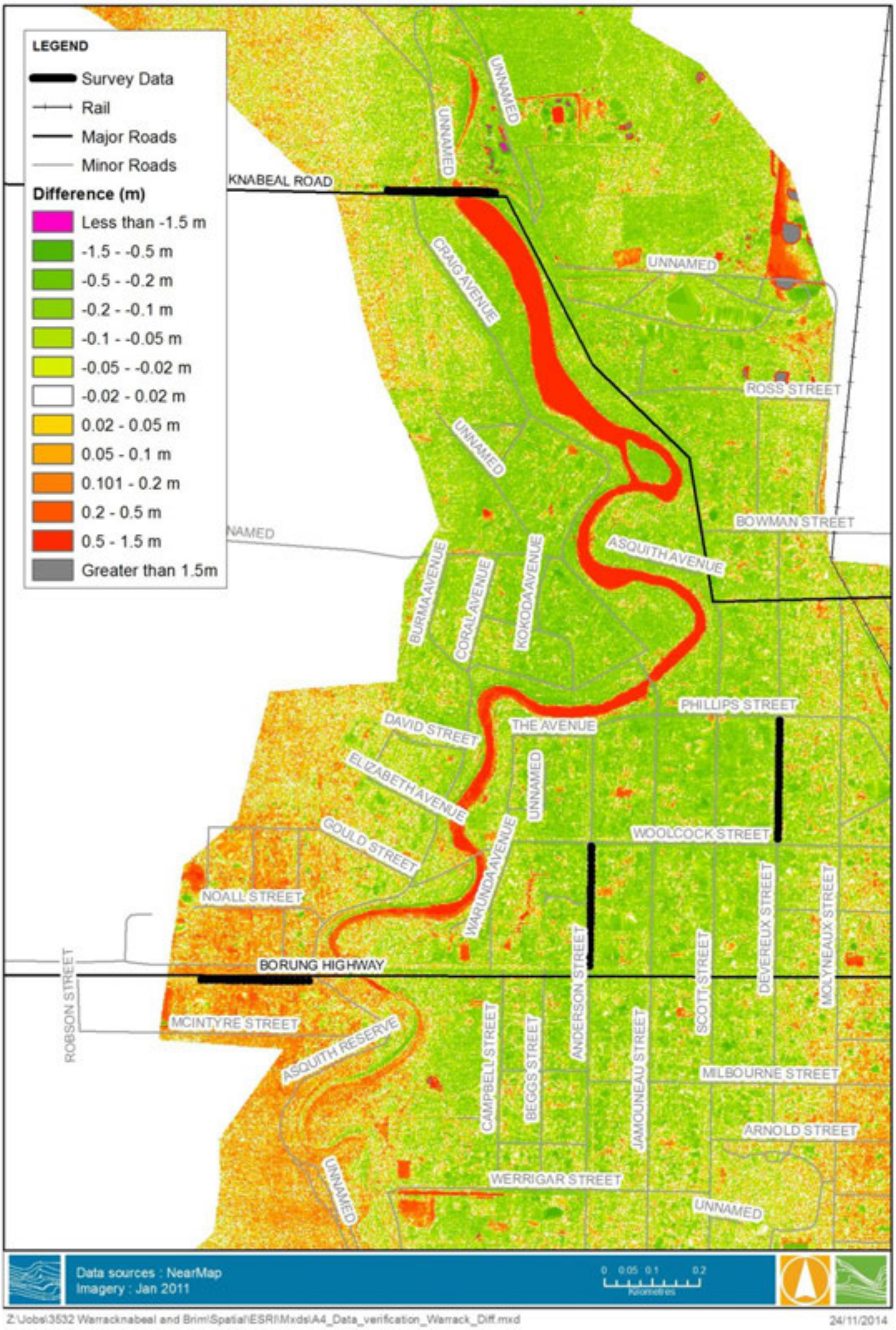


Figure 5-19 Survey transects and differences between the 2010 ISC and 2005 Warracknabeal LiDAR (2010-2005)

Broader Study Area

The survey data comparison at all surveyed locations outside of Warracknabeal showed the 2005 LiDAR data matched surveyed levels better than the 2010 LiDAR data, with the 2010 data consistently higher. The waterway transects also showed the 2010 LiDAR poorly represented the waterway channel invert due to the presence of water. This was not found in the 2005 data. This was highlighted in the Jung area where the Yarriambiack Creek channel is 1 m higher in the 2010 LiDAR than that flown in 2005, as shown in Figure 5-20.

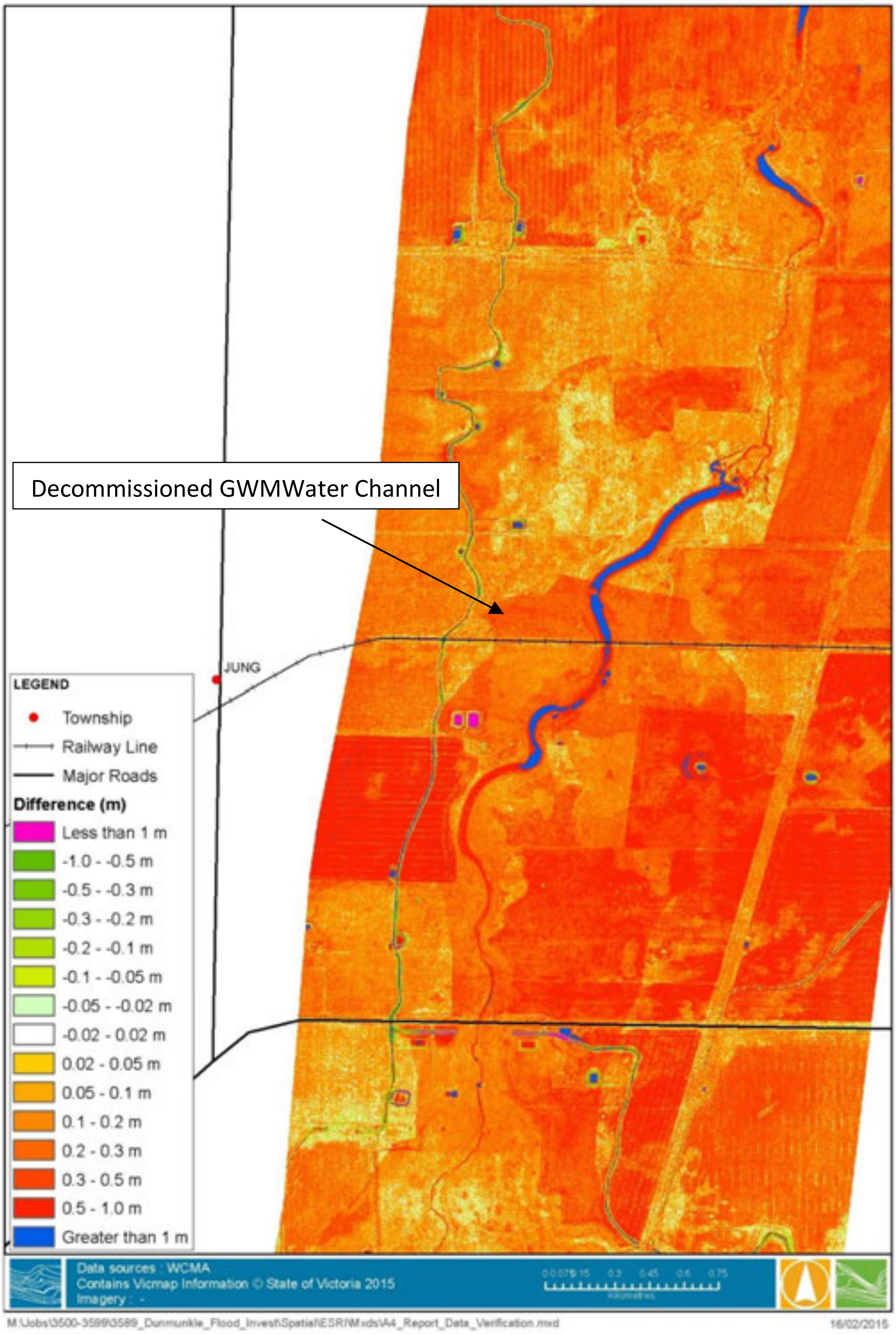


Figure 5-20 LiDAR differences: 2010 ISC LiDAR – 2005 Floodplain LiDAR

Figure 5-20 also shows a GWMWater stock and domestic channel which was represented in the 2005 LiDAR but is shown as decommissioned in the 2010 data. This indicates the potential for topographic changes to have occurred between 2005 and 2010, this is especially significant because of the broad scale channel decommissioning GWMWater have been undertaking across their management region. While some of this may be reflected in the 2010 data, none will have been captured in the 2005 data.

The comparison of the 2010 and 2005 LiDAR datasets has shown that generally the 2010 LiDAR is higher than the 2005 data south of Warracknabeal, and lower north of Warracknabeal.

5.3 Outcome

The 2010 ISC LiDAR data was shown 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 in these locations. The 2005 LiDAR also showed a much better definition of the Yarriambiack Creek channel 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, a combination of both datasets was 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 5-21 shows the transition between the 2005 and 2010 LiDAR datasets. At the transition point the LiDAR datasets have similar levels ensuring unimpeded water movement. 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 5-21.

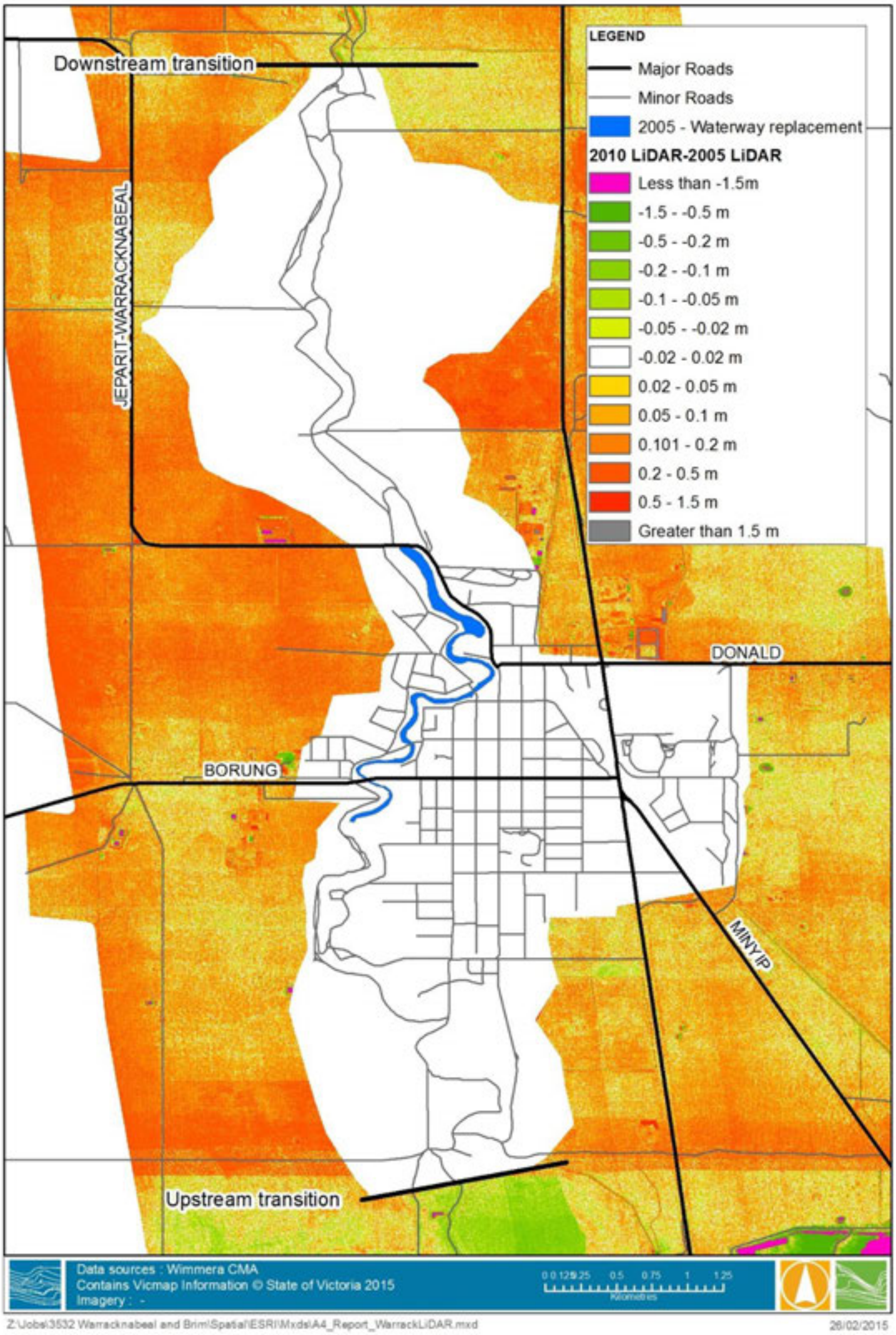


Figure 5-21 Transition between the 2005 and 2010 LiDAR Datasets.

6. AVAILABLE INFORMATION

6.1 Streamflow gauges

6.1.1 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 Murtoa (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 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 (primarily Mt William Creek). 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 6-1.

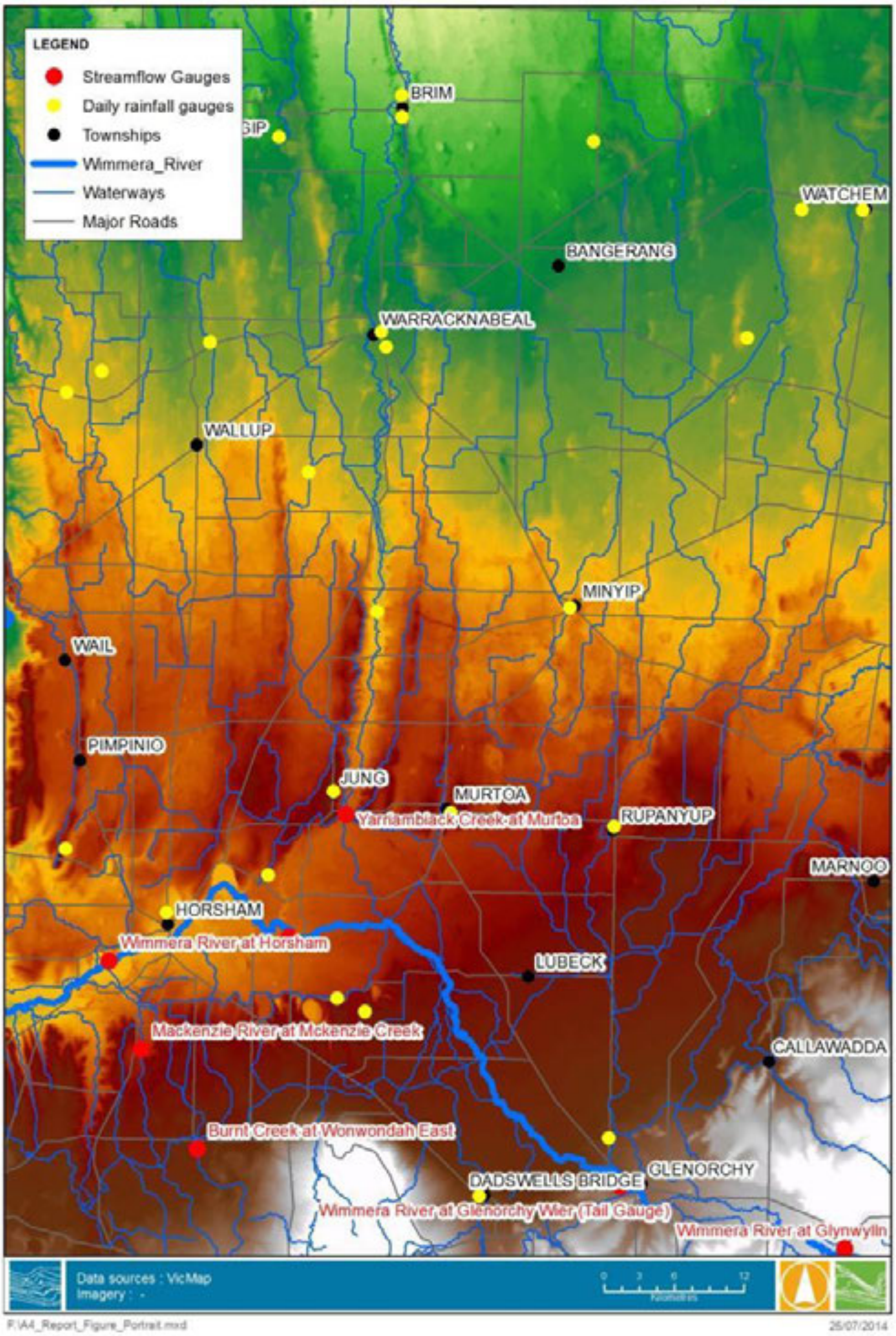


Figure 6-1 Streamflow gauges relevant to the study area

Active gauges of most relevance to the study area are shown in Table 6-1.

Table 6-1 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

The hydrographers managing and maintaining the streamflow gauging network across the Wimmera Catchment 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 Quality Code Classifications in the extracted datasets is shown in Table 6-2.

Table 6-2 Streamflow Gauge 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

As discussed, gauges at Yarriambiack Creek at Wimmera Highway Bridge and Wimmera River at Glenorchy are the most relevant to this study and particular focus was given to these gauges during review of available information. The gauges are discussed specifically in the following sections.

6.1.2 Yarriambiack Creek at Wimmera Highway Bridge

The Yarriambiack Creek streamflow gauge at Wimmera Highway Bridge has a reasonable span of record from 1978 to Current; 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 (FFA). The largest event on record was recorded during January 2011.

Figure 6-2 shows the length of gauge record and the recorded Quality Codes.

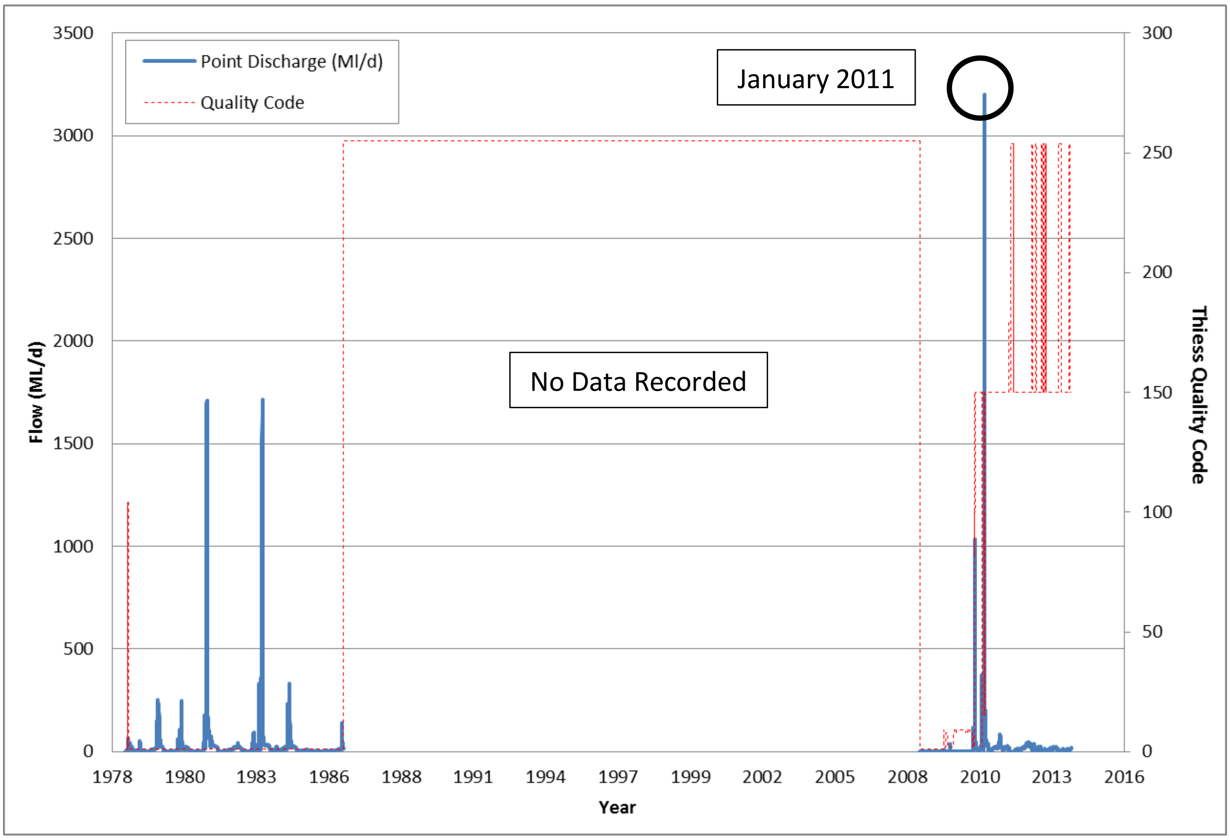


Figure 6-2 Gauge record at Yarriambiack Creek at Wimmera Highway Bridge showing flow and the Quality Codes

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 this study were January 2011, September 1983 and August 1981. The data Quality Codes (QC) 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[2]. 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 6-3.

[2] Pers. Comm. Brent Deckert Ventia

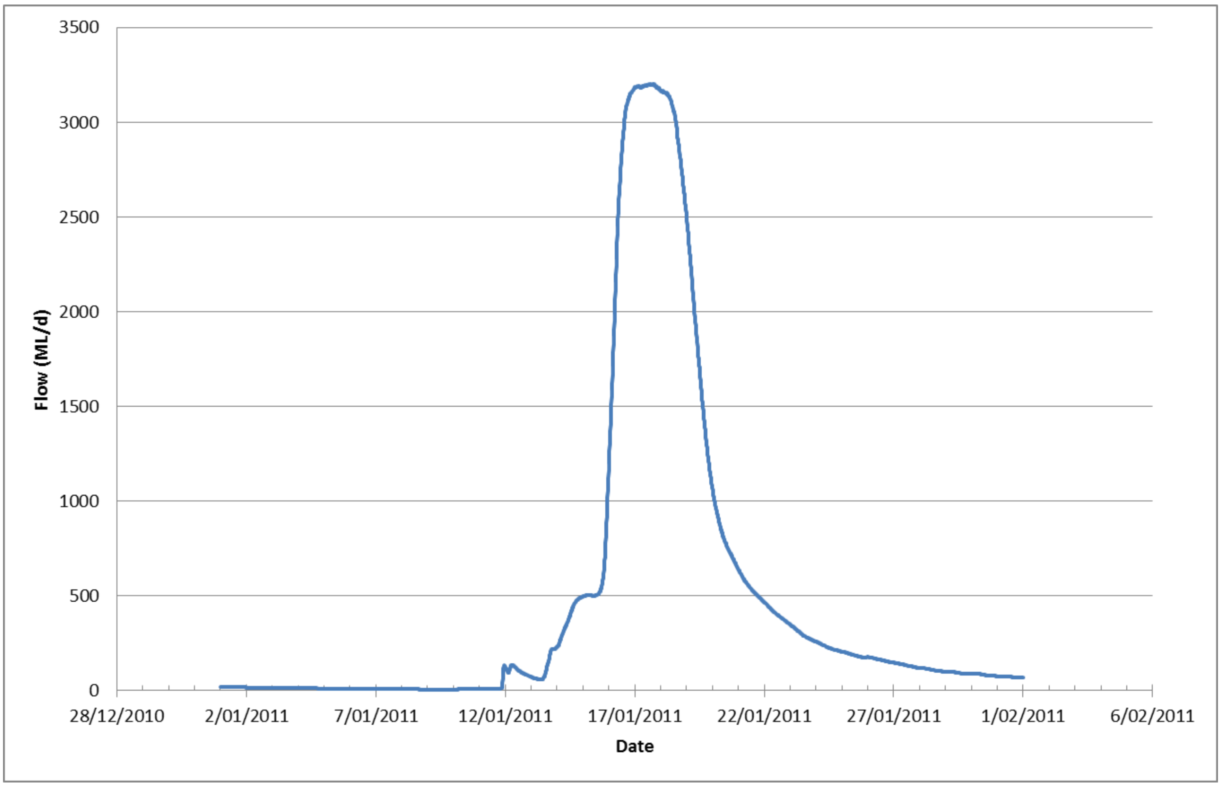


Figure 6-3 January 2011 hydrograph recorded at the Wimmera Highway Bridge gauge on Yarriambiack Creek

During January 2011 the gauge record 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 is extrapolated at flows greater than 35.8 m^3/s (3,090 ML/d) at a stage of 2.30 m, reaching a maximum extrapolated flow of 40.5 m^3/s (3,500 ML/d) at a stage of 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 6-4.

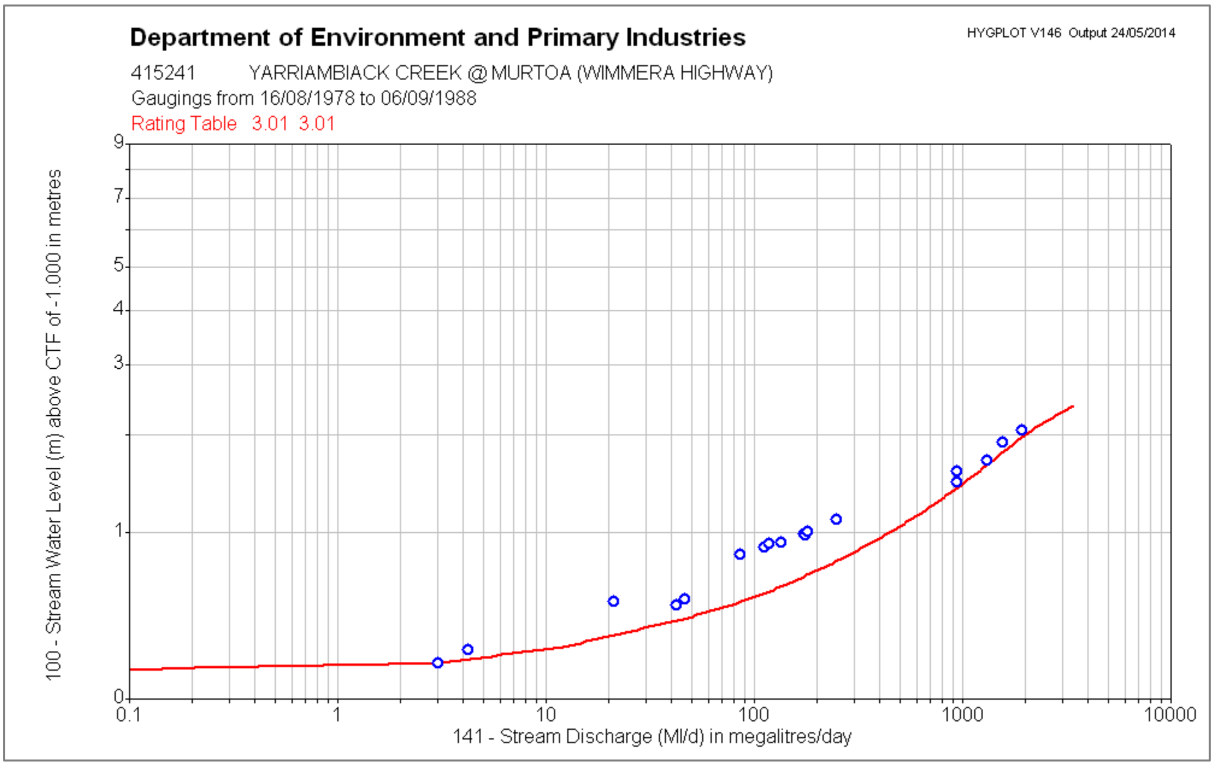


Figure 6-4 Yarriambiack Creek at Wimmera Highway Bridge streamflow gauge rating curve and measurements[3]

The rating curve is based on 18 measurements captured between 1978 and 1988. During the site inspection Wimmera CMA[4] 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.

As discussed in Section 5, this project undertook verification of the available topographic data sets by a comparison of the 2005 and 2010 (ISC) LiDAR datasets. This highlighted significant topographic changes have occurred in the direct vicinity of the Wimmera Highway Bridge gauge between 2005 and 2010, since the last gauging in 1988. Most notably the Main Western Channel was infilled as part of GWMWater's Channel Decommissioning Program in late 2010[5]. The difference between the LiDAR datasets is shown in Figure 6-5, the differences in elevation clearly highlight the removal of the channel embankment and two dams.

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

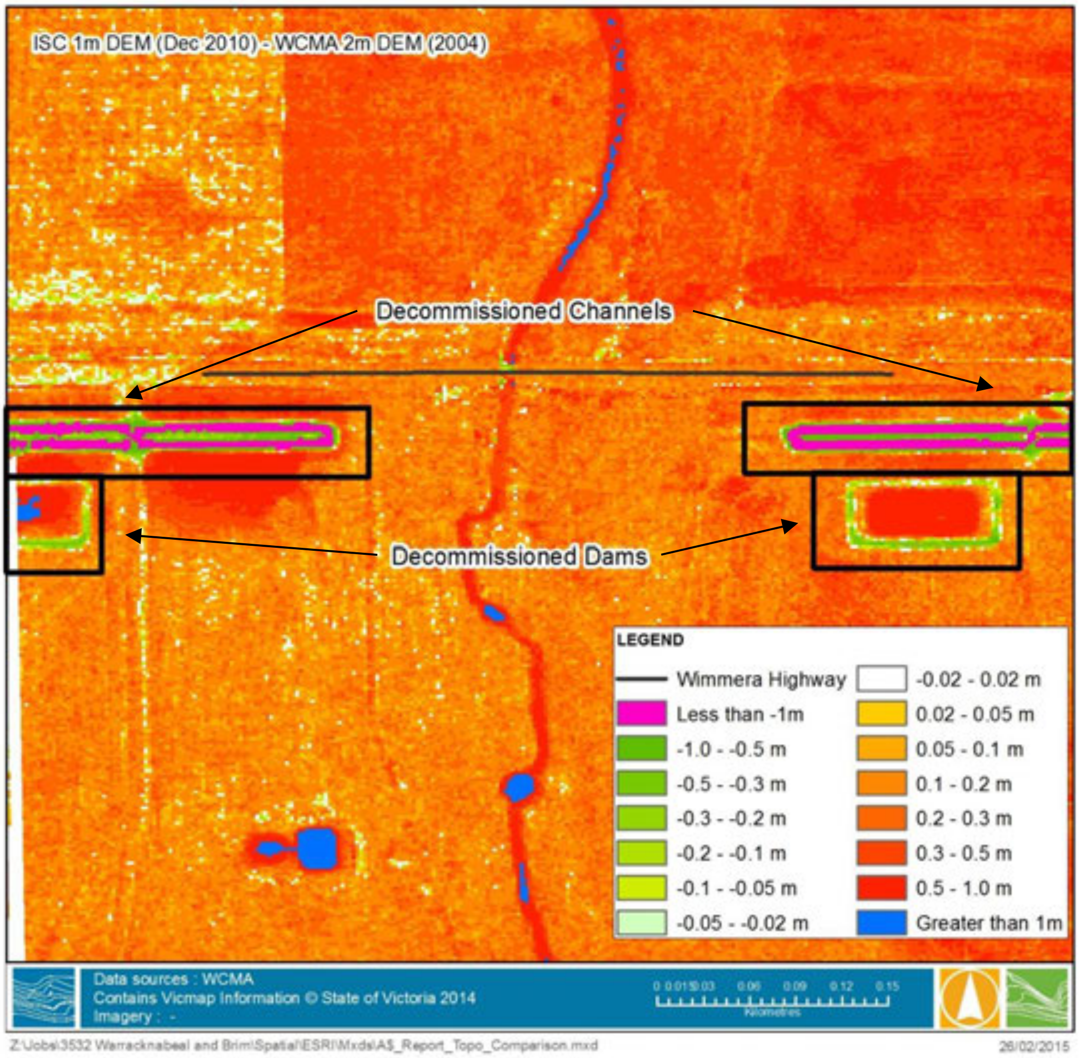


Figure 6-5 Difference between the 2004 and 2010 LiDAR datasets at the Wimmera Highway Bridge

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 6-6.

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

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

6.1.3 Wimmera River at Glenorchy

The Wimmera River gauge at Glenorchy began 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 6-7 shows the Glenorchy gauged flow record and the 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, 413 m^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.

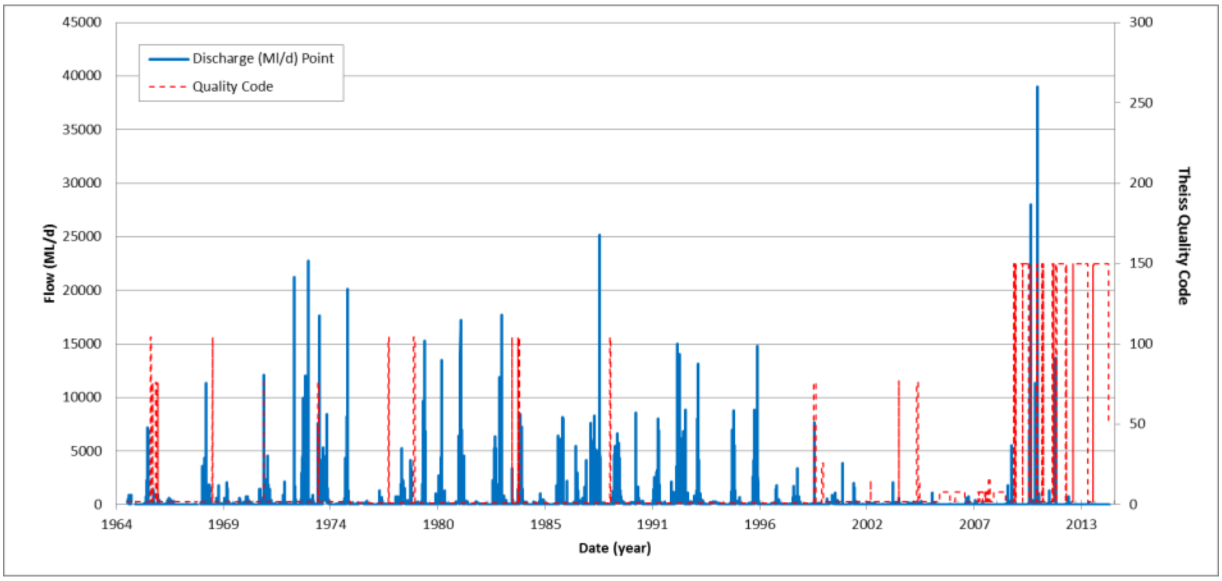


Figure 6-7 **Wimmera River at Glenorchy instantaneous gauge record and Thiess Quality Code Data**

The Wimmera River at Glenorchy rating curve and measurements are shown in Figure 6-8. 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 rating curve plot; however the scatter is probably due to old rating curves. The scatter is reduced at the upper end matching relatively consistently. The rating curve at the upper end does flatten off considerably and small changes in elevation can lead to major changes in flow estimates.

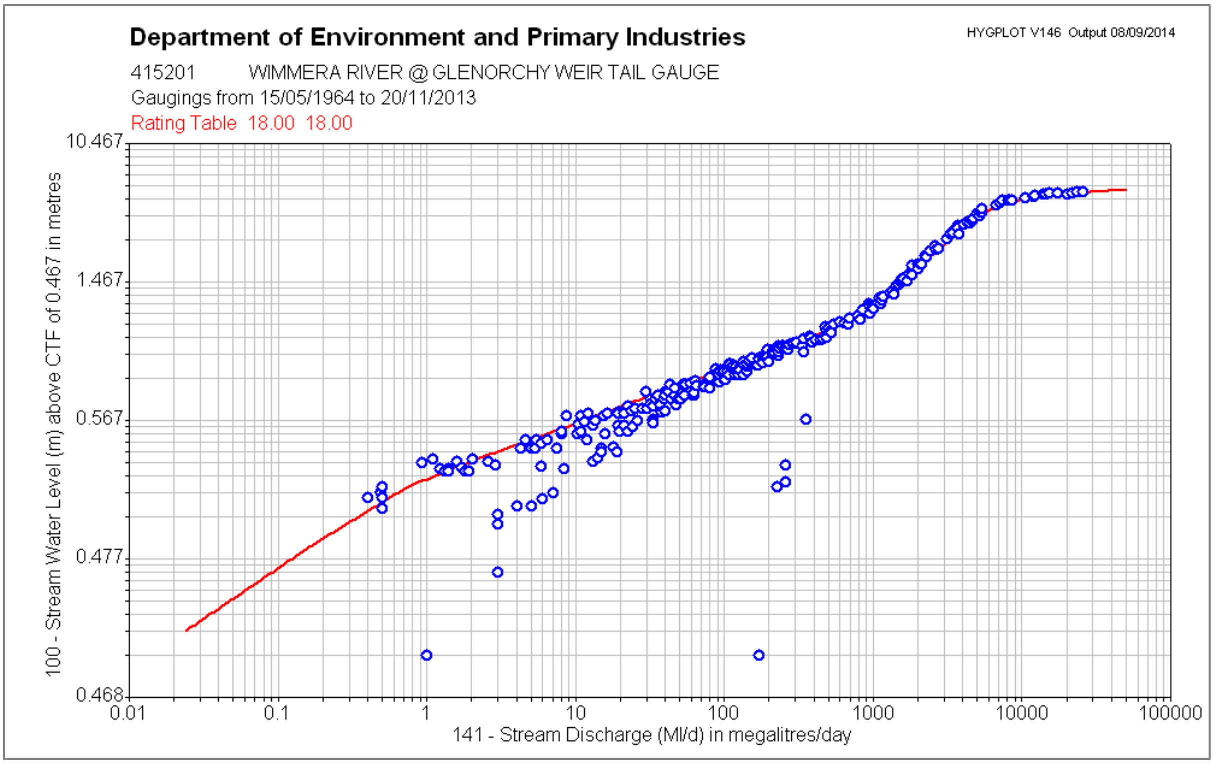


Figure 6-8 **Wimmera River at Glenorchy streamflow gauge rating curve and measurements[3]**

6.2 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 (2004) - Wimmera River Basin URBS Model
- Snowy Mountains Engineering Corporation Victoria (2001) – Assessment of the impact of priority structures on natural flow regimes and flooding in Yarriambiack Creek (Parts 1 and 2)
- WBM Oceanics Australia (2003)– Yarriambiack Creek Flood Investigation Study
- Kellogg Brown & Root (2004) – Yarriambiack Creek Management Plan
- Water Technology (2007) - Warracknabeal and Beulah Flood Study
- Water Technology (2009) – Wimmera River and Yarriambiack Creek Flow Modelling Study
- Water Technology (2012) – Beulah Flood Investigation

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

6.2.1 Warracknabeal and Beulah Flood Study[6]

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 (25 m 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 6-9. 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 6-3 and Figure 6-10.

Table 6-3 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)

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) was 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 6-4.

[6] Water Technology (2007), Warracknabeal and Beulah Flood Study, Wimmera CMA

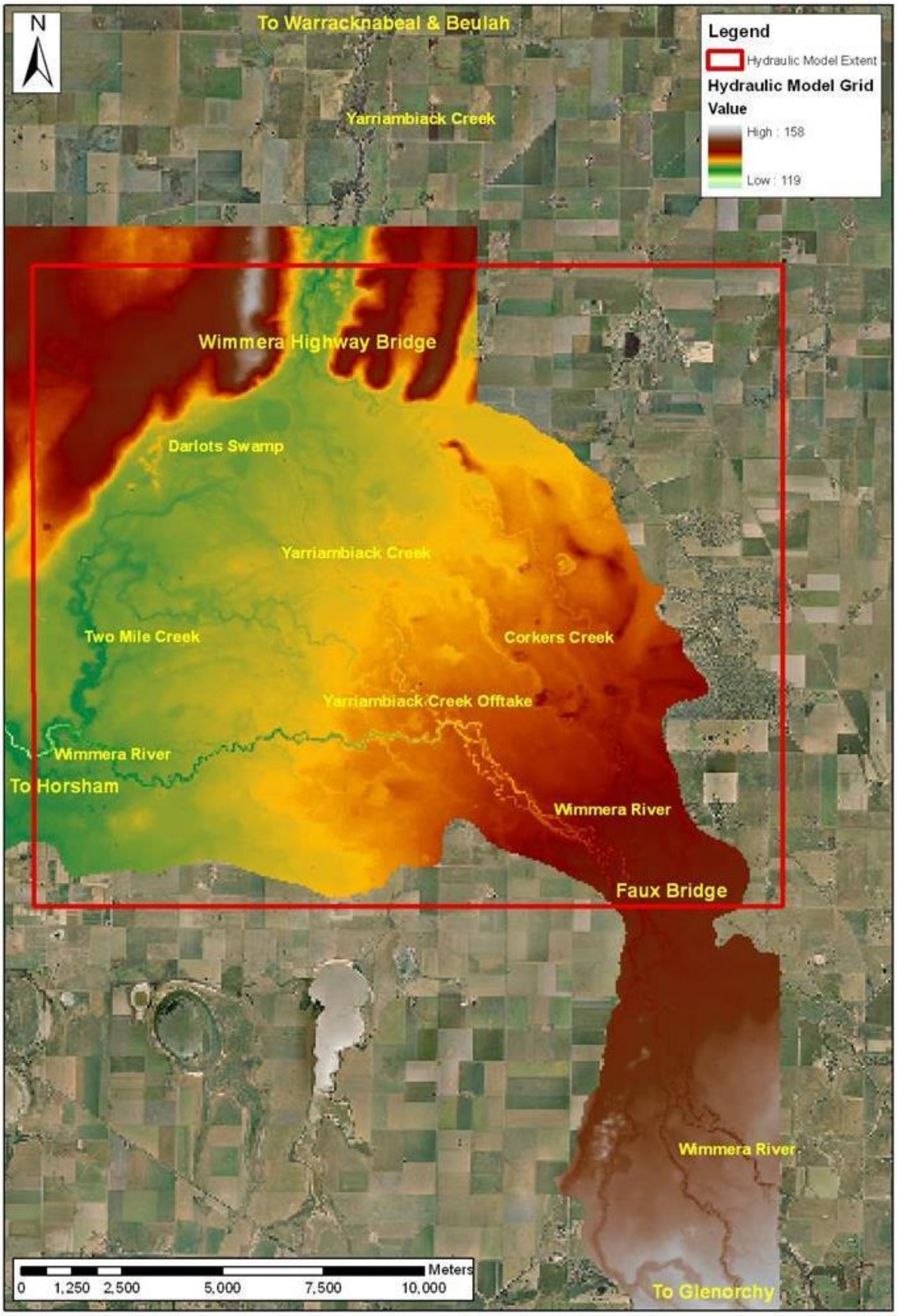


Figure 6-9 Wimmera River/Yarriambiack Creek offtake 2D hydraulic model[8]

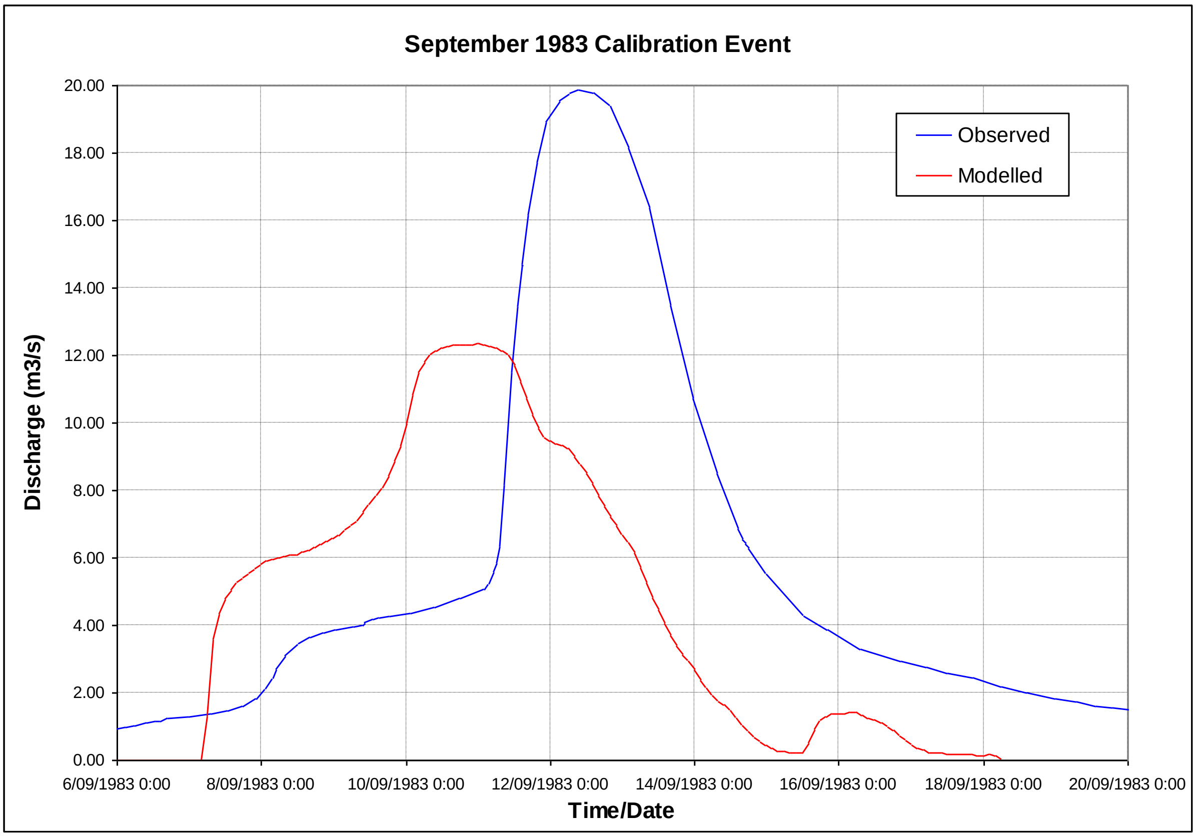


Figure 6-10 **Modelled and observed hydrographs for Yarriambiack Creek at Wimmera Highway for September 1983**[6]

Table 6-4 **Design flow splits**

Design Event (AEP)	Peak Flow (m^3/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 6-11.

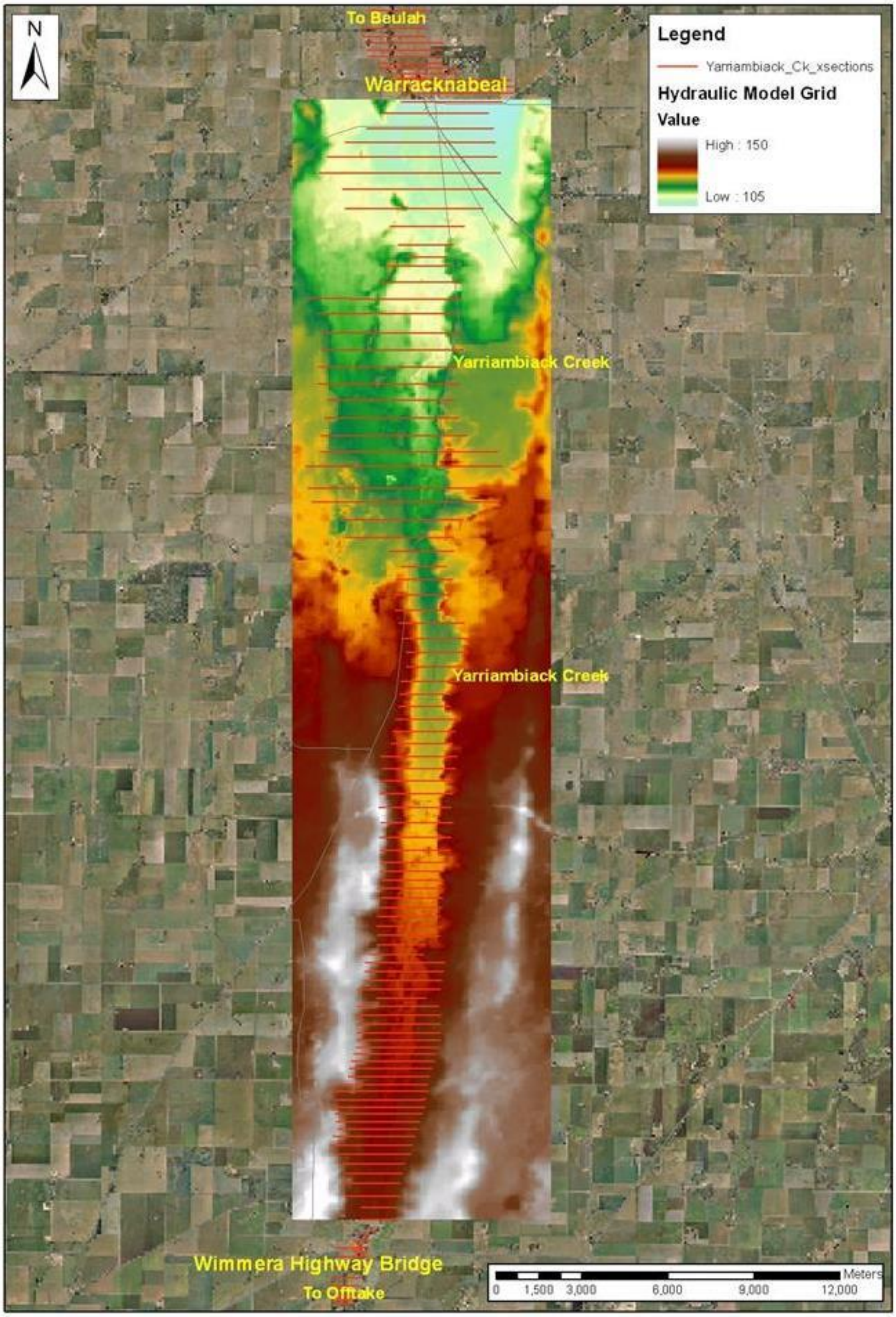


Figure 6-11 Yarriambiack Creek 1D hydraulic model[6]

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 6-5.

Table 6-5 Design flows adopted for the Wimmera Highway Bridge and Warracknabeal

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% AEP 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 6-6.

Table 6-6 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
- Non-structural mitigation option assessment (LSIO, FO planning layers)

6.2.2 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 6-12. 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 (1999), Australian Rainfall and Runoff
[8] Water Technology (2009), Wimmera River and Yarriambiack Creek Flows Study, Wimmera CMA

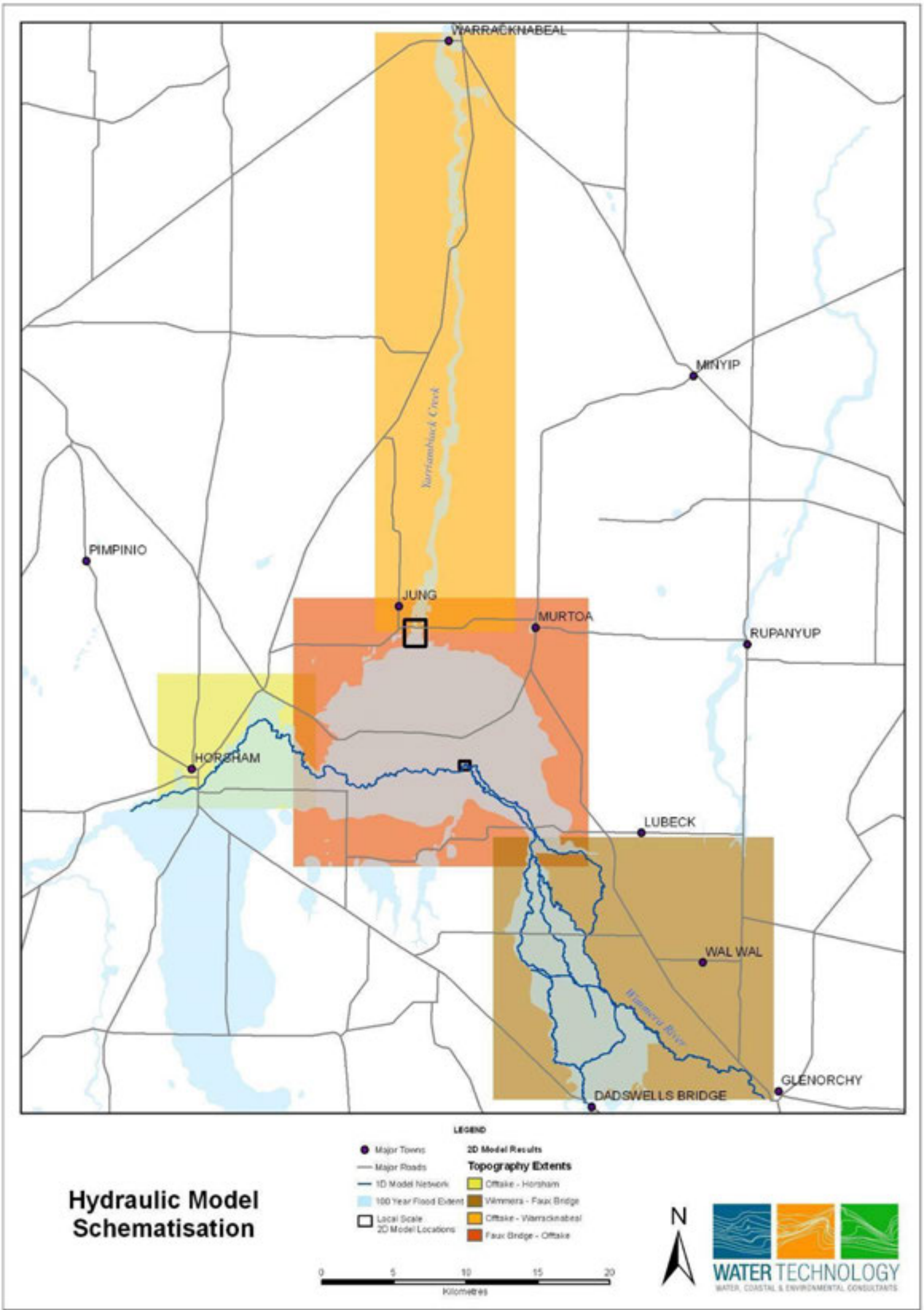


Figure 6-12 Separate hydraulic model extents[8]

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 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 6-7.

Table 6-7 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 (22,982 ML/d)
2%	336 (29,030 ML/d)	348 (30,067 ML/d)
1%	380 (32,832 ML/d)	435 (37,584 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 6-13 and Figure 6-14 respectively.

In both events the modelled flow is under that observed. The difference in the modelled and observed peak flows is shown in Table 6-8.

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

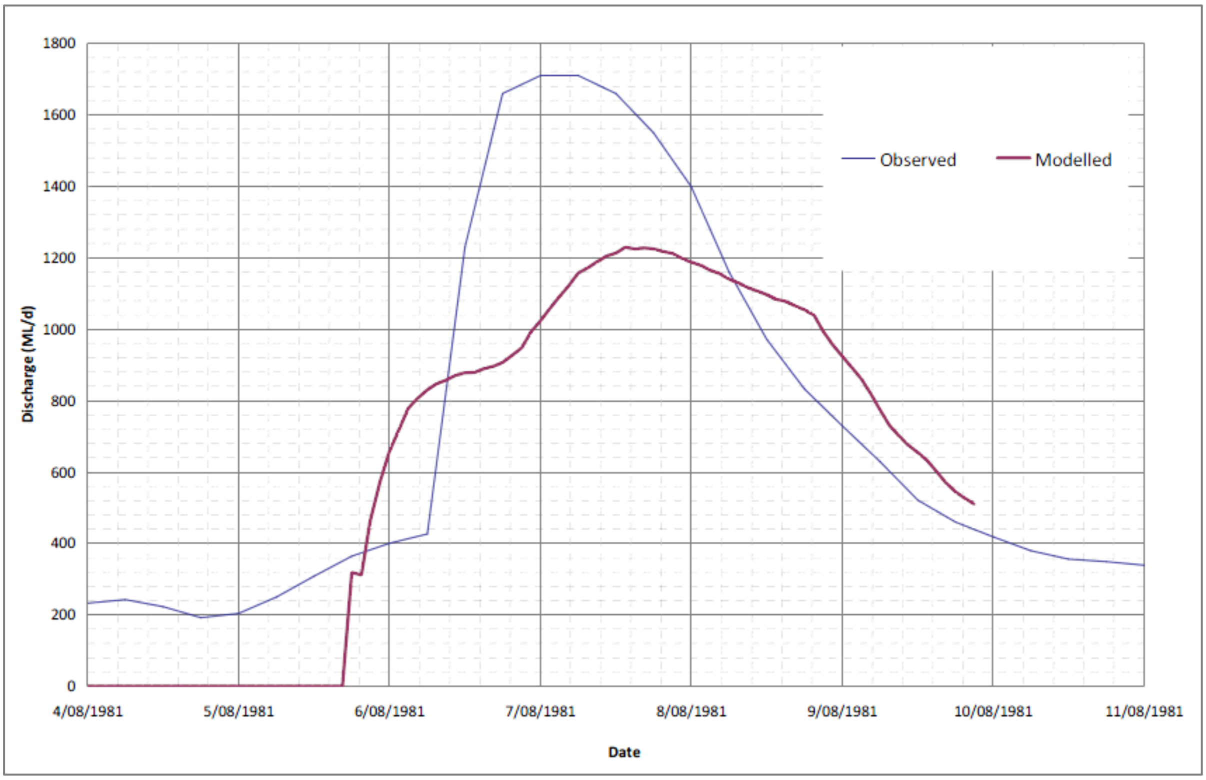


Figure 6-13 **Modelled and observed hydrographs on Yarriambiack Creek at the Wimmera Highway for August 1981**[8]

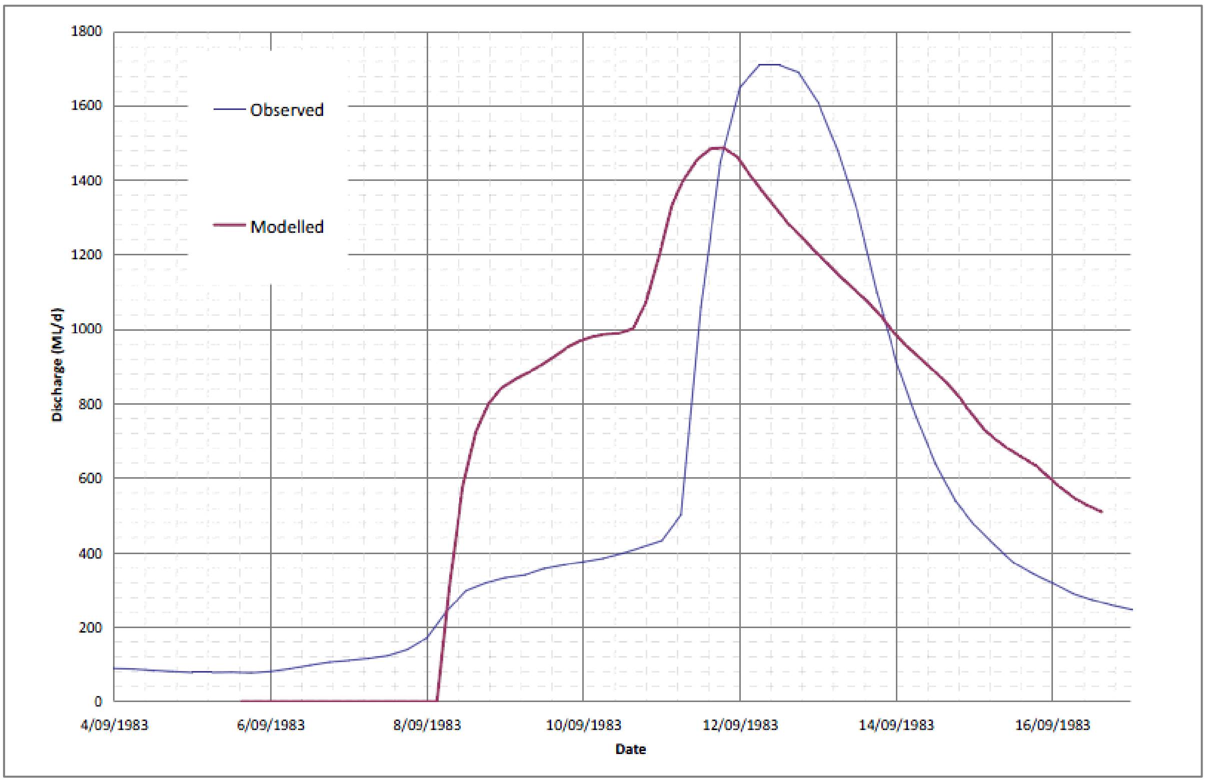


Figure 6-14 **Modelled and observed hydrographs for Yarriambiack Creek at the Wimmera Highway for September 1983**[8]

Table 6-8 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 (1,711 ML/d)	14.2 (1,227 ML/d)	5.6 (484 ML/d)	28.3%
September 1983	19.9 (1,719 ML/d)	17.2 (1,486 ML/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 6-9. Only the 20%, 5% and 1% AEP events were modelled.

Table 6-9 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 (1,460 ML/d)
1 %	36.6 (3,162 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 2 m grid resolution and the road culverts were included as 1D elements. The model extent is shown in Figure 6-15.

The modelled and observed heights at the Wimmera Highway Bridge are shown in Table 6-10.

Table 6-10 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

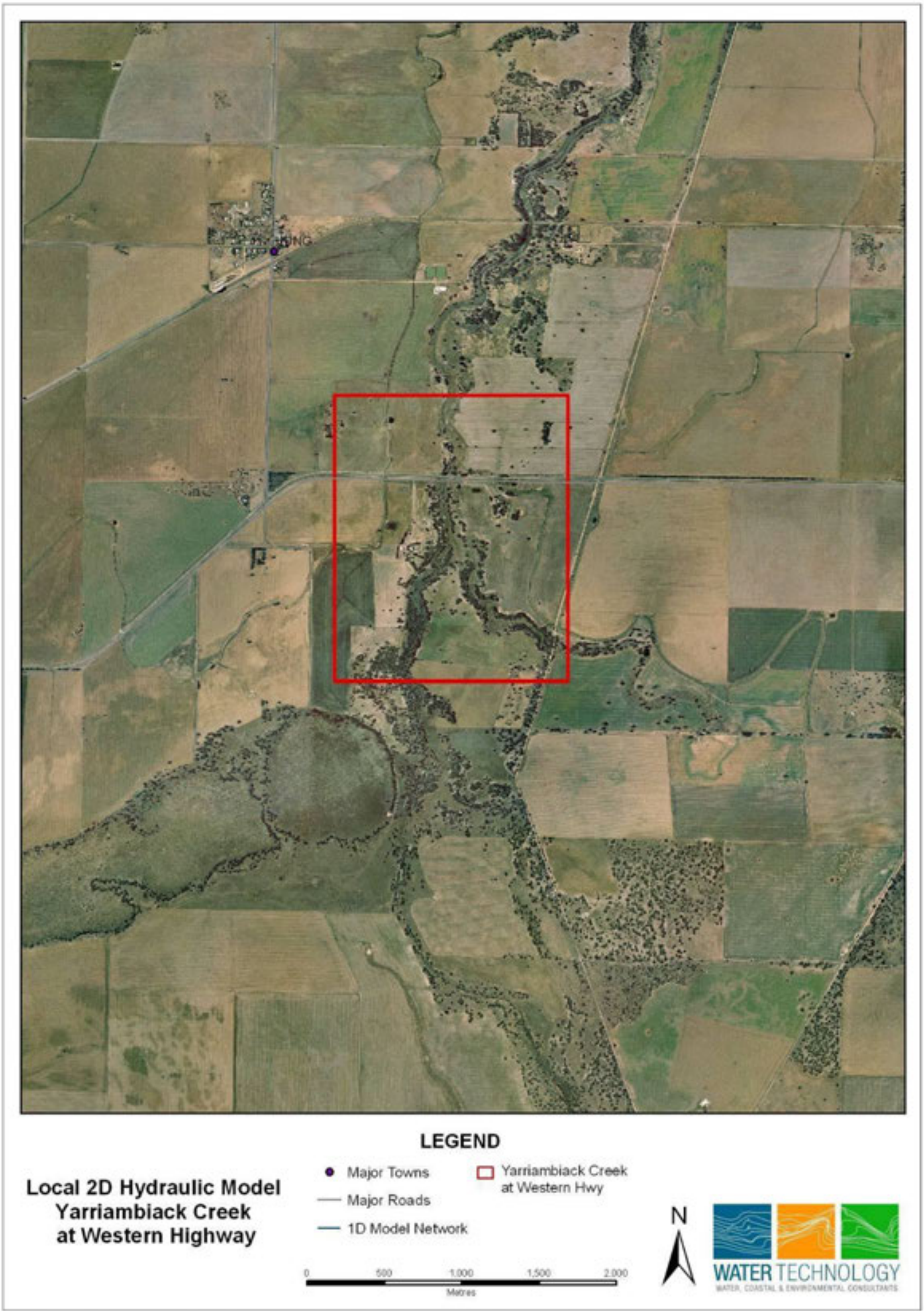


Figure 6-15 Model extent - Local scale model of Yarriambiack Creek at the Wimmera Highway Bridge

6.2.3 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 6-11.

Table 6-11 Design flow comparison at Wimmera Highway Bridge on Yarriambiack Creek between the Warracknabeal and Beulah Flood Investigation (2007) 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)[6]	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[6] 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[6] 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 9.3.1. The differences in modelled and observed flows is likely to be due to model schematisation and the modelling technology and approaches that were available during each study.

6.3 January 2011

6.3.1 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.

6.3.2 Rainfall

There are two daily rainfall gauges in direct proximity to Warracknabeal, Warracknabeal Museum (078077) and Warracknabeal (Ailsa) (078000).

During January 2011 the Warracknabeal Museum rainfall gauge recorded totals of 77, 38 and 36 mm in the 24 hours to 9am on Monday the 10th, Wednesday the 12th and Friday the 14th of January respectively.

The Warracknabeal Museum daily rainfall record for January 2011 is shown in Figure 6-16.

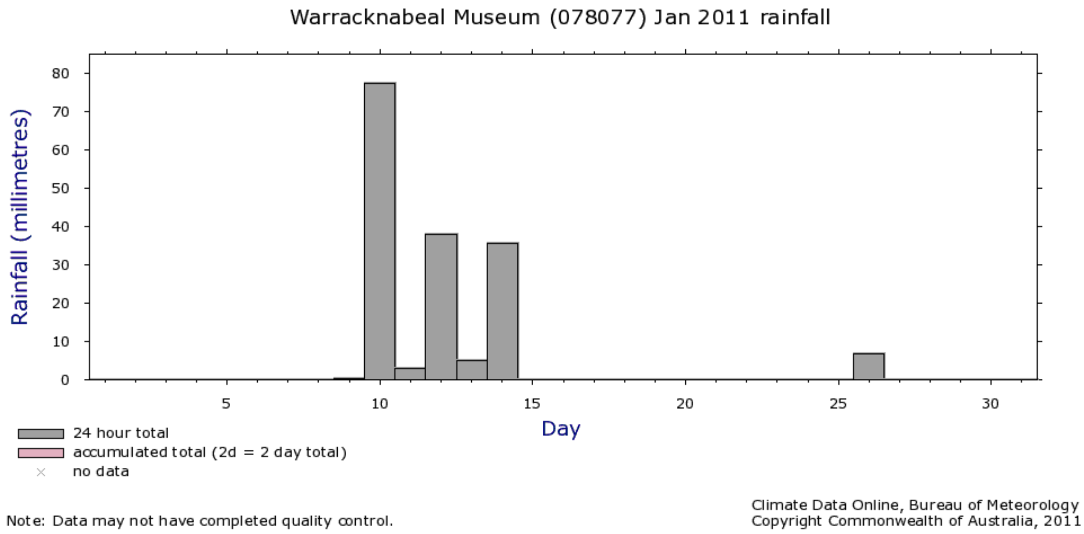


Figure 6-16 Warracknabeal Museum daily rainfall records (1st – 31st January 2011)[11]

During January 2011 the Warracknabeal (Ailsa) rainfall gauge recorded totals of 51, 52 and 36.2 , in the 24 hours to 9am on the Monday the 10th, Wednesday the 12th and Friday the 14th of January respectively

The Warracknabeal (Ailsa) daily rainfall record for January 2011 is shown in Figure 6-17.

[11] BoM (Accessed – July 2015), Climate Data Online (http://www.bom.gov.au/climate/data/)

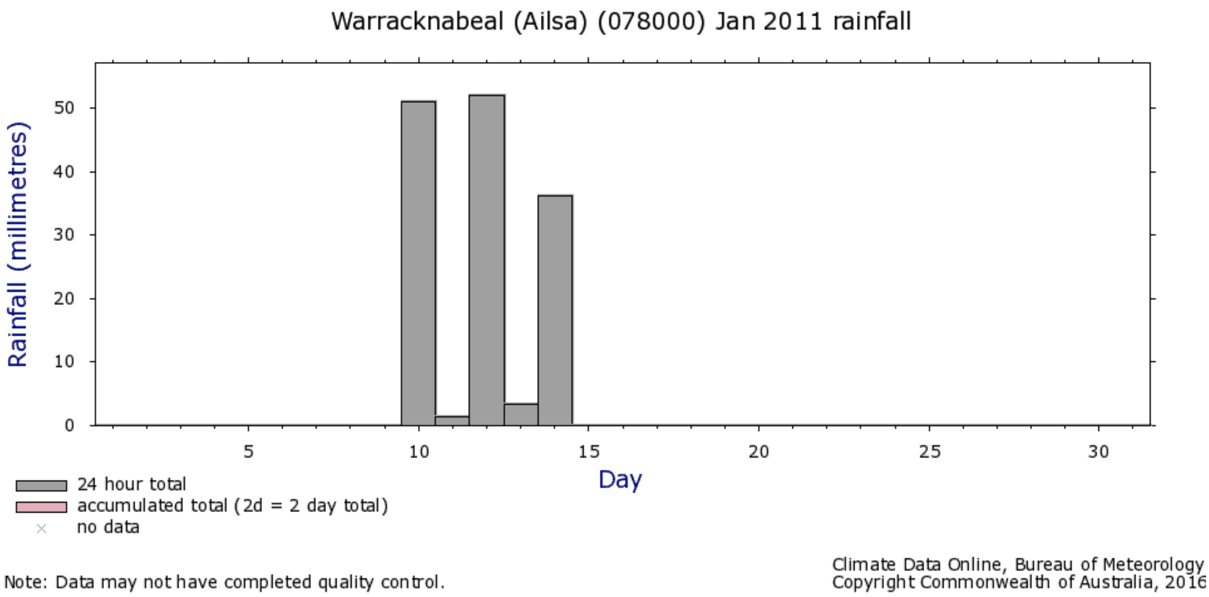


Figure 6-17 Warracknabeal (Ailsa) daily rainfall records (1st – 31st January 2011)[12]

Direct runoff caused localised flooding in and around Warracknabeal after the initial rainfall, this impacted on areas in Warracknabeal and directly east of the main township.

6.3.3 Stream Flows

As discussed in Section 6.1.1, the gauges most reflective of potential inundation within Warracknabeal, Brim and Yarriambiack Creek are the Wimmera River at Glenorchy and Yarriambiack Creek at Murtoa (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 Dunmunkle Creek Flood Investigation[13] determined a 1% AEP design flow of 424 m^3 (36,648 ML/d), this study used a very similar analysis to that undertaken in this project, which is discussed in Section 9.5.2.

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 recorded flow in the gauge history.

When compared to the design flows estimated for the gauge location during the Warracknabeal and Beulah Flood Study[6], 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).

[12] BoM (Accessed – July 2015), Climate Data Online (http://www.bom.gov.au/climate/data/)
[13] Water Technology (2015), Draft Dunmunkle Creek Design Hydrology and Hydraulics Reporting, Wimmera CMA

6.3.4 Observed Inundation

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

- Aerial photography captured on the 18th, 19th, 20th and 21st January (image extents shown in Figure 6-18) 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 6-19) 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 6-20)
- Peak water level survey points highlighted by the community captured during the initial stages of this project (Survey points are shown in Figure 6-21)
- There was also numerous ground and aerial based photos captured by the community.

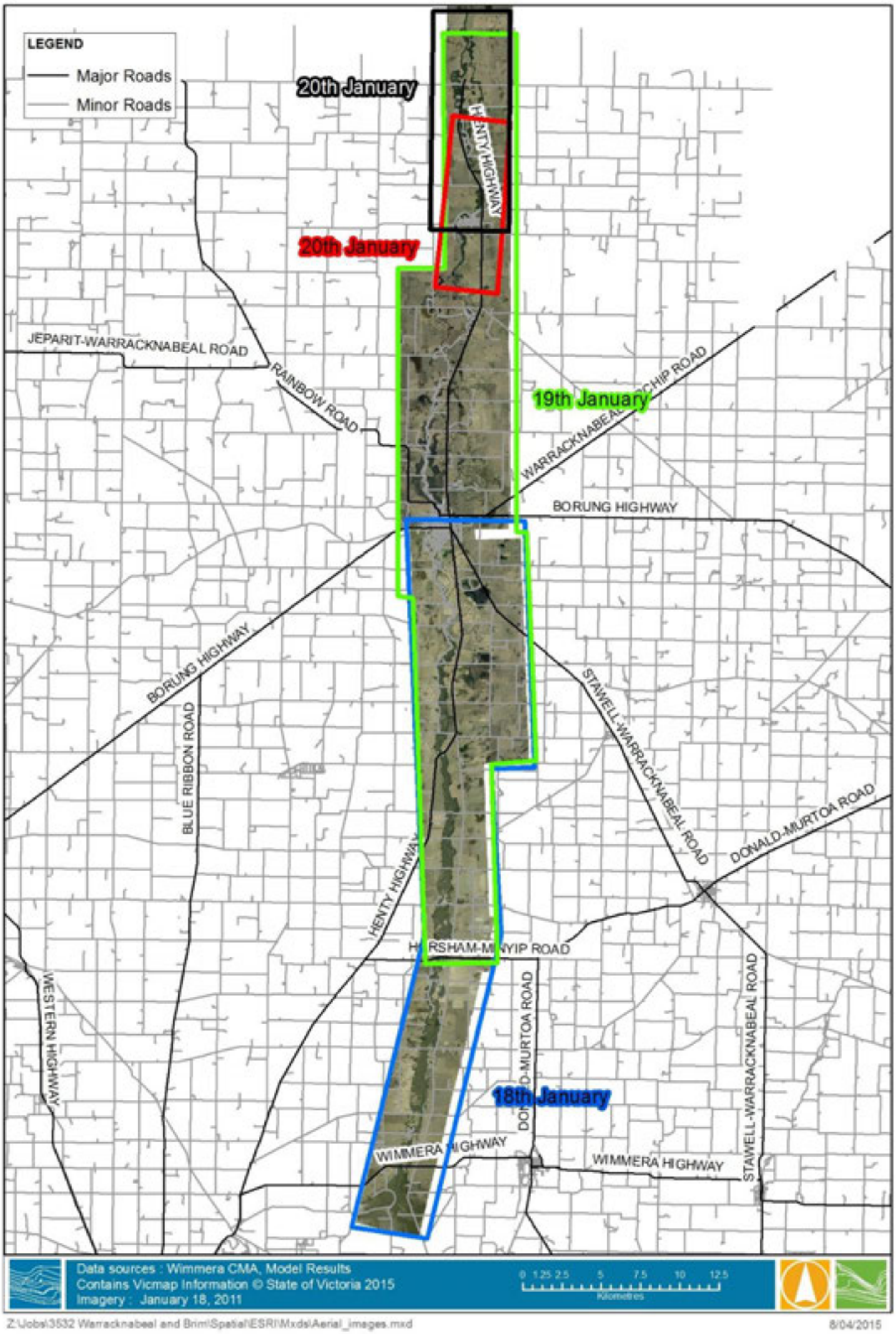


Figure 6-18 Aerial photography captured of Yarriambiack Creek during the January 2011 event

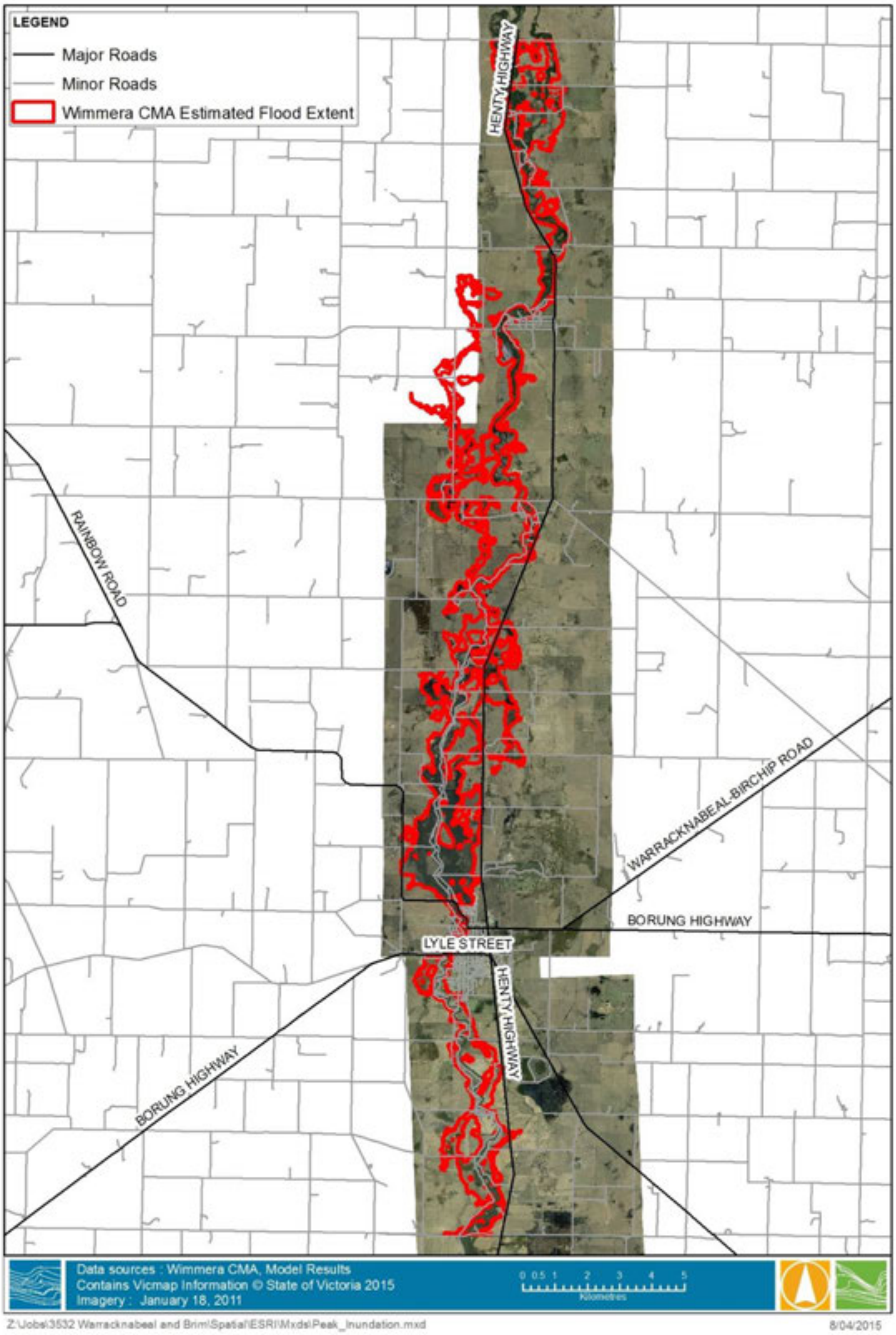


Figure 6-19 Peak inundation extent estimated by Wimmera CMA

Figure 6-20 Survey points captured by Ferguson and Perry Surveying immediately post the January 2011 event

Figure 6-21 Survey points highlighted by the community captured during the initial stages of this project

7. PROJECT CONSULATION

7.1 Overview

A key element in the development of the Warracknabeal and Brim Flood Investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, social media and meetings with a Project Steering Committee containing several members of the community. The community consultation sessions were largely managed by the Wimmera CMA and Yarriambiack Shire Council. The aims of the community consultation were as follows:

- To raise awareness of the study and to identify key community concerns; and
- To provide information to the community and seek their feedback/input regarding the study outcomes including the existing flood behaviour and proposed mitigation options for the township.

7.2 Steering Committee and Technical Working Group

The Flood Investigation was led by a Steering Committee consisting of representatives from Wimmera CMA, Yarriambiack Shire Council (YSC), Department of Environment, Land, Water and Planning (DELWP), Bureau of Meteorology (BoM), State Emergency Service (SES), Water Technology and the Warracknabeal and Brim communities.

The Steering Committee met on 5 occasions at key points throughout the study, to manage the development of the investigation.

7.3 Community Consultation

All community meetings were supported by media releases to local papers and meeting notices advertising meetings well in advance. The following community meetings were held as part of the consultation process:

- Initial community meetings, Brim – 3rd November 2014, Warracknabeal - 20th November 2014 – The first public meeting was held to outline the objectives of the study to the community, communicate what the community can expect from the study and gather input from the community on observed inundation and potential mitigation solutions;
- Second community meeting, Brim - 29th July 2015, Warracknabeal – 30th July 2015 – The second community meeting presented calibration results for the January 2011 and September 2010 events and outlined a list of potential flood mitigation options identified to date. Community feedback was sought on the flood modelling results and their preference/suggestions for additional flood mitigation options; and
- Third community meeting, Brim – 11th July 2016, Warracknabeal 11th July 2016 – The final public meeting presented the flood warning recommendations, planning scheme layers, Warracknabeal final levee design and project outcomes. Community feedback was sought on the levee design, location and appearance.

Additional to the formal community meetings Yarriambiack Shire Council held informal ‘drop in’ sessions for members of the community to express their views on the levee in a more private setting. These were held on the 29th June 2016 and 6th July 2016 from 4-5pm.

7.4 Community Feedback

In general, the Yarriambiack Creek community was very pleased with the rigour and outcomes of the Warracknabeal and Brim Flood Investigation. The Warracknabeal community was largely the focus of the proposed structural mitigation works due to the high flood consequence in the township. Wimmera CMA and Yarriambiack Shire Council provided extensive information on Facebook prior to the community meetings along with “drop in” sessions. During the final community meeting the only concerns raised were to do with the finer design features of the levee, colouring of concrete walls, gardens to make the levee look more natural etc.

8. FLOOD MECHANISMS

8.1 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.

8.2 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 outside the major townships 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 8-1, 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, in this area there are several buildings that were impacted by inundation during January 2011. 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.

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.

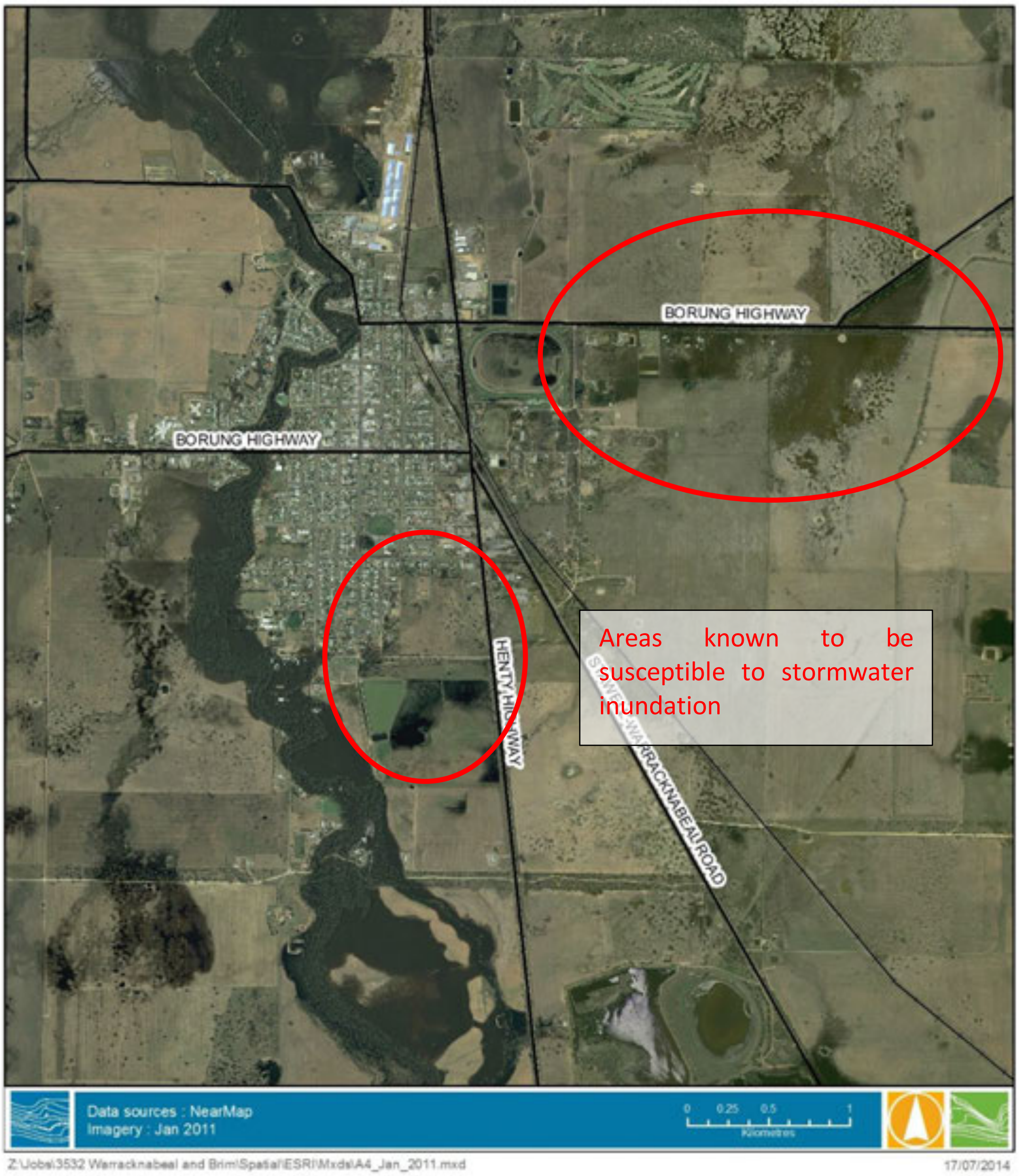


Figure 8-1 Inundation in Warracknabeal observed 19th January 2011 (NearMap)

Figure 8-2 Inundation in Brim observed on 19 January 2011

8.3 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 floods 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.

8.4 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 8-3.

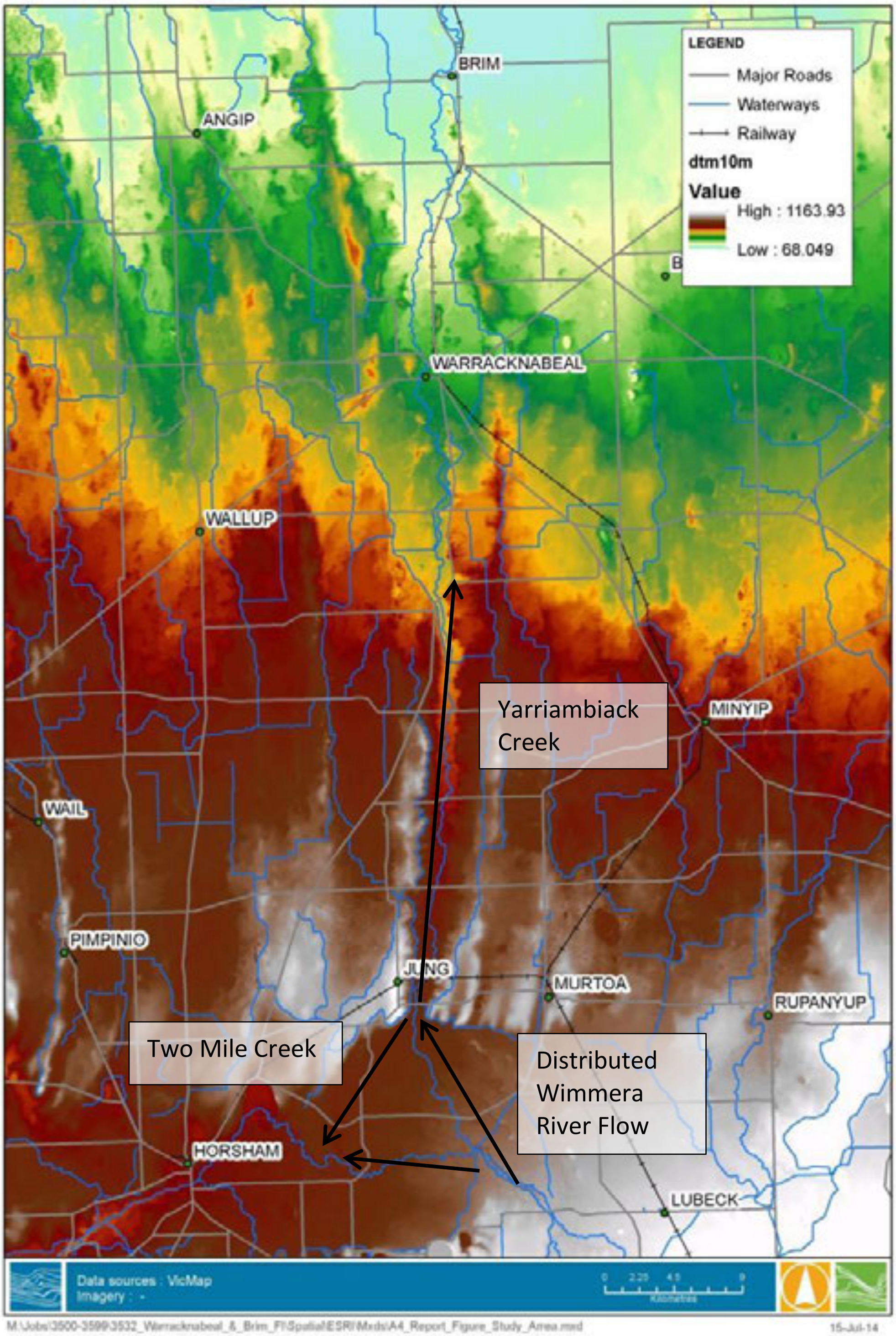


Figure 8-3 Flow distribution to Yarriambiack Creek from the Wimmera River, return through Two Mile Creek and north toward Warracknabeal and Brim

9. HYDROLOGY AND HYDRAULICS

9.1 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.

9.2 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.

9.3 Modelling Structure

9.3.1 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 6.2.2. This model included the Main Western Channel which was decommissioned in late 2010 as discussed in Section 5.2.2. 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 9-1.

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 9-2. 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 9-1 Yarriambiack Creek at Wimmera Highway – Feature Survey

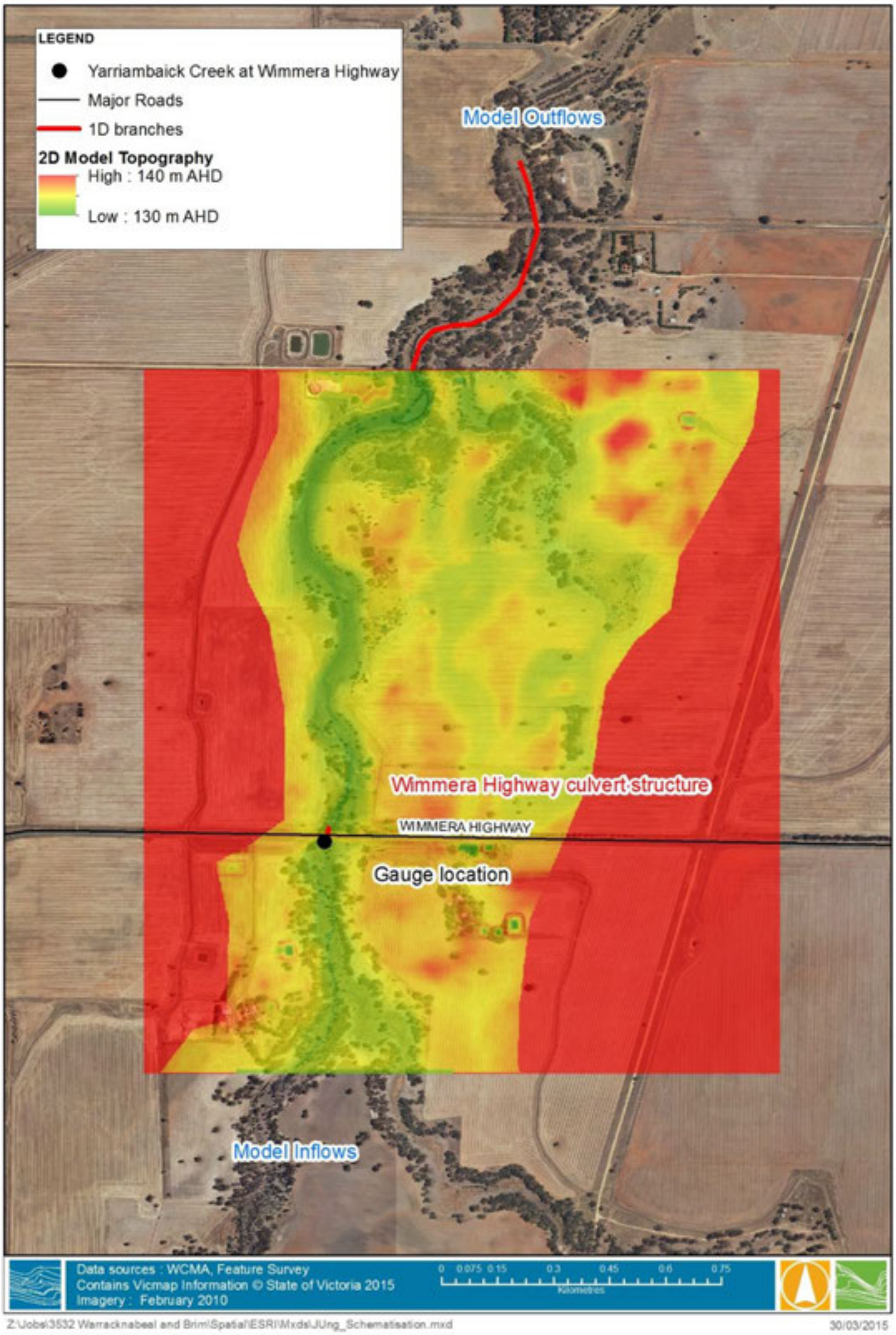


Figure 9-2 Yarriambiack Creek at Wimmera Highway – Hydraulic Model Structure

9.3.2 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 6.2.2, 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[14] 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 9-3.

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.

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

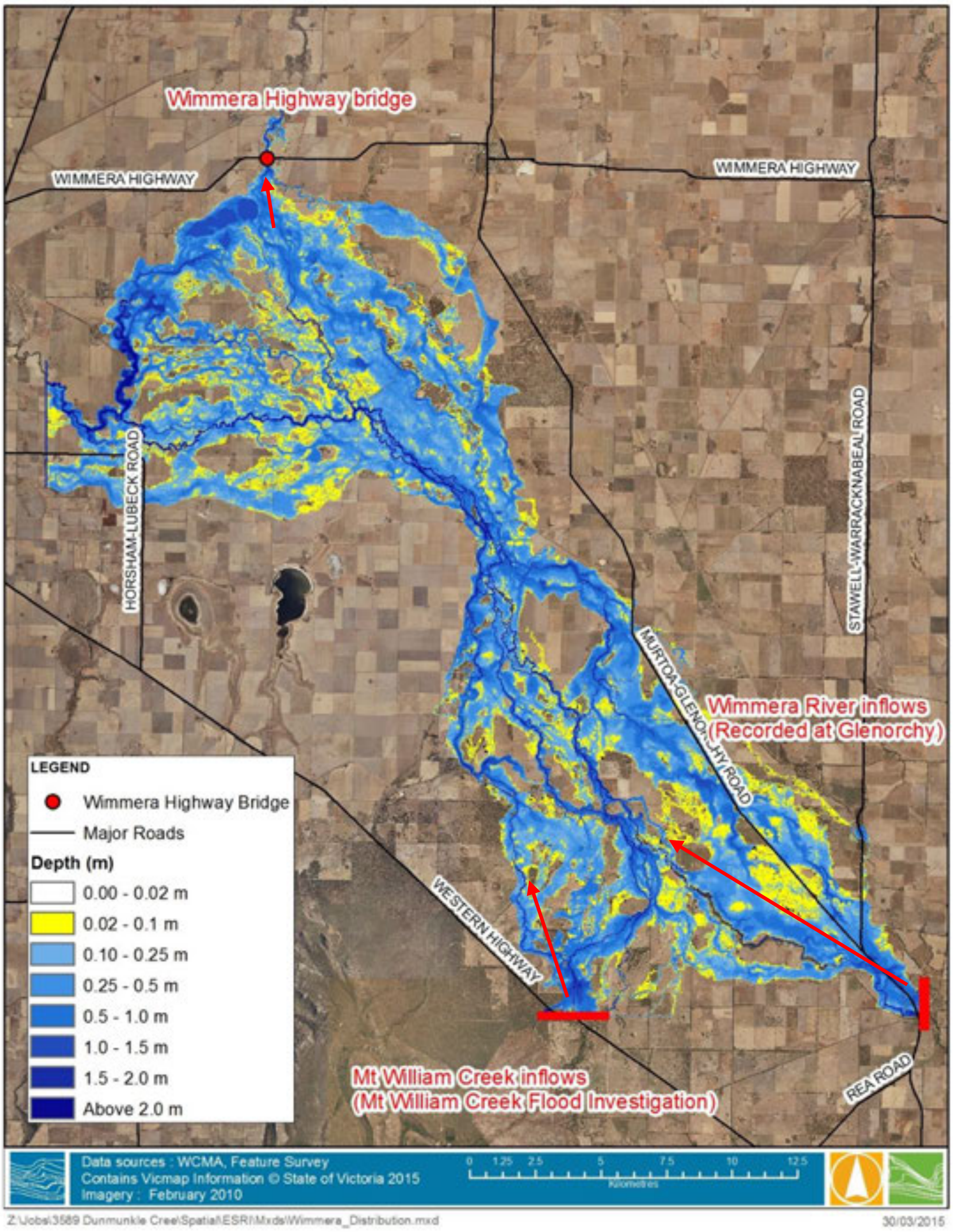


Figure 9-3 January 2011 – Hydraulic model structure Wimmera River at Glenorchy to Yarriambiack Creek at Wimmera Highway and Mt William Creek at Dadswells Bridge to Mt William – Wimmera River confluence

9.3.3 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 5.

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 9-4.

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.

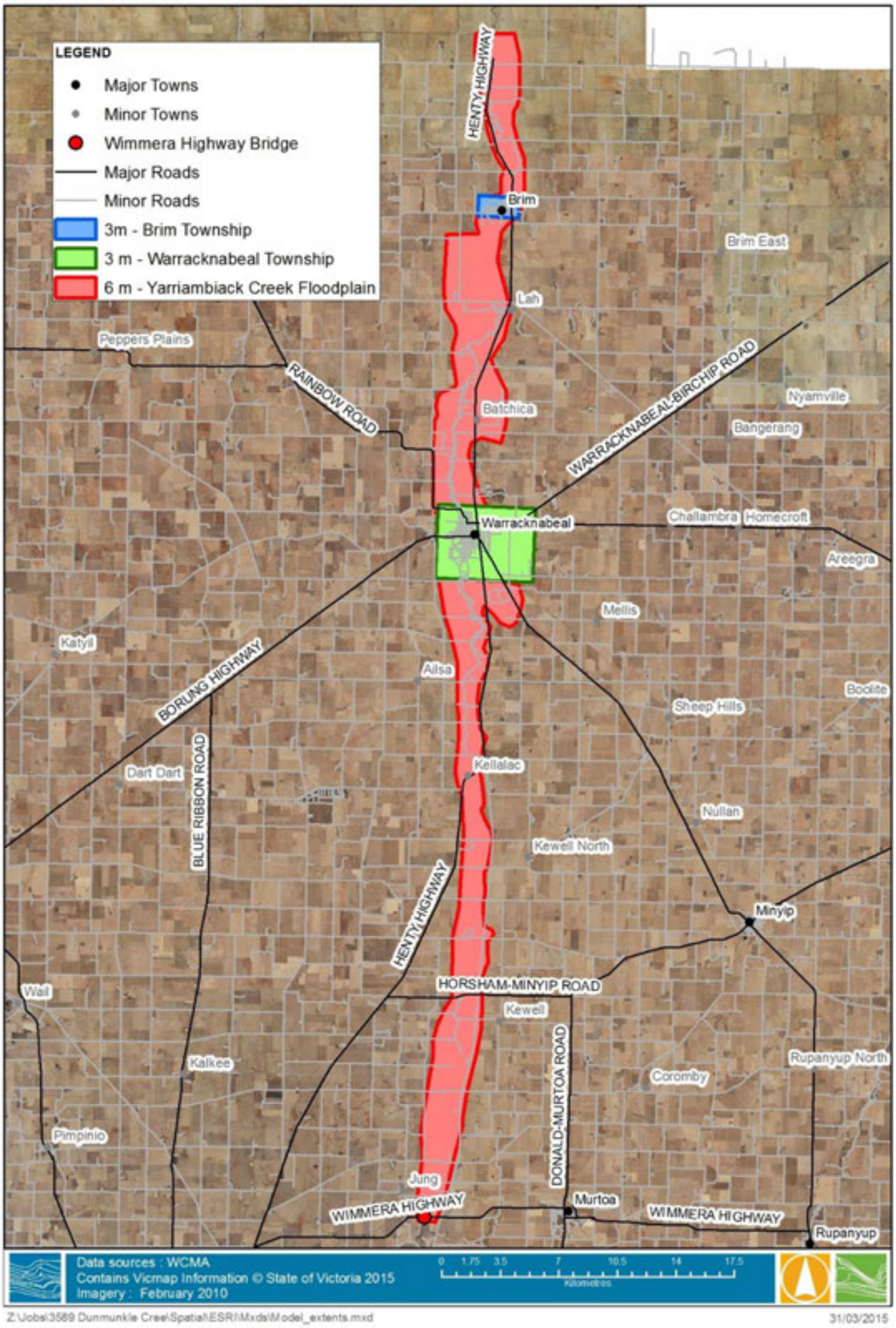


Figure 9-4 Yarriambiack Creek model extent and mesh resolutions

9.4 Hydraulic Model Calibration

9.4.1 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.

9.4.2 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 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 9-5, 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 9-6, 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 6-4. 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 slope once the culvert obvert is exceeded and the significant decrease in slope 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 9-7, with a peak flow comparison shown in Table 9-1.

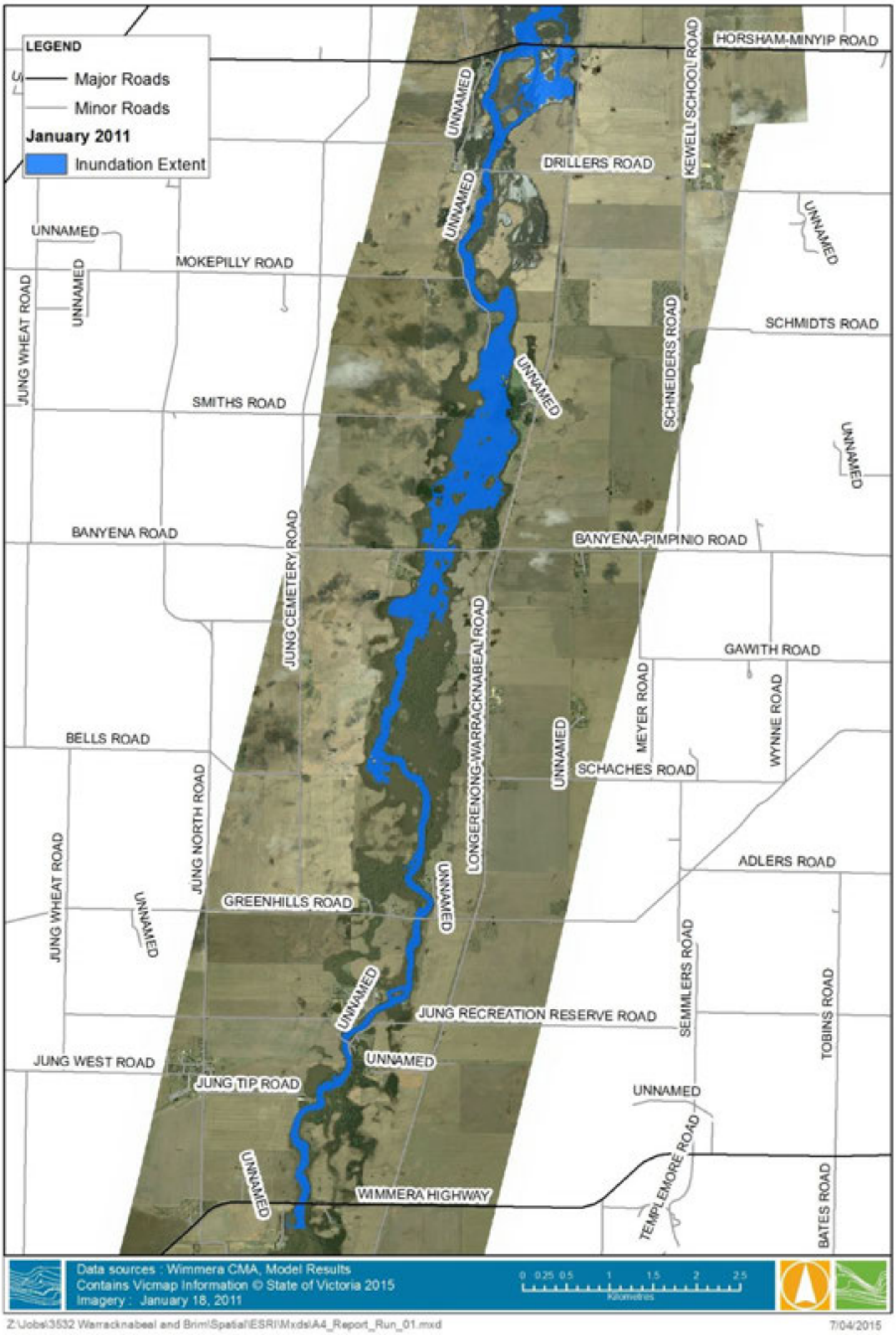


Figure 9-5 Yarriambiack Creek floodplain model – January 2011 gauged flow flood extent

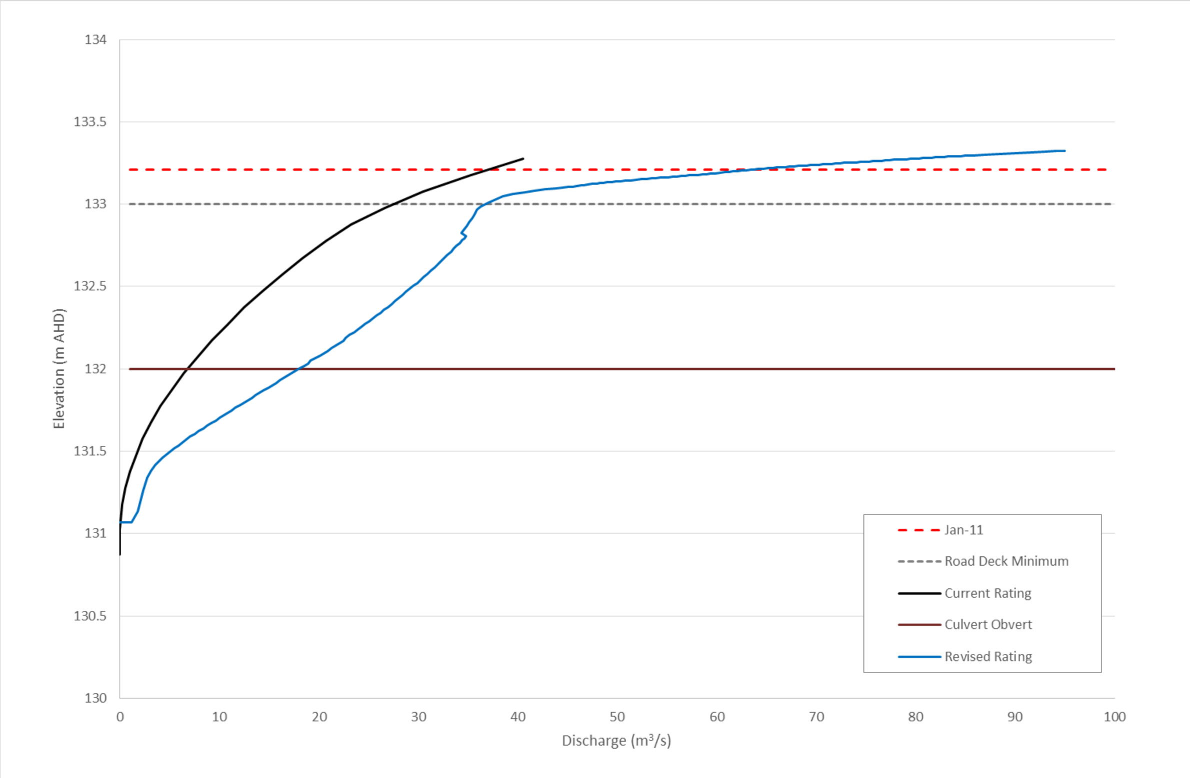


Figure 9-6 Yarriambiack Creek at Wimmera Highway – Current and revised rating curves

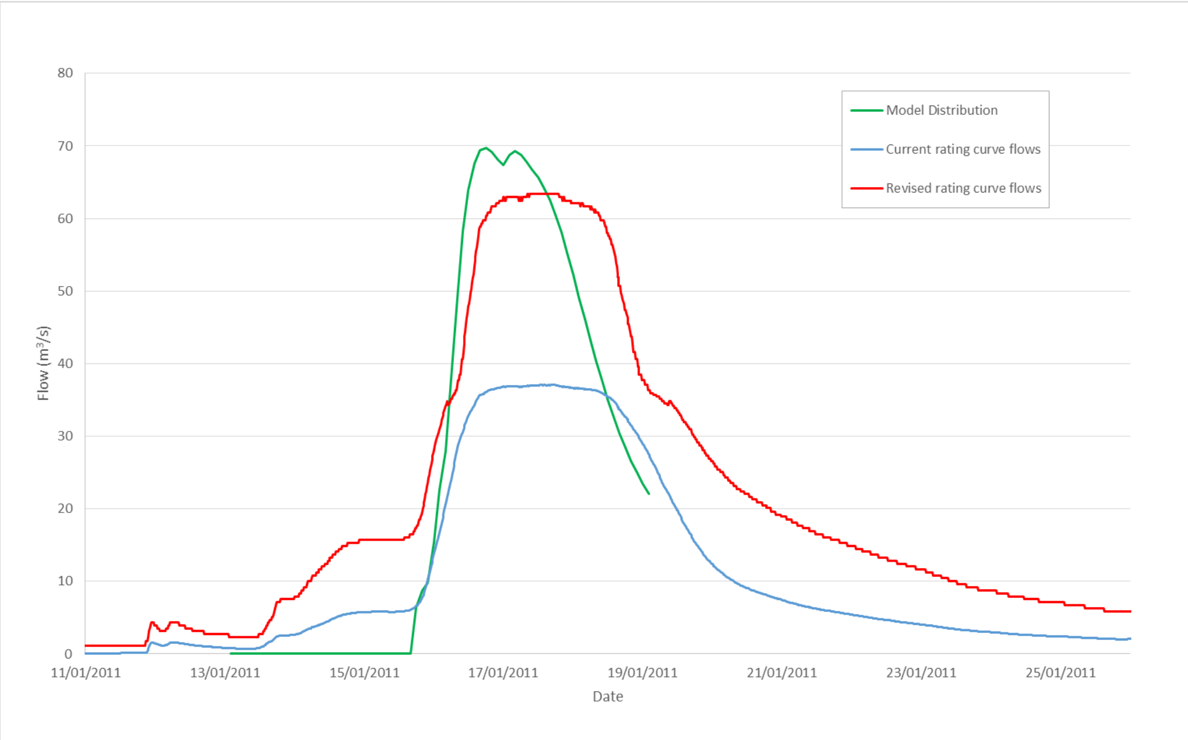


Figure 9-7 January 2011 – Flows at the Yarriambiack Creek at Wimmera Highway for the current rating curve, revised rating curve and hydraulic model distribution

Table 9-1 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 3 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[15] and considered appropriate for use in this project.

As discussed in Section 6.3.4 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 9-2 shows the range of differences between the modelled and surveyed peak flood heights with a graphic representation shown in Figure 9-8.

Table 9-2 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 9-8 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 9-9 and Figure 9-10 respectively.

[15] Chow (1941), Open Channel Hydraulics

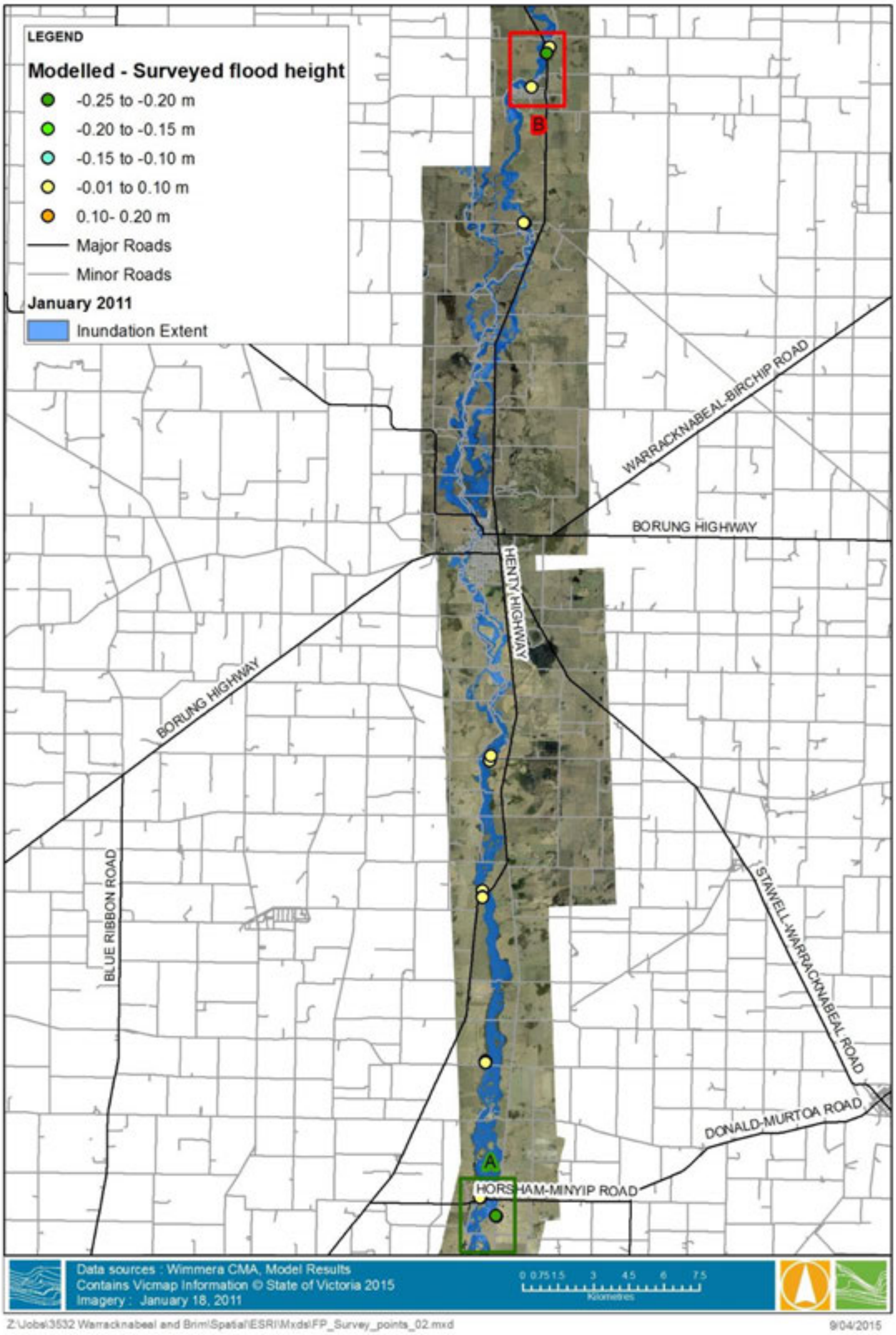


Figure 9-8 January 2011 – Ferguson and Perry Surveying peak flood height comparison

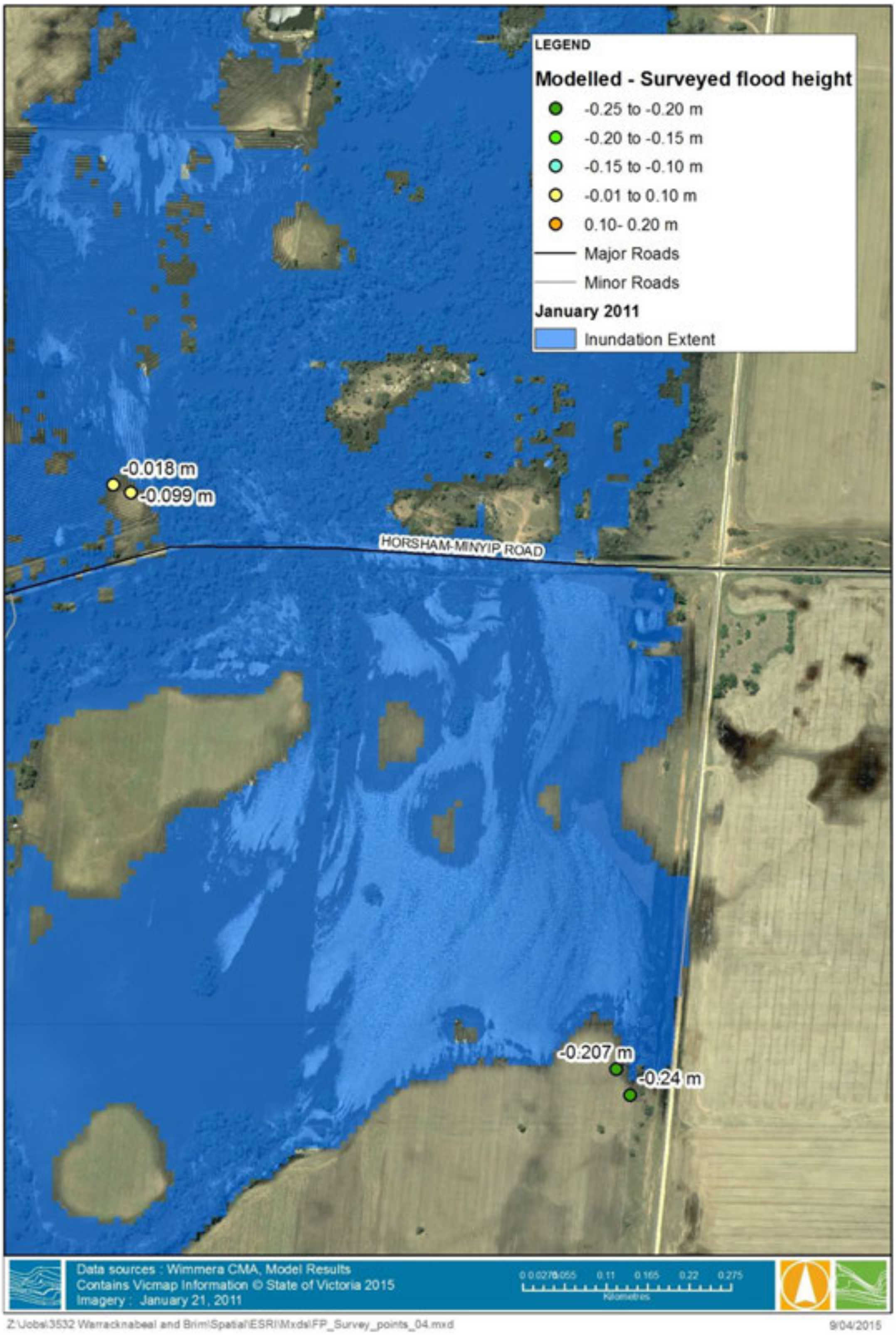


Figure 9-9 January 2011 – Ferguson & Perry Surveying peak flood height comparison – Area A

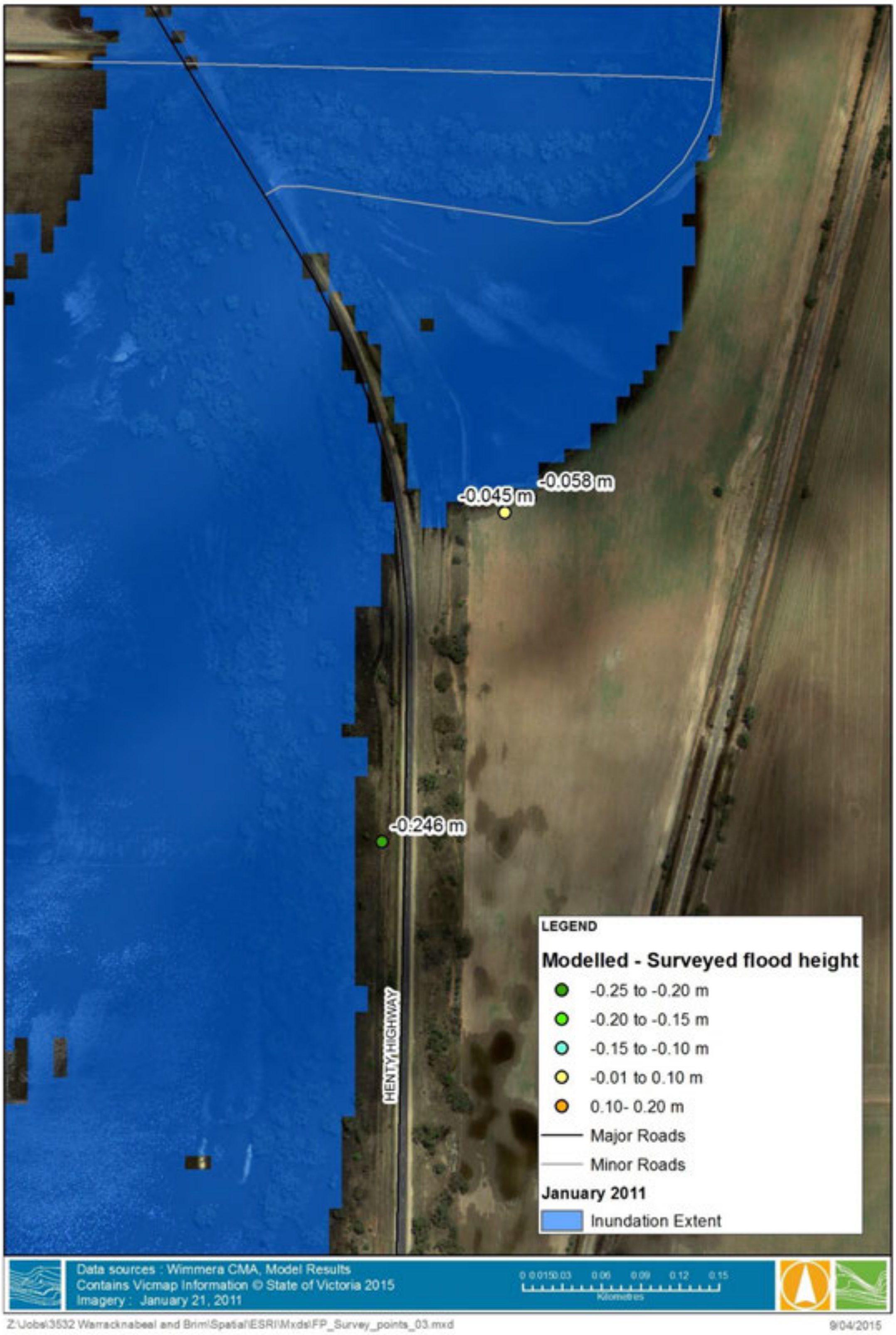


Figure 9-10 January 2011 – Ferguson & Perry Surveying peak flood height comparison – Area B

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 9-3 shows the range of differences between the modelled and surveyed peak flood heights with a graphic representation shown in Figure 9-11.

Table 9-3 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 9-11 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 also provided.

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 0.25 m. 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.

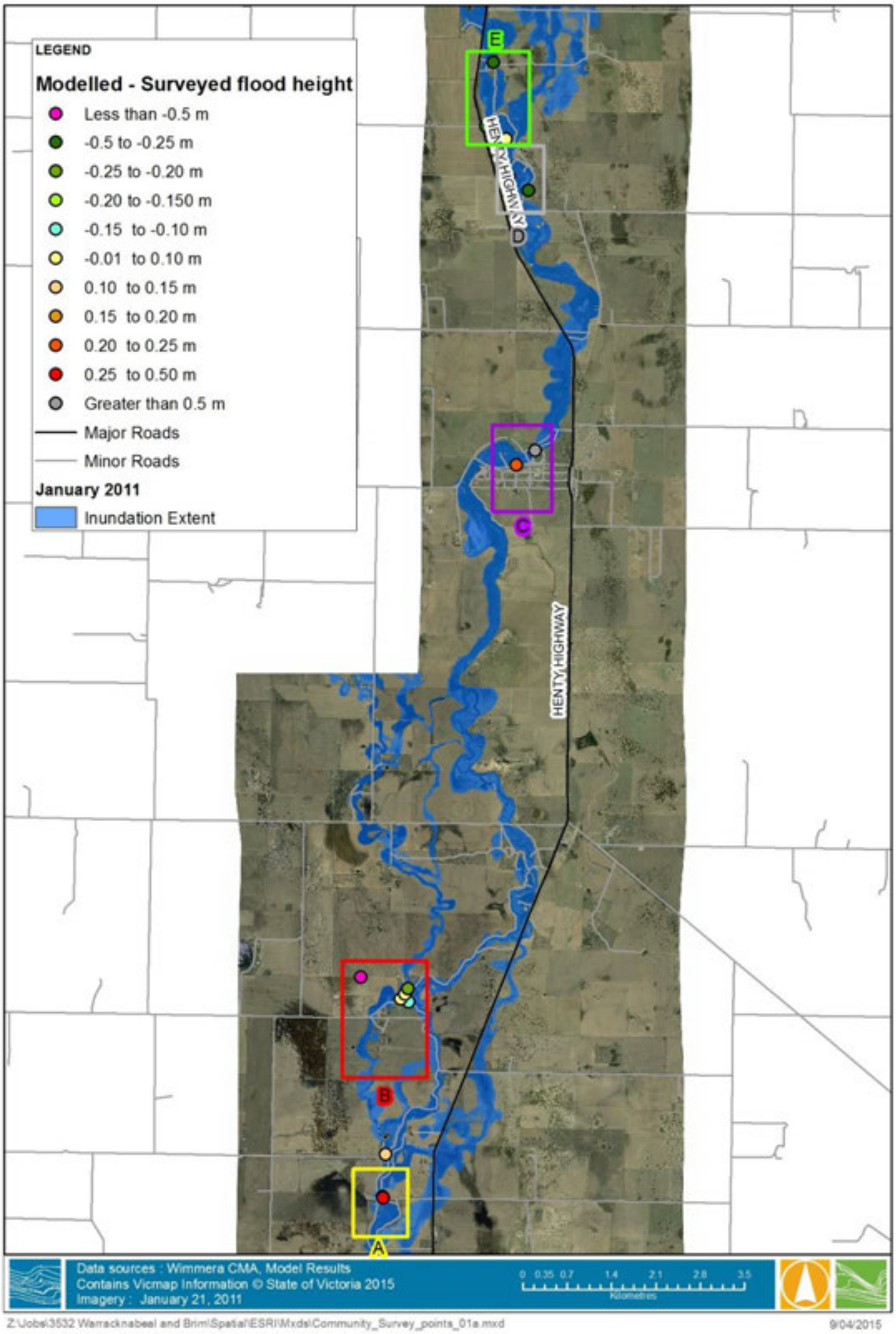


Figure 9-11 January 2011 – Community Collected Surveying peak flood height comparison

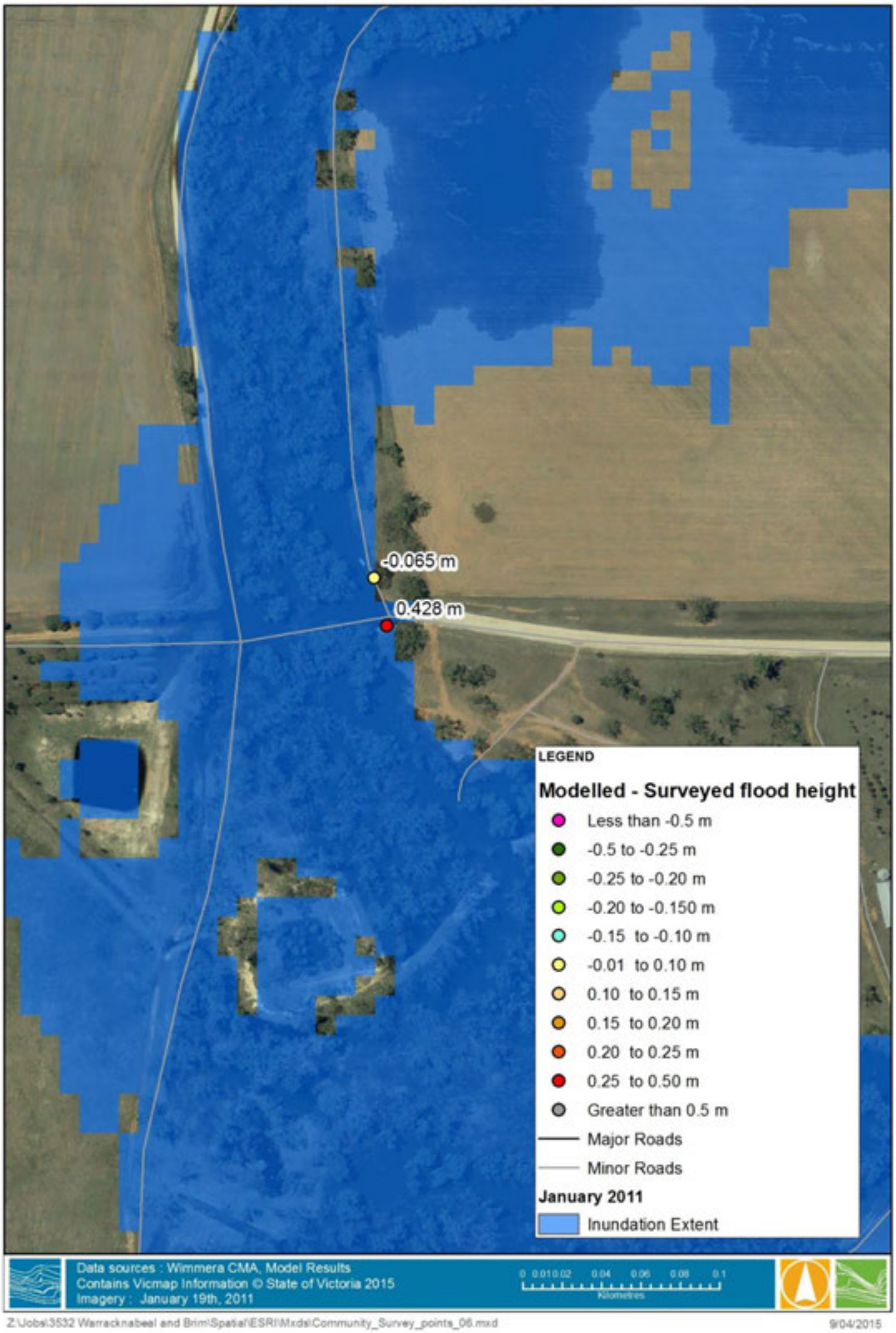


Figure 9-12 January 2011 – Community Collected Surveying peak flood height comparison – A

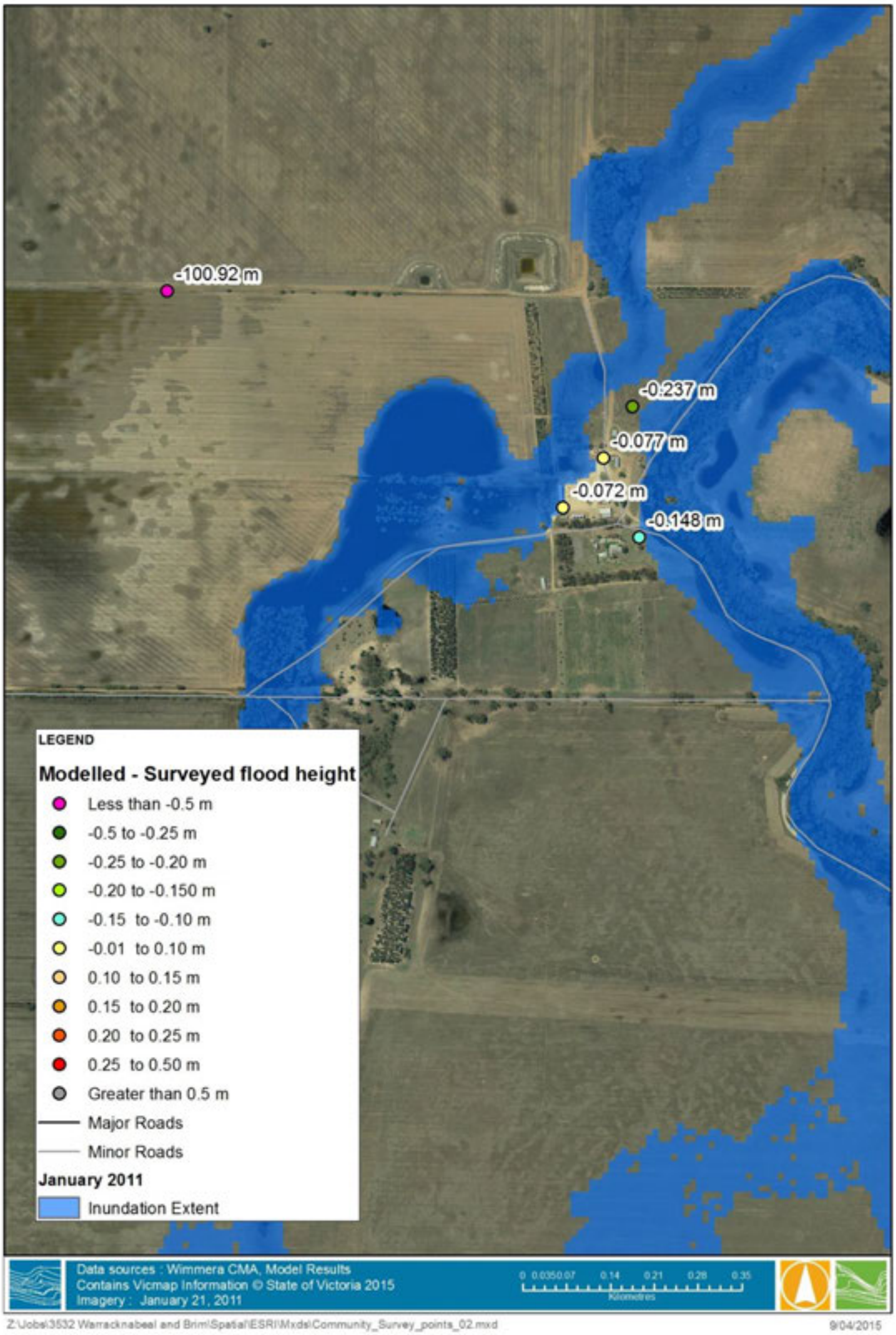


Figure 9-13 January 2011 – Community Collected Surveying peak flood height comparison – B

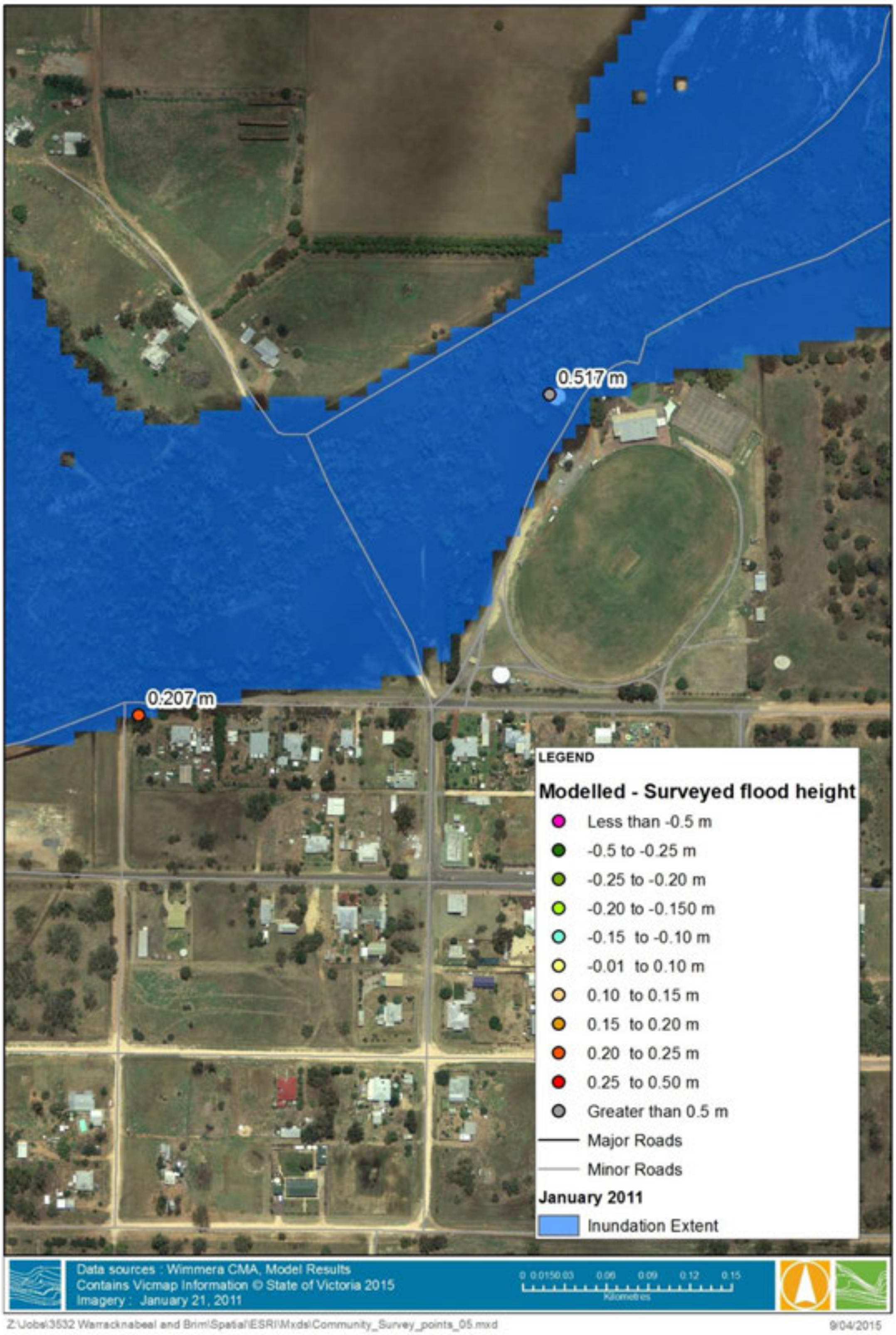


Figure 9-14 January 2011 – Community Collected Surveying peak flood height comparison – C

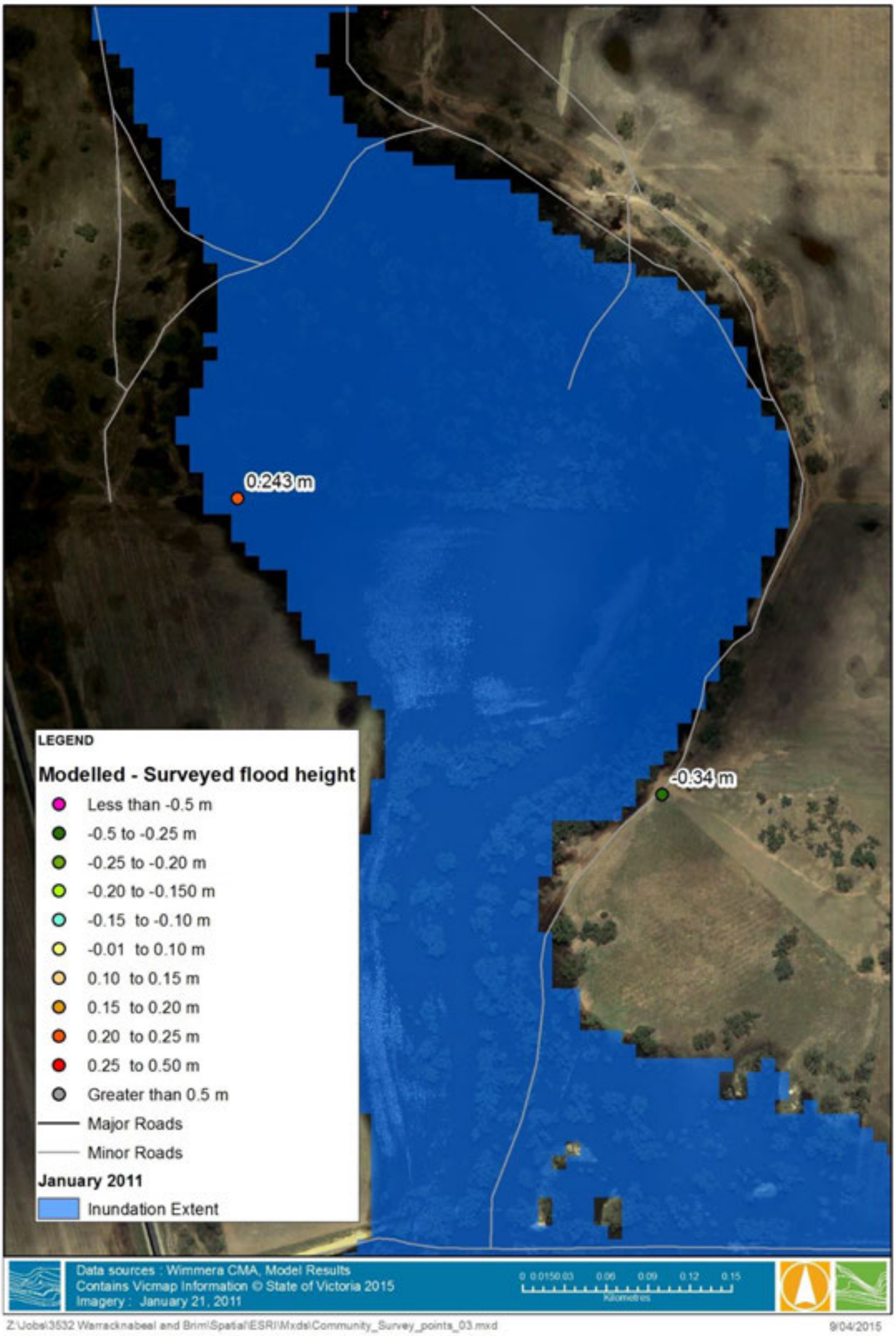


Figure 9-15 January 2011 – Community Collected Surveying peak flood height comparison – D

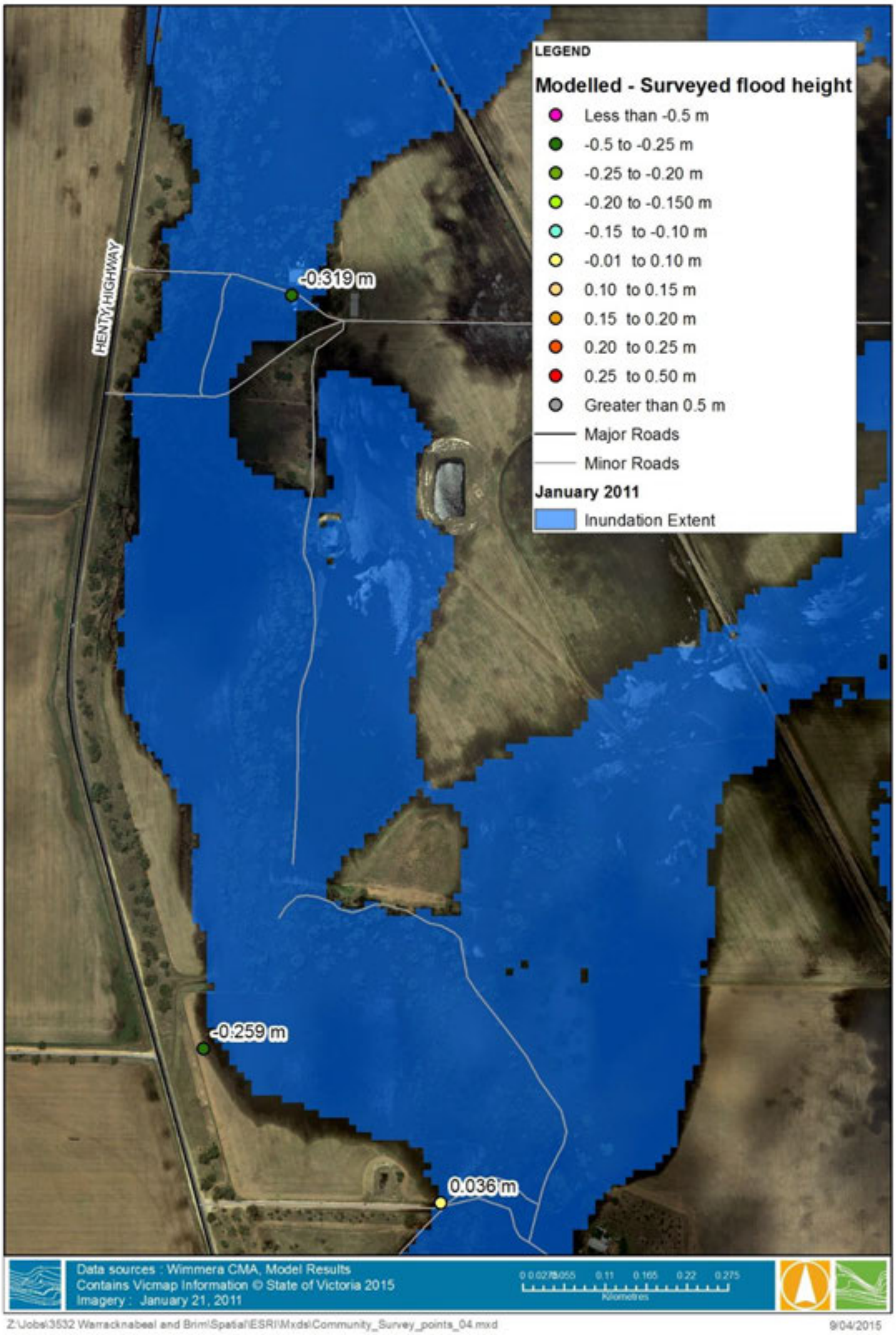


Figure 9-16 January 2011 – Community Collected Surveying peak flood height comparison - E

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.

9.4.3 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 9-17. All of the points are located between Warracknabeal and Kellalac.

Figure 9-17 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 9-18

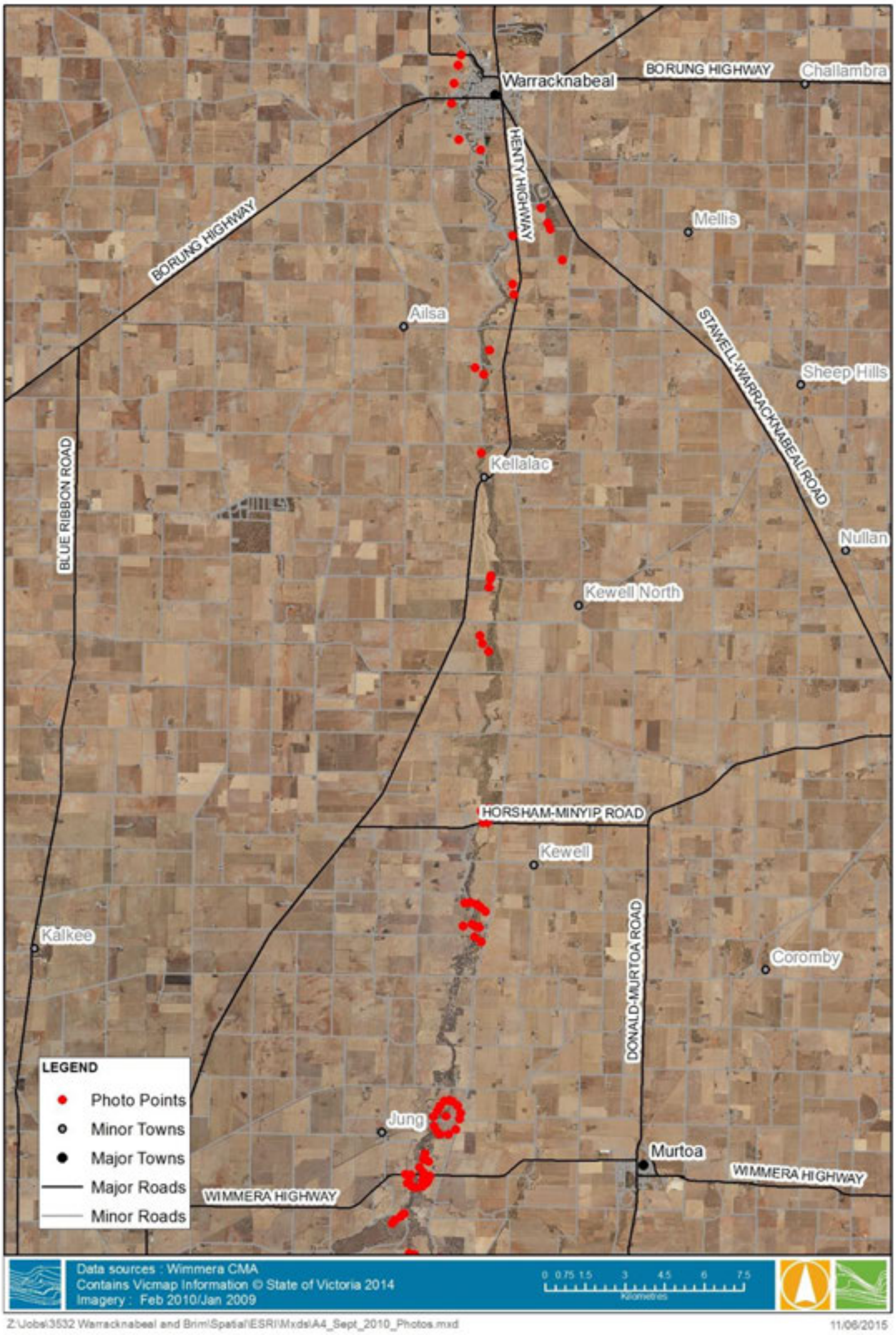


Figure 9-18 September 2010 – Aerial photograph locations

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 9-19. This confirms the revised rating curve can be used to estimate the September 2010 flows.

Figure 9-19 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 9-20.

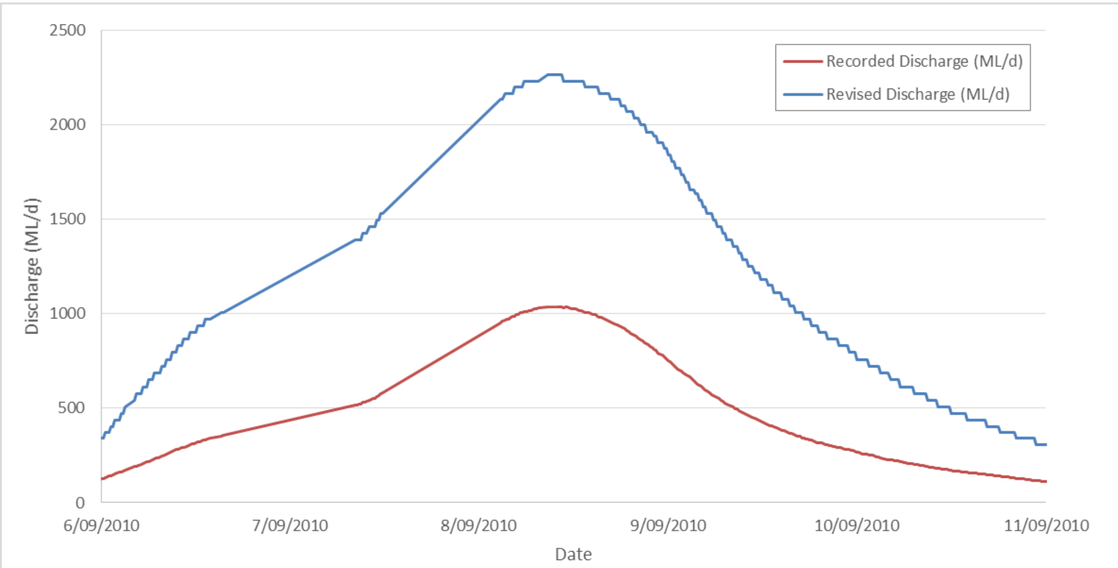


Figure 9-20 September 2010 recorded and revised hydrographs

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 9-21, 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 9-22.

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 9-23 and Figure 9-24.

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.

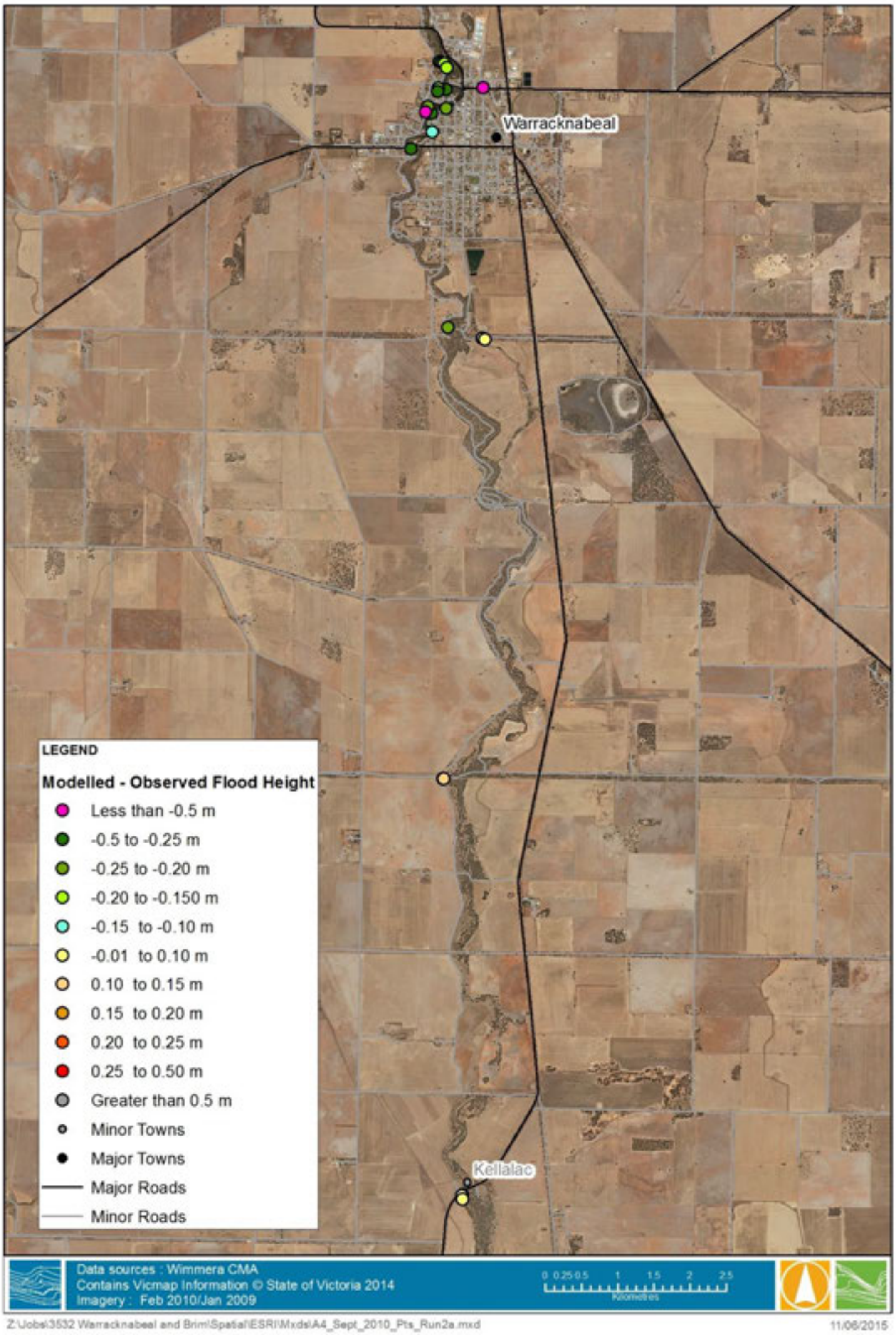


Figure 9-21 September 2010 modelled and observed flood heights using the current rating curve

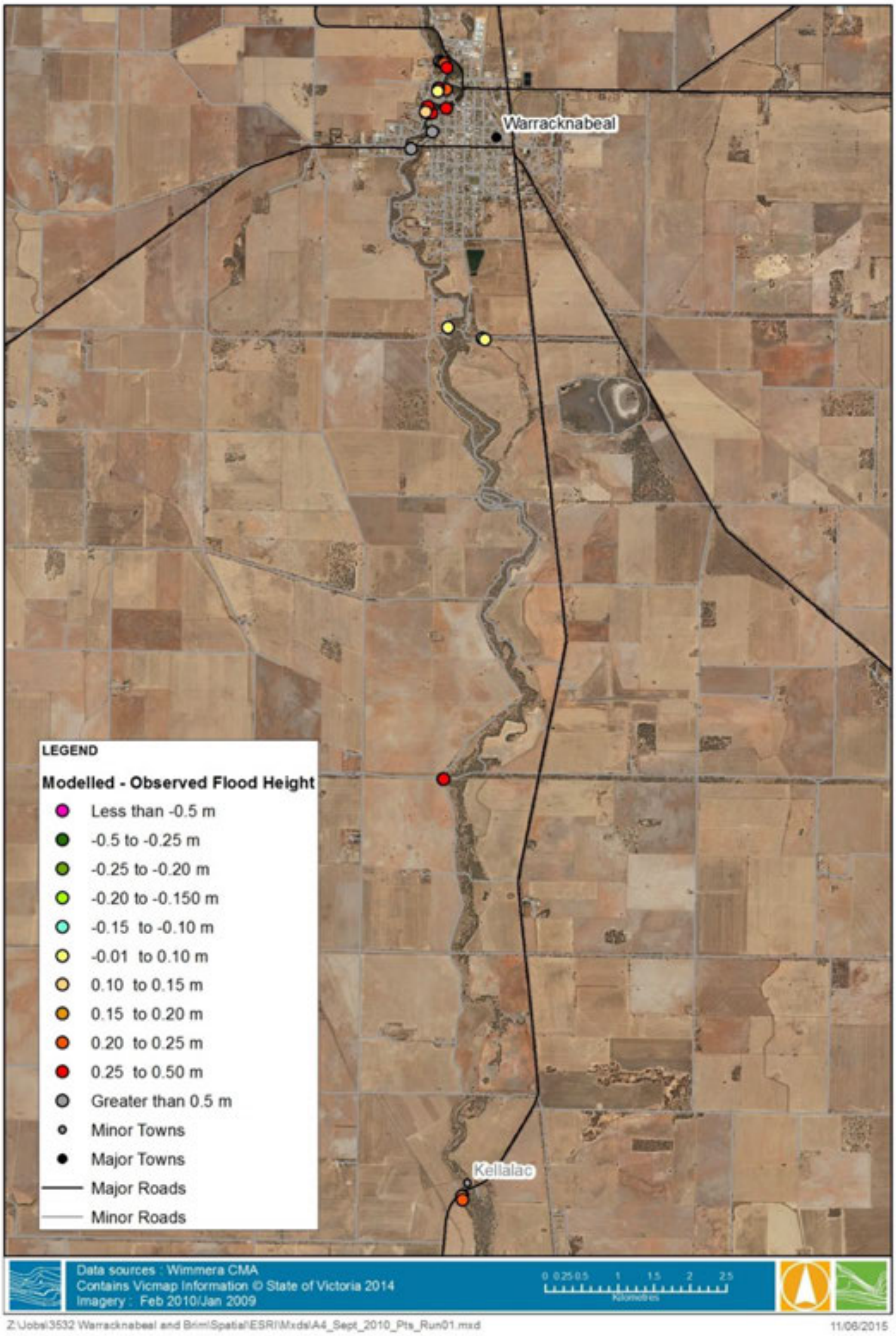


Figure 9-22 **September 2010 modelled and observed flood heights using the revised rating curve**

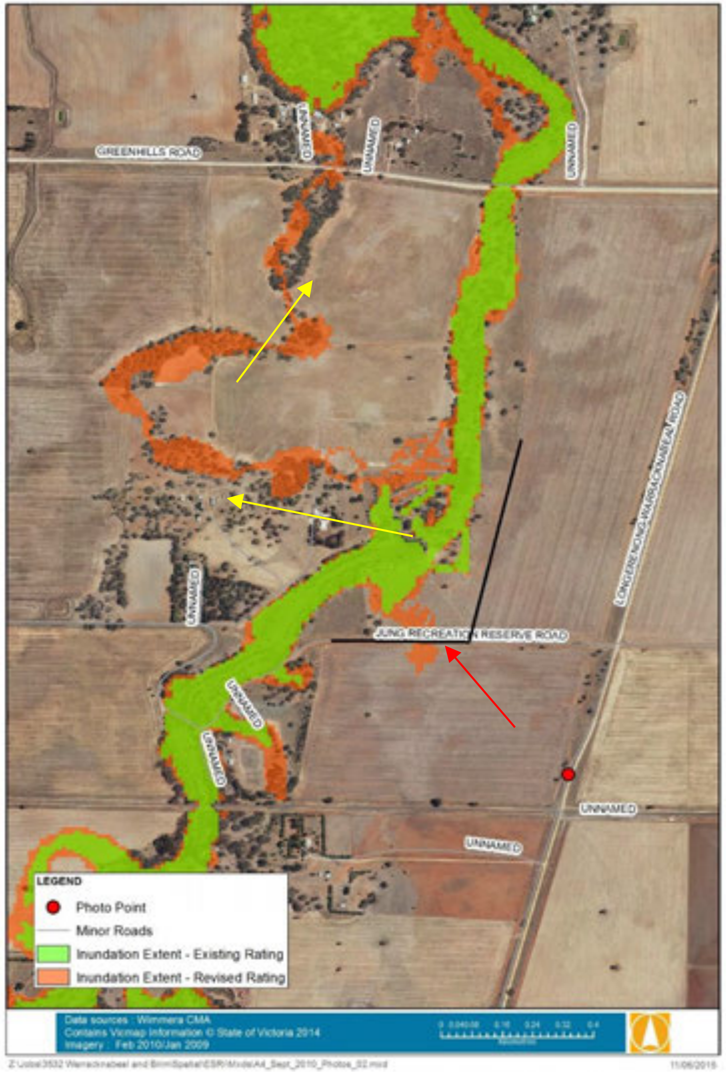


Figure 9-23 September 2010 modelled extent and captured aerial photography – Location 01

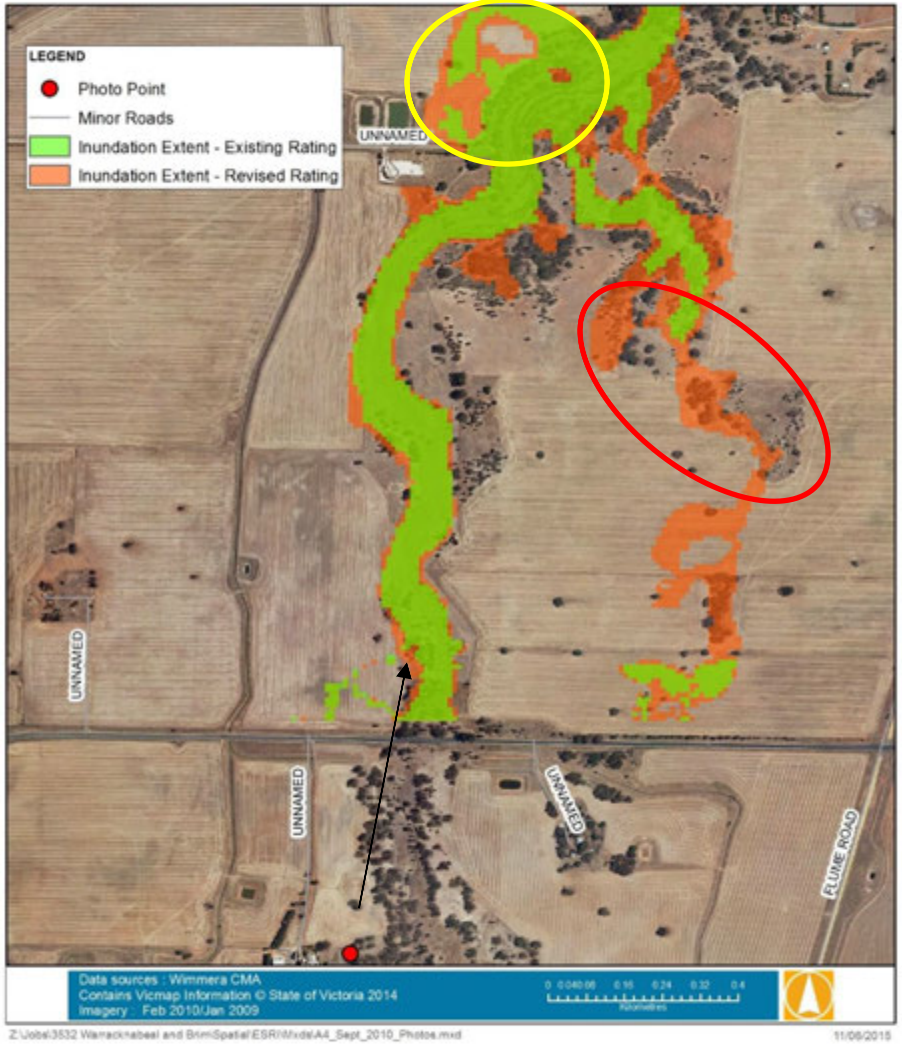


Figure 9-24 September 2010 modelled extent and captured aerial photography – Location 02

9.4.4 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 9-25. 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, resulting hydrograph volume and initial soil moisture storage. 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, a much larger hydrograph volume and the September 2010 event months earlier, the losses would likely have been less and the impact on the resulting flood levels less. It is 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.

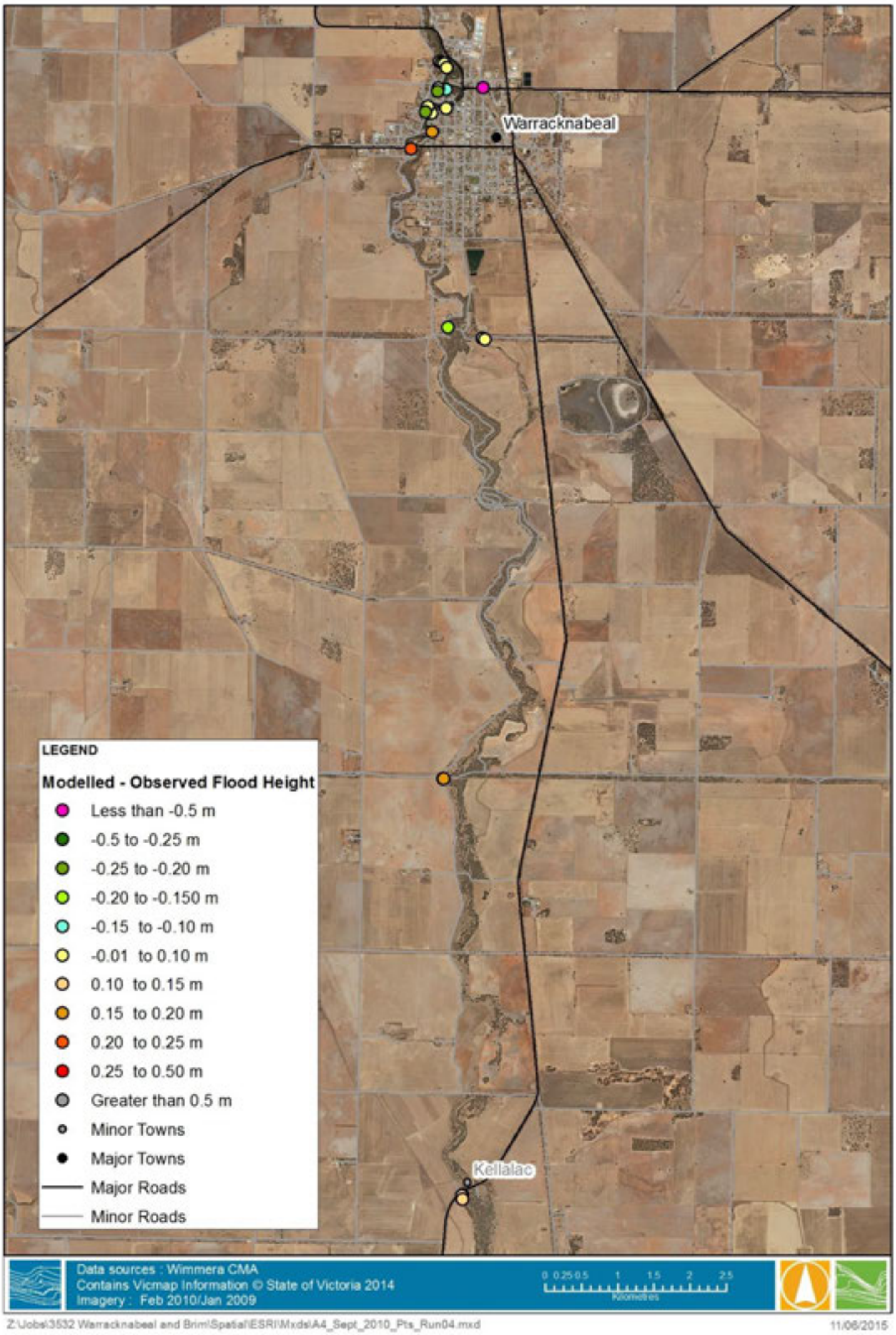


Figure 9-25 September 2010 modelled and observed flood heights using the revised rating curve and a infiltration loss of 3 mm/d

9.5 Design Hydrology

9.5.1 Overview

The Warracknabeal and Beulah Flood Investigation[6] 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 6-6 in Section 6.2.1.

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[14] to determine the most appropriate flow combination.

9.5.2 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 9-4.

Table 9-4 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	m³/s	ML/d	m³/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 instantaneous recorded flows due to the peak flow being averaged out or missed during the day in the daily flow record. 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[16], 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.

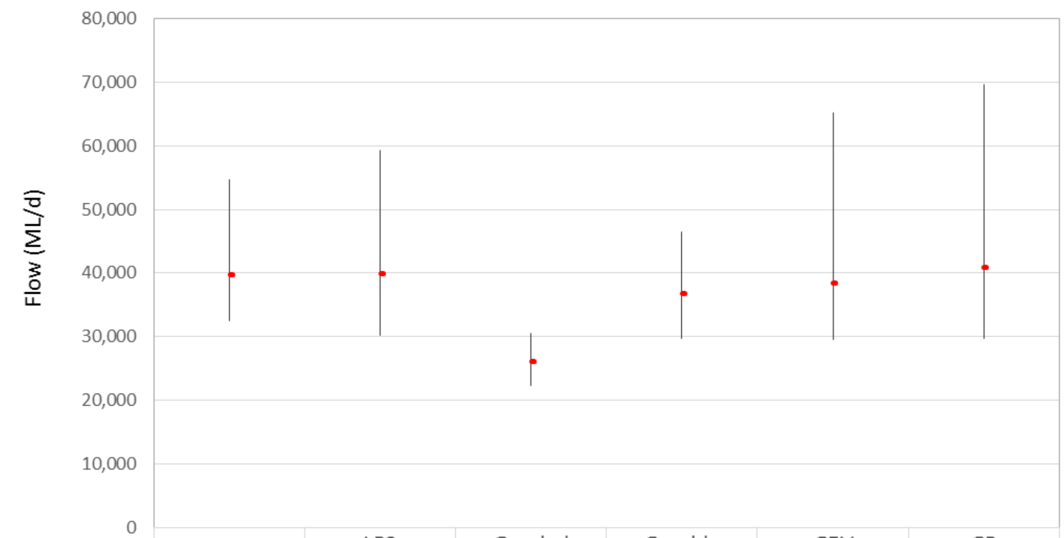
A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table 9-5.

Table 9-5 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 9-26, 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.

[16] University of Newcastle (1999), Flike Flood Frequency Analysis



	LP3 RAW	LP3 Censored	Gumbel Raw	Gumble Censored	GEV Censored	GP Censored
Upper confidence limit	54,767	59,339	30,496	46,454	65,239	69,619
Lower condifence limit	32,574	30,256	22,394	29,654	29,535	29,713
Determined flow	39,681	39,781	26,017	36,648	38,286	40,840

Figure 9-26 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 9-27, Figure 9-28 and Figure 9-29 respectively. The remainder are shown in Appendix A.

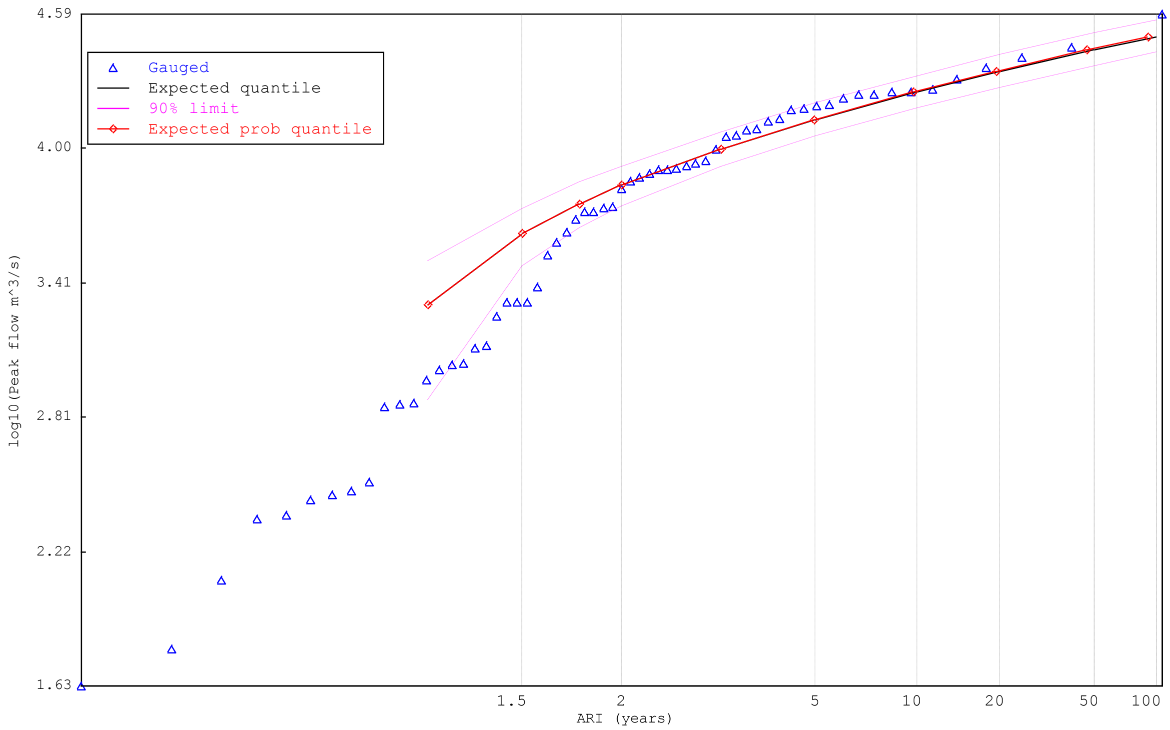


Figure 9-27 Gumbel Distribution – Raw annual series

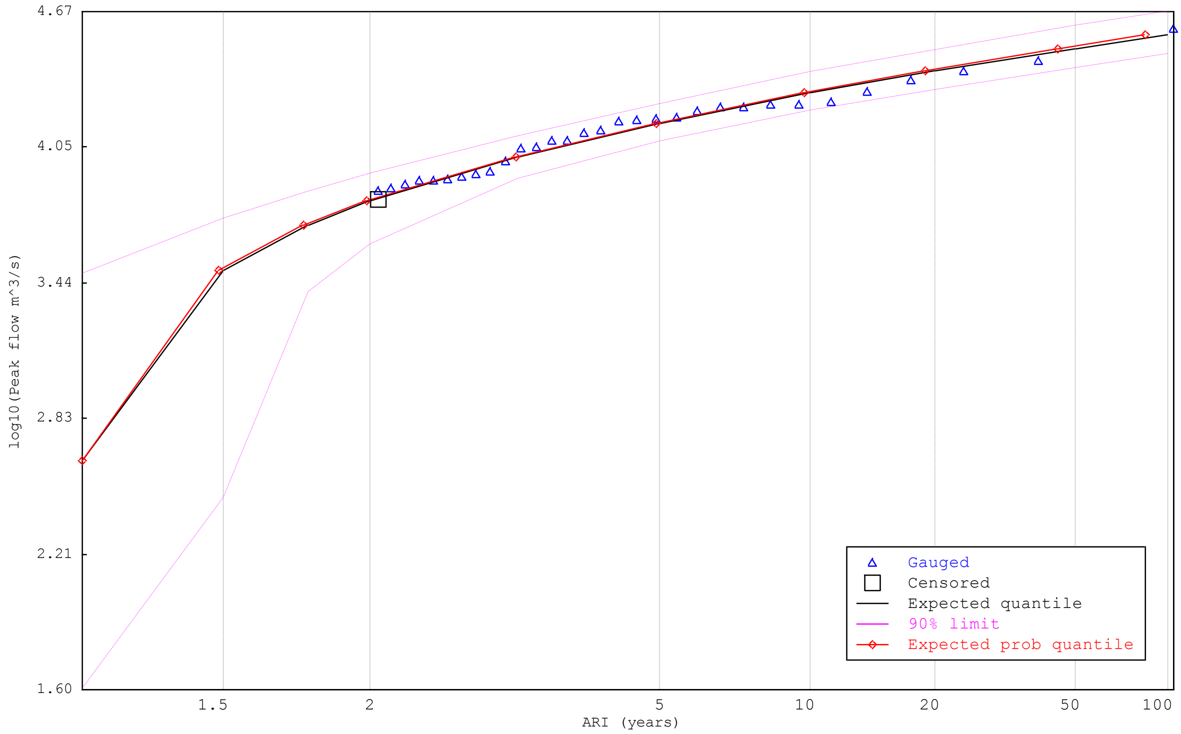


Figure 9-28 Gumbel distribution – Censored annual series

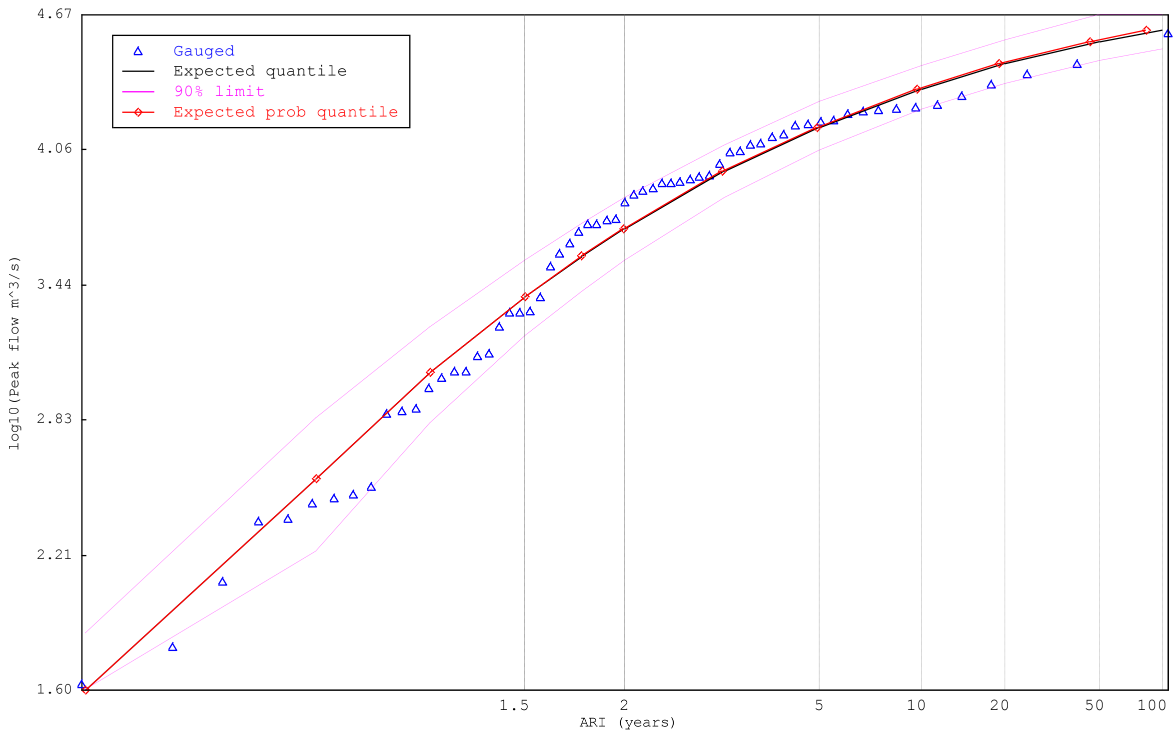


Figure 9-29 LP3 Distribution – Raw annual series

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 9-6.

Table 9-6 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 9-30. 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.

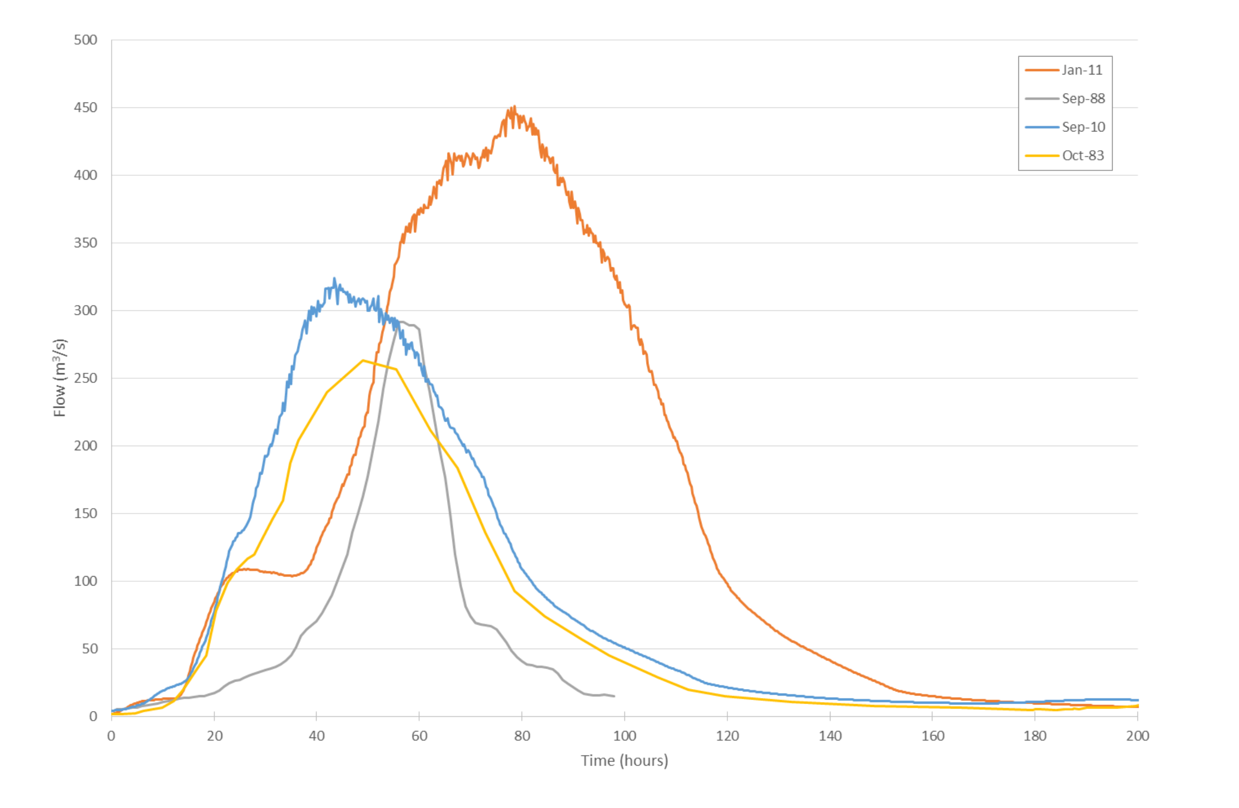


Figure 9-30 LP3 Distribution – Raw annual series

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 to 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 9-7, with the January 2011, September 2010, October 1988 and September 1983 events shown in Table 9-8.

Table 9-7 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 9-8 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 to 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 9-31. 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 9-32, 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 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.

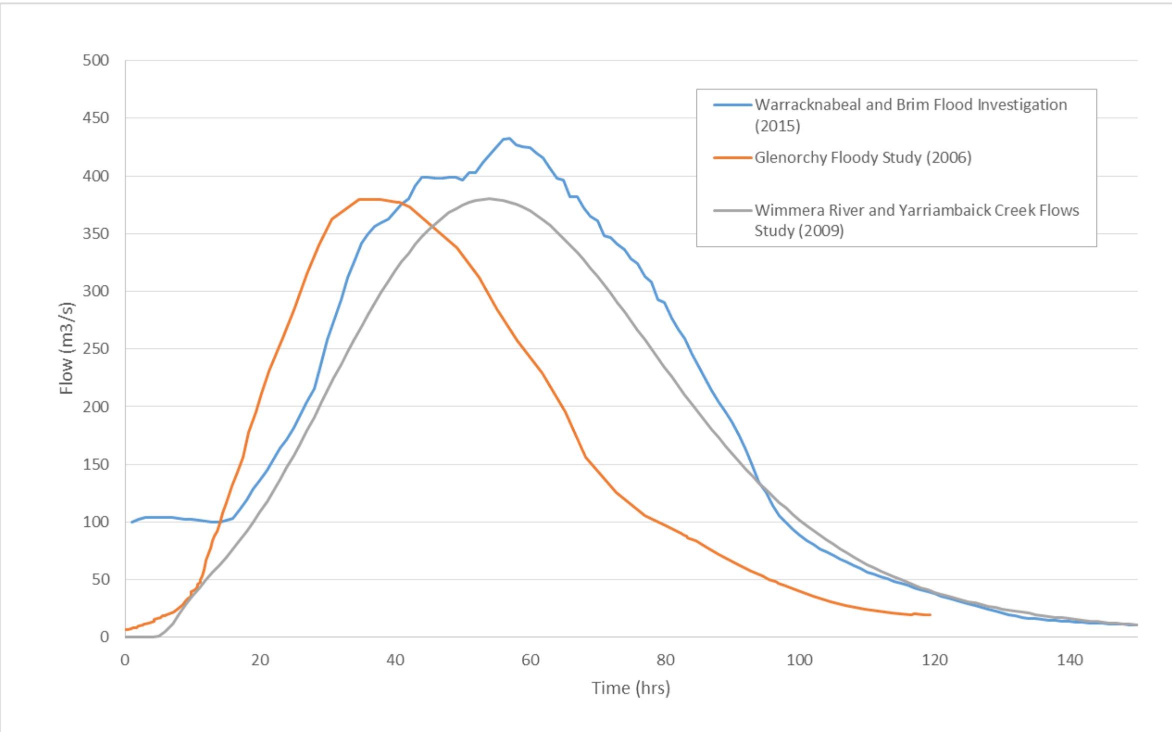


Figure 9-31 1% AEP hydrograph overlayed on hydrographs used in the Glenorchy Flood Study and Wimmera Rivera and Yarriambiack Creel Flows Study

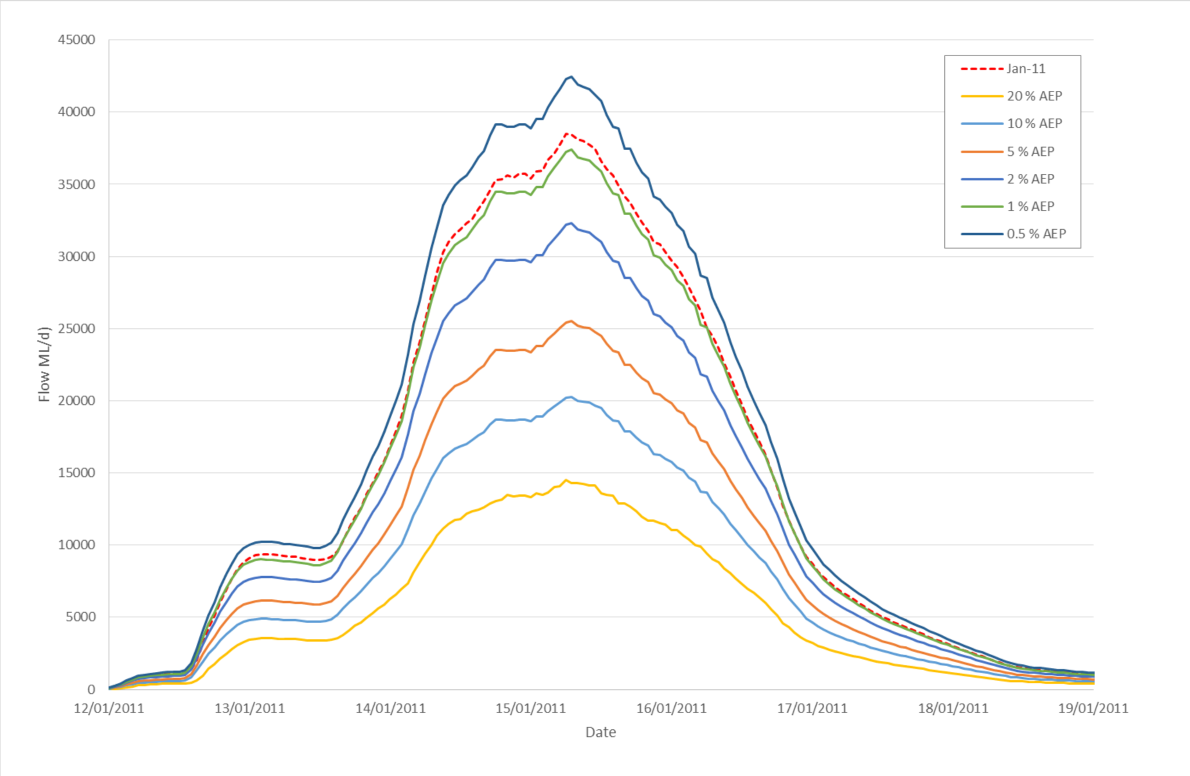


Figure 9-32 Glenorchy design flow hydrographs

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

9.5.3 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 6.2 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 9-9, with a comparison of the 1% AEP event shown in Figure 9-33.

Table 9-9 Dadswells Bridge peak flows

Event	Peak Flow (m³/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%

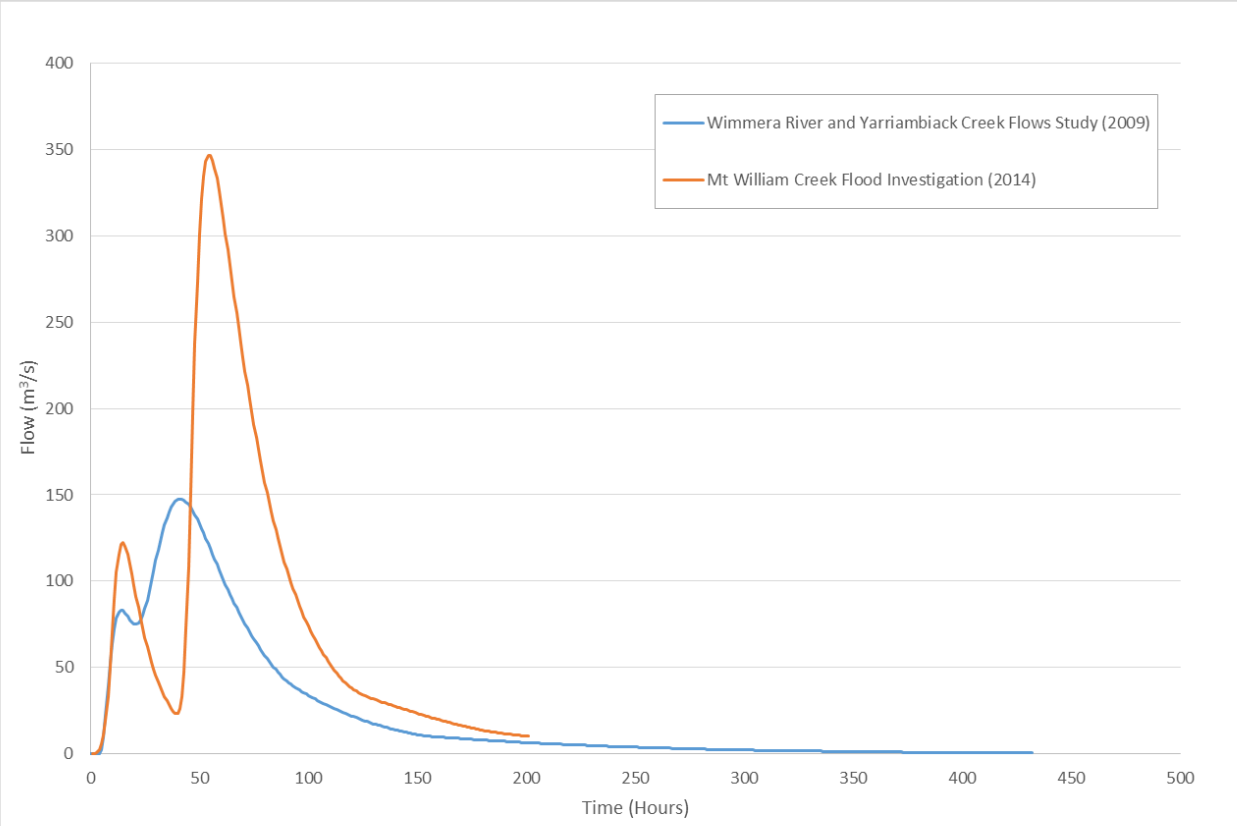


Figure 9-33 1% AEP hydrograph comparison – Wimmera River and Yarriambiack Creek Flows Study/Mt William Creek Flood Investigation

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[14] 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 9-10 and

Table **9-11** respectively.

Table 9-10 Wimmera River and Yarriambiack Creek Flows Investigation[8] URBBS model calibration – Upper Wimmera River subarea

Event	Routing Parameters		Rainfall losses		Wimmera River at Glenorchy Peak Flow	
	α	β	IL (mm)	CL (mm/hr)	Recorded (m^3/s)	Modelled (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 9-11 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 Peak Flow		Wimmera River at Horsham Peak Flow (m^3/s)	
	α	β	IL (mm)	CL (mm/hr)	Recorded (m^3/s)	Modelled (m^3/s)	Recorded (m^3/s)	Modelled (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 9-12.

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 9-13 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 9.5.2) 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[14] 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 9-12 Mt William Creek Flood Investigation[14] 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[14] (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 9-13 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[14] - 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 (5,478 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 in line 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[17]. Flooding on Mt William Creek at Dadswells Bridge was determined as slightly higher than a 0.5% AEP event[14].

9.5.4 Stormwater modelling

Stormwater modelling was undertaken for the 2 hour, 1% AEP flood event only applying the ARR recommended rainfall intensities and Zone 2 temporal pattern across the 2 hour storm duration. Rainfall was directly applied to the Warracknabeal and Brim catchment areas as a rainfall on grid model with no losses.

9.5.5 Probable Maximum Flood

Initially, PMF flows were to be generated using the rapid assessment method detailed by Nathan et al[18]. 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:

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

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

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

Where Q_p is the PMF peak flow (m^3/s), A is the catchment area (km^2).

The area upstream of the Wimmera River at Glenorchy streamflow gauge is 1,953 km^2, which resulted in a peak flow of 13,740 m^3/s. This flow is considered unreasonably high at Glenorchy and it was decided that an alternative method to estimate a PMF like flow was required. It was decided that the flood frequency analysis would be extrapolated out to the 100,000 year ARI event. The FFA determined a peak flow of 1,024 m^3/s at Glenorchy. This is considered a much more reasonable estimate as it is approximately double the January 2011 flow.

A relationship between the flow at Glenorchy and the flow at Jung was determined by plotting the determined AEP peak flows and developing an equation for the relationship. The peak flow relationship and equation is shown in Figure 9-34.

Using the equation a peak flow at Jung of 550 m^3/s (47,520 ML/d) was determined, the 0.5% AEP hydrograph was scaled to match this flow for the PMF event.

[17] Water Technology (2012), East Horsham Flood Plan, Horsham Rural City Council; Water Technology (2011), January 2011 Flood Report, Wimmera CMA; Water Technology (2012), Horsham Bypass Hydrology and Hydraulics Investigation (2012), VicRoads

[18] 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

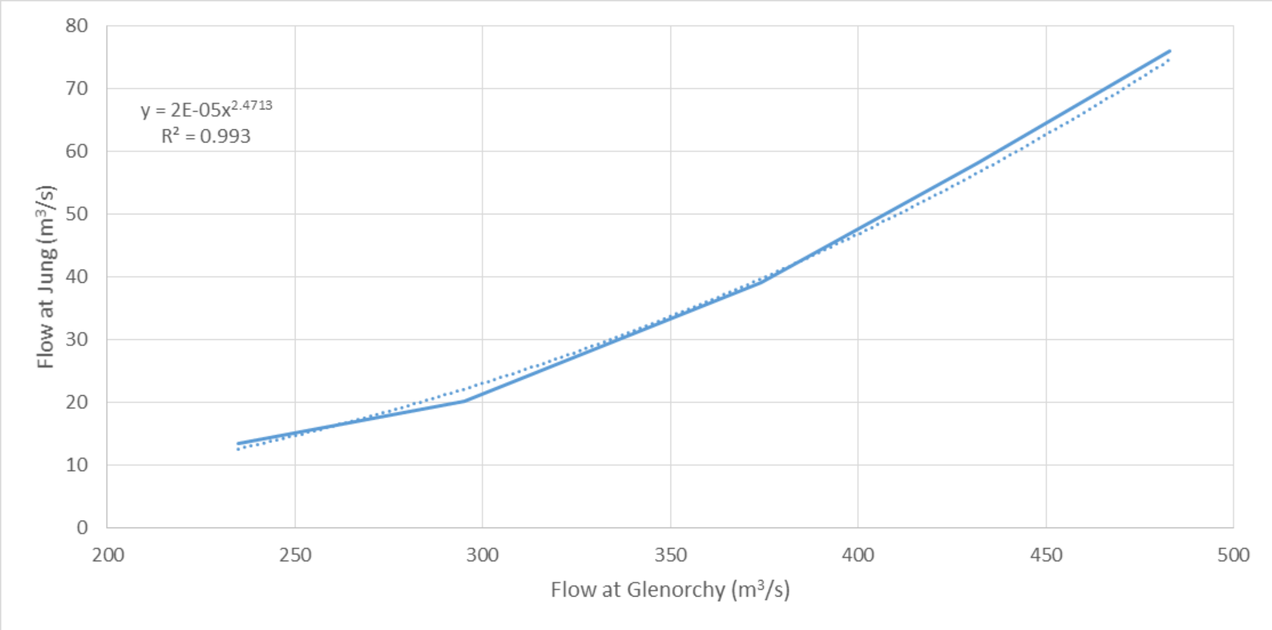


Figure 9-34 Glenorchy and Jung peak flow relationship and equation

9.5.6 Climate Change Scenarios

The impacts of climate change were tested by increasing the rainfall intensity by 5% per degree of warming, in line with latest guidance from Australian Rainfall and Runoff[19]. A scenario of 2°C of warming (i.e. 10% increase in rainfall intensity) was adopted for this sensitivity test. This is consistent with 'Climate Change in Australia Projections'[20] report which suggests for an intermediate climate scenario, a temperature increase of between 1.1°C to 2.0°C is likely for the Southern Slopes of Australia.

The 10% increase in rainfall intensity was applied to the BoM URBS model to determine the increase in peak flow expected at Glenorchy. This relative increase was then applied to the 1% AEP peak flow determined in the Flood Frequency Analysis.

A 10% increase in rainfall intensity resulted in a 22% increase in peak flow at Glenorchy, this increase was applied to the 1% AEP flows at Jung.

A comparison of the 1% AEP flood flows at Jung under existing and climate change scenarios is shown in Figure 9-35.

[19] Engineers Australia (2014), Australian Rainfall and Runoff Discussion Paper: An Interim Guideline for Considering Climate Change in Rainfall and Runoff (Draft). Report No. ARR D3

[20] CSIRO. (2005). Climate Change in Eastern Victoria - Stage 1 Report: The effect of climate change on coastal wind and weather patterns. CSIRO.

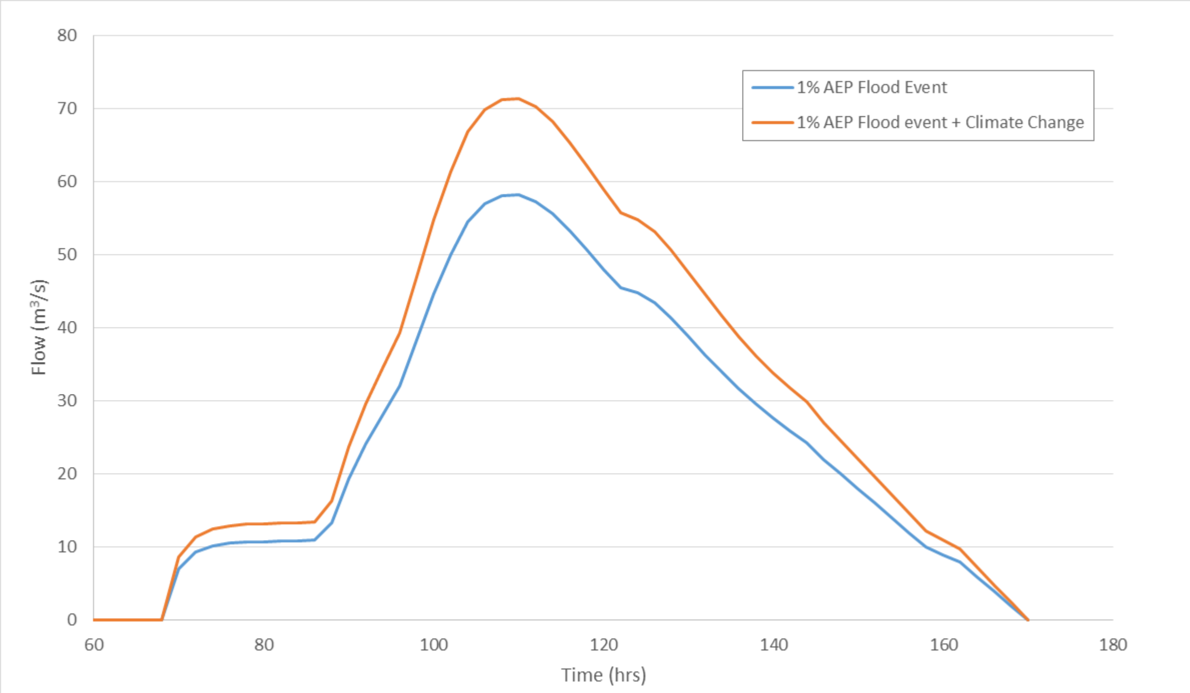


Figure 9-35 **1% AEP hydrograph comparison –Yarriambiack Creek at Jung for existing and climate change scenarios**

9.6 Design Hydraulics

9.6.1 Overview

Hydraulic model parameters adopted in the design modelling were based on those determined during the January 2011 calibration. This included a uniform Manning's 'n' roughness of 0.05, no initial water conditions in the model and no continuing losses representative of infiltration and evaporation.

These parameters were chosen because they were proven to give the best match to the available calibration data for the January 2011 event, which is close to a 1% AEP event of which is of most interest to this study.

9.6.2 Remnant Levee

Overview

During January 2011 approximately 6 km of earthen levee was constructed protecting the majority of the Warracknabeal township from inundation. The levee was constructed in a short period of time given the volume of fill required and length of levee constructed. Similarly, during the January 2011 event levees were also constructed in Brim, however these were not at the same scale as those constructed in Warracknabeal and were not required.

Post the January 2011 event, large sections of the levee were decommissioned to allow traffic access to resume and return Yarriambiack Creek to its normal state. However, some sections of levee were formalised by Yarriambiack Shire Council to be more aesthetic and structurally sound and others were just left in a similar state to that initially constructed.

Warracknabeal

The January 2011 levee alignments and remaining sections of levee in Warracknabeal are shown in Figure 9-36. Levees were constructed on private and public land, as well as roads. Photos of the levee in Warracknabeal captured by Yarriambiack Shire Council are shown in Figure 9-37, with photos of the remnant levee captured during the site visit shown in Figure 9-38.

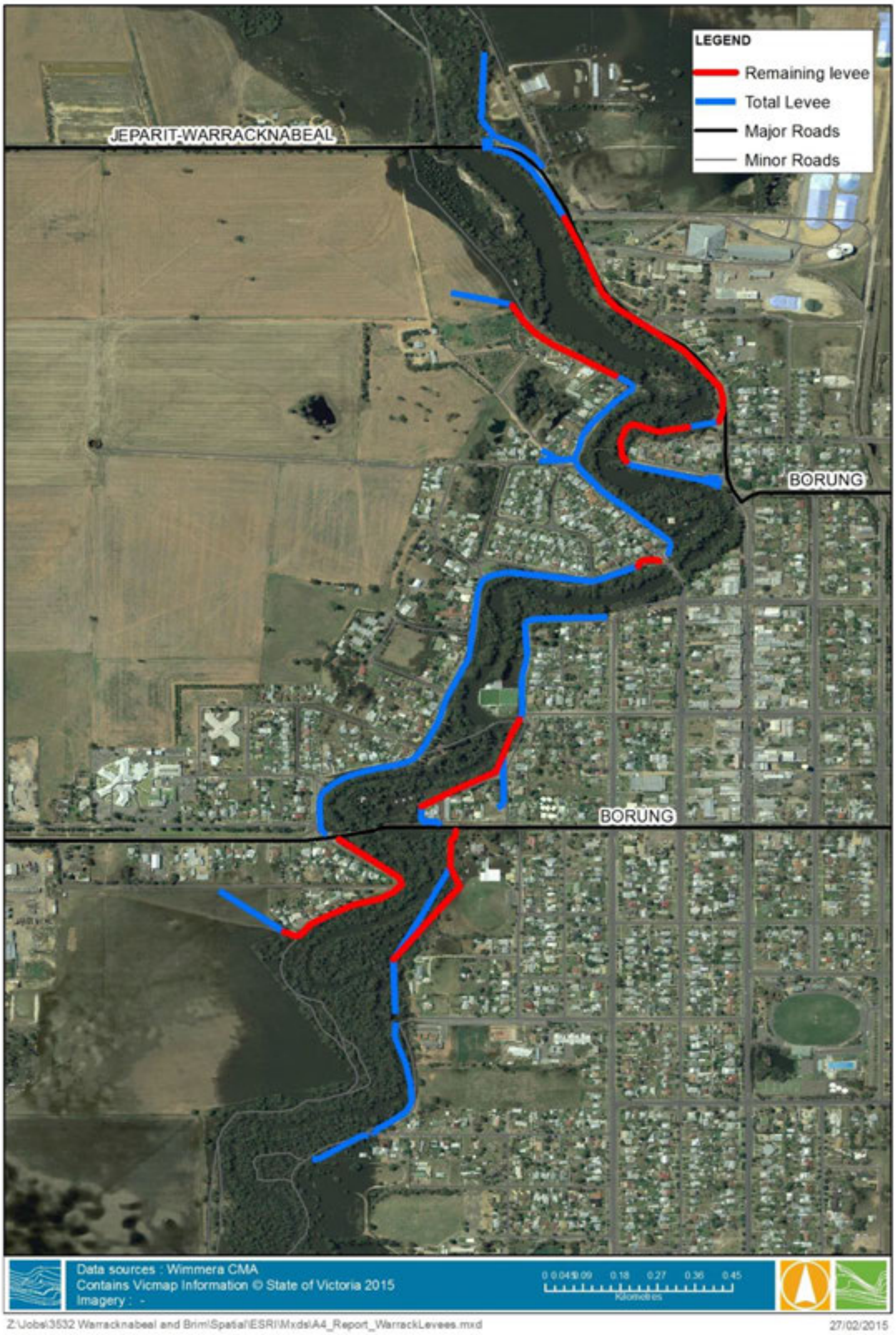


Figure 9-36 January 2011 levee and remnant sections of levee

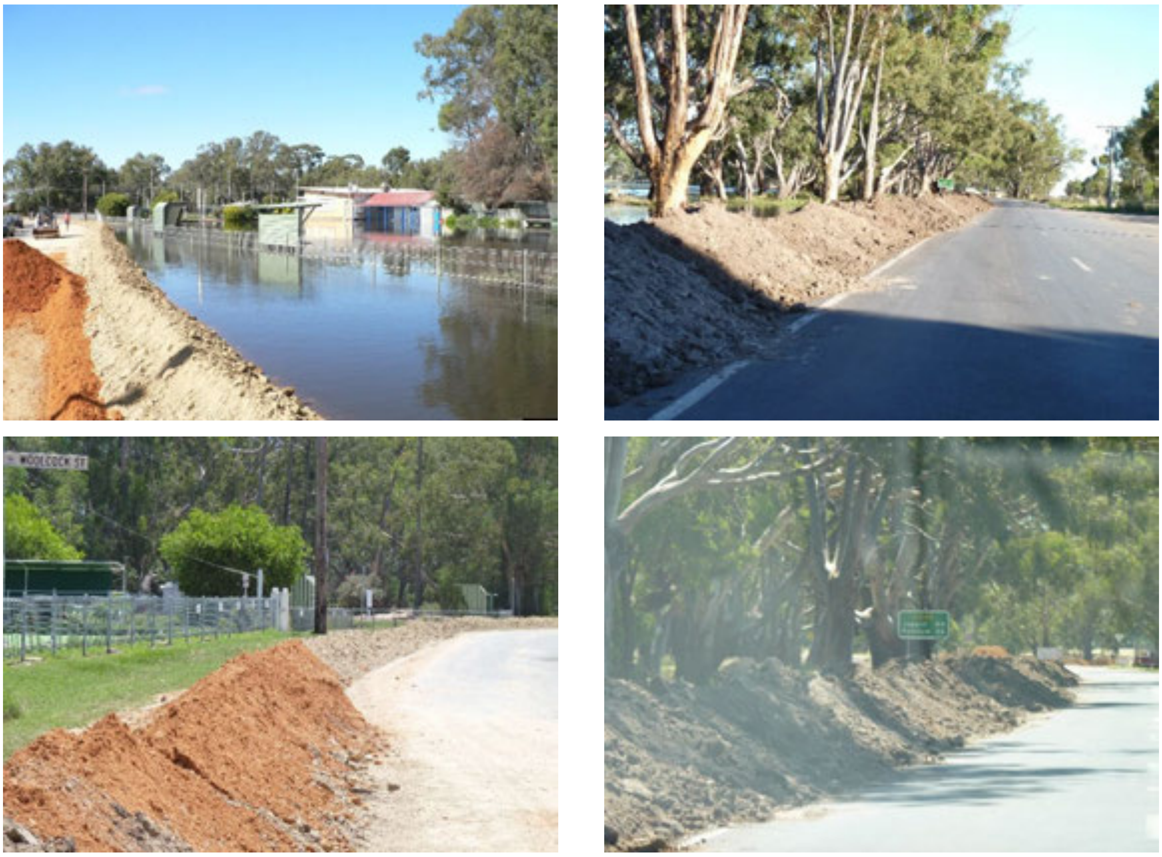


Figure 9-37 January 2011 levee and remnant sections of levee (Photos provided by YSC)

Figure 9-38 Remnant sections of levee (Photos captured during the project site visit)

Brim

The levees constructed in Brim during January 2011 were in place at the time of the initial site inspection (5th September 2014) and it was expected the levees would remain in place in their constructed form without formalisation by Yarriambiack Shire Council. The location of these levees is shown in Figure 9-39.

Discussion with Brim community members during the community consultation have indicated flood water did not reach the levees.

Figure 9-39 Brim levee locations

Photos of the two levees constructed are shown in Figure 9-40. The left image shows the northern most section of levee immediately west of the township while the right image shows the longer southern levee preventing a breakout from Yarriambiack Creek towards Brim.

Both levees have very high sand content with no compaction. These levees should not be relied upon for future protection as they are not being maintained and are of poor construction standard.

Figure 9-40 Brim sections of levee (Photos captured during the project site visit)

Discussion and Outcome

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 in Brim are not.

The Draft Victorian Floodplain Management Strategy[21] 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. Current practice seems to be to include levees in their current condition in the modelling, so there is some uncertainty in the policy in this regard.

Given the process required for the Warracknabeal levees to be formalised into the Planning Scheme and the reality this study will result in a revision of the Planning Scheme regardless of the final levee recommendations it is not unexpected a planning scheme amendment has not occurred since January 2011. 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

[21] Draft Victorian Floodplain Management Strategy – Department Environment Land Water Planning (2014)

gardens. As such the Project Steering Committee determined they would be included in the design modelling completed during this study due to their potential to reduce the inundation extent in some areas and increase it in others. If an event was to occur and there was not sufficient time or resources to construct the decommissioned sections of levee, the currently constructed levee system will give a more accurate account of the inundation that would occur.

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 Project Steering Committee determined they would not be included in the design modelling during this study.

9.6.3 Yarriambiack Creek Flood Modelling – Flood Intelligence and Design Flood Behaviour

Overview

A significant amount of flood intelligence was generated by this study including flood levels, inundation depth, extent, timing information and inundation compared to floor levels. This information was compiled in the Warracknabeal and Brim Flood Intelligence Report. The Flood Intelligence Report was written in the SES recommended Municipal Flood Emergency Plan (MFEP) structure for direct inclusion to the YSC MFEP. This study report includes a summary of the information included in the MFEP, including the following:

- A description of the flood impacts for each modelled AEP. This is in the same format as presented in the YSC MFEP and the description of each event must be read with respect to the lesser AEPs before it.
- A description of historic travel times between gauges and townships within the study area

The full flood intelligence cards described in the Flood Intelligence Report including flood response actions and properties at risk are shown in Appendix D.

Mapping of all of the design events is shown in Appendix E, the study area was separated into three divisions due to its length.

20% AEP Event Summary

Yarriambiack Creek remains relatively confined to the channel, some breakouts into vegetated areas including:

- Immediately north of Banyena Pimpinio Road (south of the Golf Course)
- Immediately south of Horsham-Minyip Road (agricultural paddock)
- Several flood runners between Horsham Minyip Road and Daveys Road
- Between Mayberrys Road and Moloneys Road (over topping of Moloneys Road in several locations east of the Yarriambiack Creek channel to depths of up to 30cm)
- Immediately south of Dumbuoy Road (overtopping in several locations)
- Agricultural inundation between Tarrent Road and Morella Road (western side of Yarriambiack Creek)
- Quarry west of Yarriambiack Creek at Lah

There is one property isolated during a 20% AEP flood event due to inundation of Dumbouy Road, immediately south of Warracknabeal (The Rusty Nail).

Numerous minor road crossings of Yarriambiack Creek are likely to be inundated, as well as private crossings.

10% AEP Event Summary

The flood extent is similar to the 20% AEP event with only a small increase in Wimmera River flow.

Flood pattern remains the same with a slight increase in depth and extent. The flood extent is increased most in the areas of:

- Banyena Pimpinio Road
- Depth of inundation at Moloneys Road increased by around 5cm.
- Inundation of Ailsa Road at several locations at depths less than 10cm.
- Roses Road (multiple points of inundation – inundation isolating a dwelling on Yarriambiack Creek north of Roses Road)
- Flood runners between Tarrant Road and Morella Road
- Immediately upstream of the Brim Weir pool

No major additional roads have been inundated; however depth of inundation has increased by 50-150 mm depending on location.

5% AEP Event Summary

The flood extent shows several additional breakouts from the 10% AEP event, including:

- Between Schaches Road and Banyena Road
- Banyena Road is inundated at multiple locations
- Drillers Road is inundated at multiple locations (provides access to one property)
- Yarriambiack Drive is inundated at several locations
- Inundation of Roses Road has increased (isolation of one property in very close proximity to flood water)
- Moloneys Road inundation increased by 10 cm.
- Inundation of Ailsa Road increased on the eastern side
- Increase in inundation extent downstream of Cemetery Road
- Inundation upstream of the Warracknabeal Weir Pool increases to a low area to the west
- Water breaks out of Yarriambiack Creek downstream of Warracknabeal Weir and enters the industrial area immediately north of the township.
- Morella Road inundated at several locations
- Overtopping of the Henty Highway south of Ryans Road
- Inundation in very close proximity (<10 m) to a property east of the Henty Highway immediately south of Ryans Road, potential to be flooded below floor.
- Property west of the Henty Highway north of Ryans Road isolated.

Inundation depths have generally increased by 10-20 cm compared to 10% AEP levels.

2% AEP Event Summary

The flood extent shows an increase in inundation from the 5% AEP event. During a 2% AEP event there are four dwellings flooded above floor and 1 business. The major changes in impacts are:

- Greenhills Road inundated at several locations with a property west of Greenhills Road potentially isolated surrounded by flood water
- Horsham Minyip Road inundated in several locations at depths up to 25 cm
- One property to the east immediately north of Daveys Road surrounded by flood water and isolated
- Minyip Dimboola Road inundated for a significant length (greater than 500 m)
- Yarriambiack Drive inundated for a significant length (greater than 250 m)
- Property immediately north of Roses Road inundated below floor (west of Yarriambiack Creek)
- Inundation of the Henty highway at Kellalac
- Several inundation points of Mayberrys Road
- Significant inundation of Ailsa Road (greater than 500 m)
- One property flooded below floor north of Dumbuoy Road (The Rusty Nail)
- Significant increase in inundation west of Cemetery Road with two properties inundated below floor and one property isolated in Cemetery Road
- Two properties inundated below floor in Asquith Avenue
- Inundation up McIntyre Road
- Significant increase in inundation along Warunda Avenue with eight properties inundated, five below floor, three above. Inundation of the access to this area
- Significant inundation in Kokoda Avenue with 6 properties flooded below floor and one above
- Significant inundation in Craig Avenue with twelve properties flooded below floor south of Menin Street and three north of Menin Street
- One property in Asquith Avenue inundated below floor
- Significant inundation through the industrial area north of Warracknabeal, one property flooded above floor
- Significant inundation of Baums Road (greater than 300 m)
- Isolation of two properties north of Ryans Road, both east and west of the Henty Highway

1% AEP Event Summary

Similar to January 2011 flood when extensive damage was caused to both residential and agricultural land. In Warracknabeal a significant levee was constructed during January 2011 which largely mitigated the potential damages, so some differences are expected.

The extent is similar to that of the 2% AEP event with no change to the properties inundated south of Warracknabeal, with greater depths of inundation. There are increased numbers of properties inundated in Warracknabeal, in total the number of dwellings flooded above floor is 11, 3 businesses flooded and 166 additional properties flooded. Of these properties 74 buildings are flooded below floor.

- Water in very close proximity or flooding under floor of all Cemetery Road properties west of Dumbuoy Road
- Sheds flooded and in close proximity to a property at the western end of Wood Street
- Two buildings in Asquith Reserve flooded above floor with a further four flooded below floor and several in very close proximity to inundation
- Two buildings in McIntyre Street flooded below floor
- Four buildings flooded below floor in Lyle Street on the northern side, two on the southern side including the Convent.
- Flooding at St Mary's Catholic Primary School potentially flooding buildings below floor
- One building flooded below floor in Fong Tong Avenue but all properties at risk of below floor inundation
- Three dwellings in Warunda Avenue flooded above floor, all properties either flooded below floor or in very close proximity to inundation
- One property in The Avenue flooded above floor, all properties either flooded below floor or in very close proximity to inundation (large increase inundation extent on the 2% AEP event)
- A backwater is now occurring up Anderson Street with the potential to flood properties below floor
- There is a large increase in inundation from the 2% AEP event west of Yarriambiack Creek, in and around Symes Street, Menin Avenue, Kokoda Avenue, Tobruk Avenue, David Street and Alamein Avenue. There are four dwellings flooded below floor, three in Craig Avenue and one in Kokoda Avenue. There are properties flooded below floor in all streets and avenues north of Elizabeth Street. Access to the western side of Warracknabeal is limited with inundation in all streets.
- Northern end of Craig Avenue inundated
- Inundation at the industrial area north of Warracknabeal with one building flooded above floor and likely to be numerous other properties flooded below floor
- Floodwater sitting against the Henty Highway south of Morella Road and inundating the highway at Darts Road
- An overland flow path west of Yarriambiack Creek is activated, floodwater flows from Batchica West Road, flows parallel to Yarriambiack Creek and stops flowing south of Hood Road.
- Flood water is in very close proximity to a dwelling west of Yarriambiack Creek on Batchica West Road.
- The overland flow path causes isolation of two properties on Witneys Road, one on Lah West Road and one on Exchange Road. Inundation is close to each dwelling and associated sheds.
- The Henty Highway is inundated south of Lah Angle Road
- Brim West Road west of the Brim weir pool is inundated
- Inundation and isolation worsened along the Henty Highway at Ryans Road.

- Overland flow south of Ryans Road creating an additional flow path to the north east of Yarriambiack Creek.

0.5% AEP Event Summary

South of the Henty Highway at Kellalac the inundation extent is similar to that of the 1% AEP event with all minor and major roads overtopping. All property isolation is the same with greater depths preventing access. Changes to inundation from the 1% AEP event include:

- An additional overland flow path south of Bell Road on the western side of Yarriambiack Creek
- An additional breakout from Yarriambiack Creek north of Werrigar Street causes isolation of one property at the far western end of Lynch Street
- Floodwater impacts on all of McIntyre Street with Dimboola Road properties experiencing flooding at the rear
- Three properties in Dimboola Road inundated below floor west of Yarriambiack Creek
- Four properties in Asquith Reserve flooded above floor
- One property in McIntyre Street flooded below floor
- All properties between Warunda Drive and Yarriambiack Creek are flooded below floor, three flooded above floor in Lyle Street
- Seven properties in Warunda Avenue flooded above floor, one below
- All properties in The Avenue flooded above or below floor, three above
- Inundation in Anderson Street increased to flood all properties between the Avenue and Woolcock Street below floor, one above
- All properties on the western side of Yarriambiack Creek north of Elizabeth Street are at high risk of below floor inundation, properties are flooded above floor in all streets
- A breakout from Yarriambiack Creek at Asquith Avenue overtops Rainbow Road and inundates properties on Kelsall Street (seven below floor) Bowman Street (nine below floor, five above floor), Devereux Street (one below floor, two above floor), Clifford Street (13 below floor), Railway Road (three below floor), Schickerling Street (one above floor, one below floor) and east of the Henty Highway (one below floor). This inundation does not occur in the 1% AEP event and is a significant extension in inundation. A significant depth of flood water accumulates on the western side of the Henty Highway with the road overtopping.
- The grain storage facility is impacted with one building flooded above floor
- The Henty Highway is inundated to a much greater extent south of Goads Road
- Properties on Witneys Road experience much greater inundation around buildings with some sheds potentially flooded

North of Brim the flood extent and depth increase with a similar pattern of inundation. All road major and minor in the vicinity of Yarriambiack Creek are likely to be inundated including the Henty Highway at several locations.

PMF Event

The PMF event is estimated to be significantly larger than the 0.5% AEP event, the resolution and extent of the model developed for the design modelling undertaken in this project could not be used and an alternate flood model was developed with a much broader extent. During the PMF event all areas adjacent to Yarriambiack Creek are inundated.

Travel times

Flood warning for Yarriambiack Creek downstream of Jung is primarily based around the gauge information available at the Yarriambiack Creek at Murtoa (Wimmera Highway) and the Wimmera

River at Glenorchy. Further upstream along the Wimmera River initial warning can also be attained from Wimmera River gauges at Glynwylln and Eversley. Travel times between these gauges and the communities along Yarriambiack Creek can be calculated based on the timing of previous events. The most recent of these is September 2010 and January 2011. The time of these events is shown in Figure 9-41 and Figure 9-42 respectively. The recorded peak timing of the events is also shown in Table 9-14 with the inclusion of several other ungauged locations along Yarriambiack Creek including Warracknabeal and Brim.

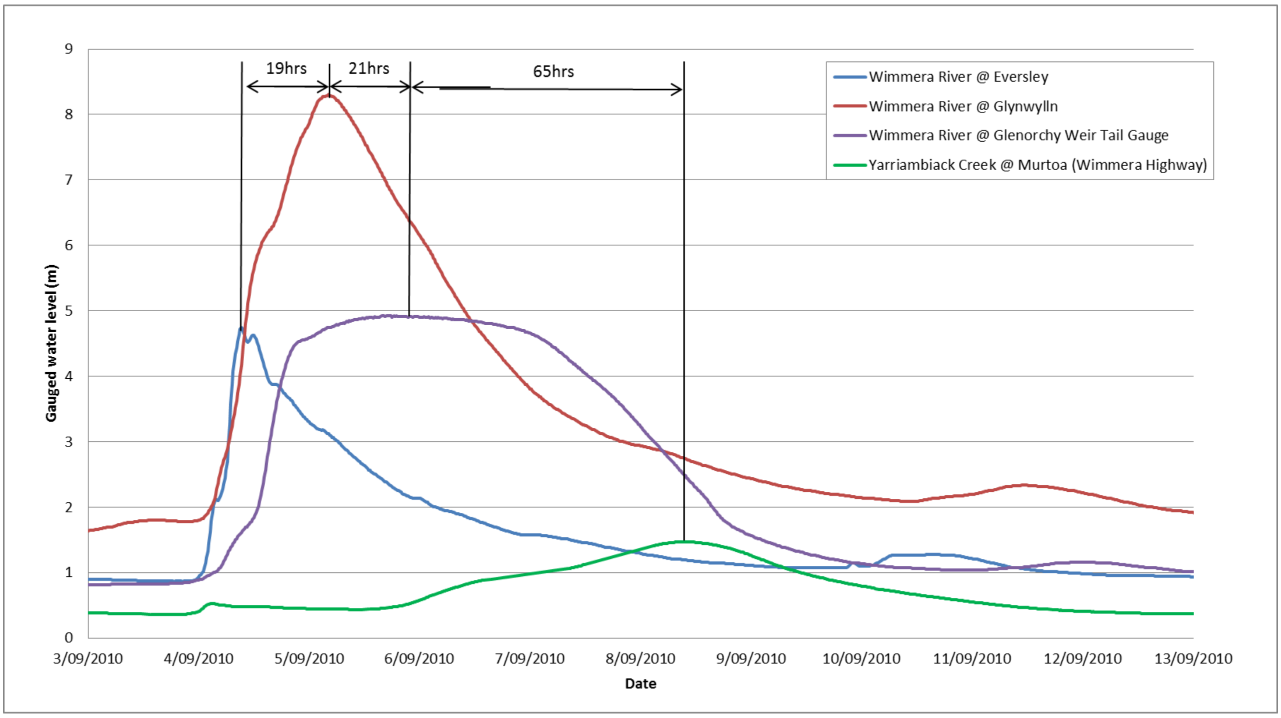


Figure 9-41 September 2010 - Gauged water levels and travel times

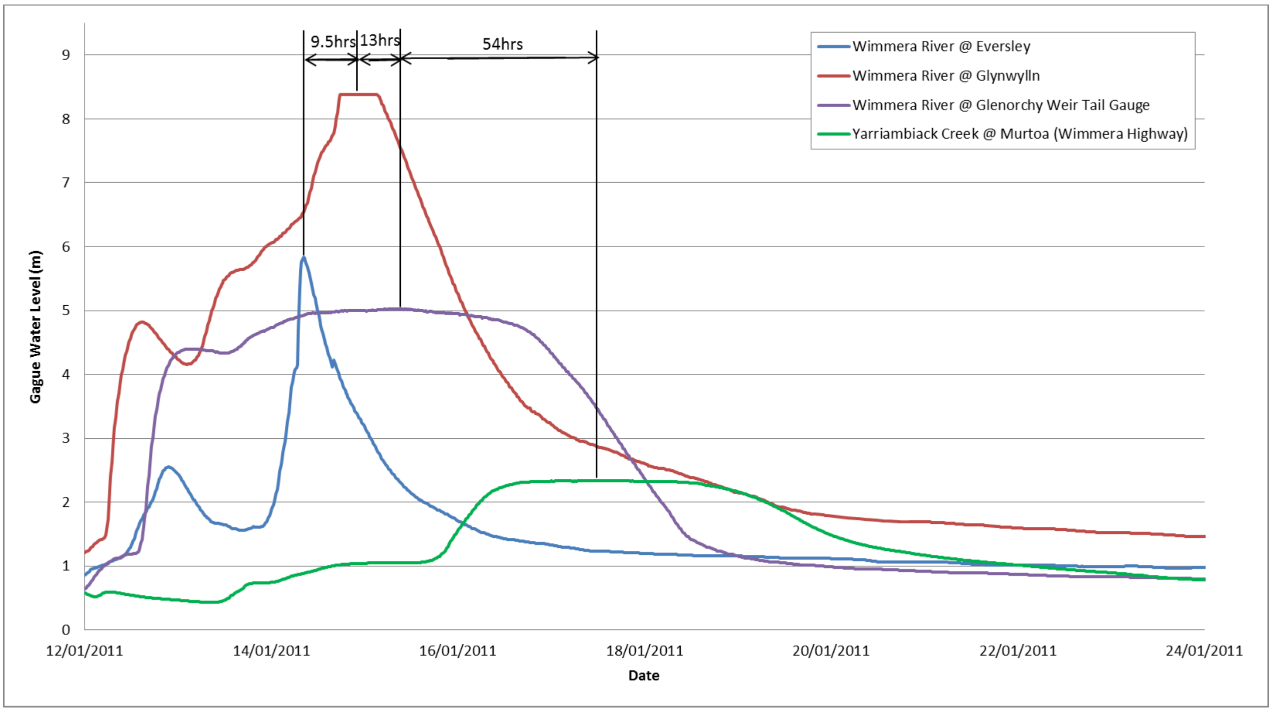


Figure 9-42 January 2011 - Gauged water levels and travel times

Table 9-14 Timing of peak flow on the Wimmera River for historic events – Timing beginning at the Wimmera River at Eversley streamflow gauge

Reach	January 2011	September 2010
Wimmera River at Eversley	0	0
Wimmera River at Glynwylln	9.5 hrs	19 hrs
Wimmera River at Glenorchy	22.5 hrs	40 hrs
Yarriambiack Creek at Murtoa (Wimmera Highway)	77 hrs	105 hrs
Yarriambiack Creet at Ailsa Road	113 hrs	169 hrs
Yarriambiack Creek at Warracknabeal	123 hrs	193 hrs
Yarriambiack Creek at Brim	161 hrs	321 hrs

9.6.4 Warracknabeal Stormwater Modelling - Design Flood Behaviour

Stormwater modelling of the Warracknabeal and Brim townships was completed to give Yarriambiack Shire Council a better understanding of the areas at risk of flood damage and prioritise their stormwater infrastructure upgrades. The model covered the entire local Warracknabeal catchment area. Modelling was completed for the 1% AEP flood event for a 2 hour duration. No losses were used in the modelling as a conservative measure. Note that the 2 hour duration may not be the critical storm duration for this local catchment, but was used as in indicative guide to areas that would accumulate local overland flow in a storm event.

Brim – Results

Brim has two localised catchment areas; immediately to the south of the township, between Yarriambiack Creek and the Henty Highway and east of the Henty Highway contributing water to north of the township.

Stormwater can cause damage and below floor inundation to properties at the eastern end of Swan Street and both the eastern and western ends of King Street.

The areas impacted by stormwater for the whole Brim township are shown in Figure 9-43, with a closer inspection of the problem areas shown in Figure 9-44.

Warracknabeal – Results

Warracknabeal suffered from stormwater inundation in several locations across the township during January 2011, these included:

- Borung Highway
- Gardiner Street
- Lyle Street
- Molyneaux Street
- McIntyre Street
- Asquith Reserve
- Kelsall Street
- Thomas Street
- Franklin Street
- Shank Street
- Roll Street
- Campbell Street

Stormwater modelling of the township has also indicated stormwater could become an issue in several other streets between Gardiner Street and Lyle Street. Stormwater modelling of the 2 hour 1% AEP event for the Warracknabeal township is shown in Figure 9-45 with a closer perspective of the problem areas south of the Borung Highway and north of Gardiner Street shown in Figure 9-46 and Figure 9-47 respectively.

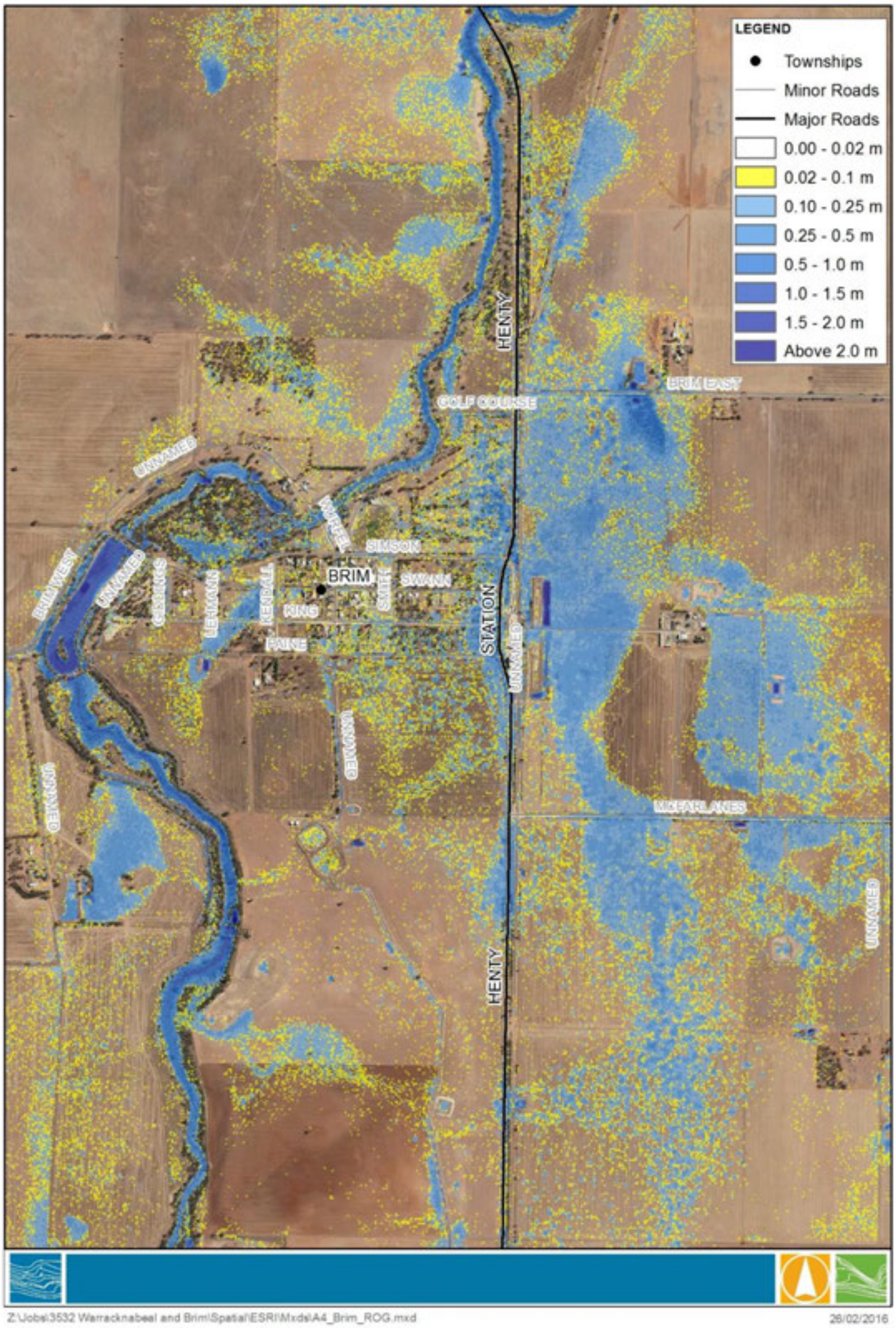


Figure 9-43 Brim township - 1% AEP 2 hr Duration Flood Event Inundation

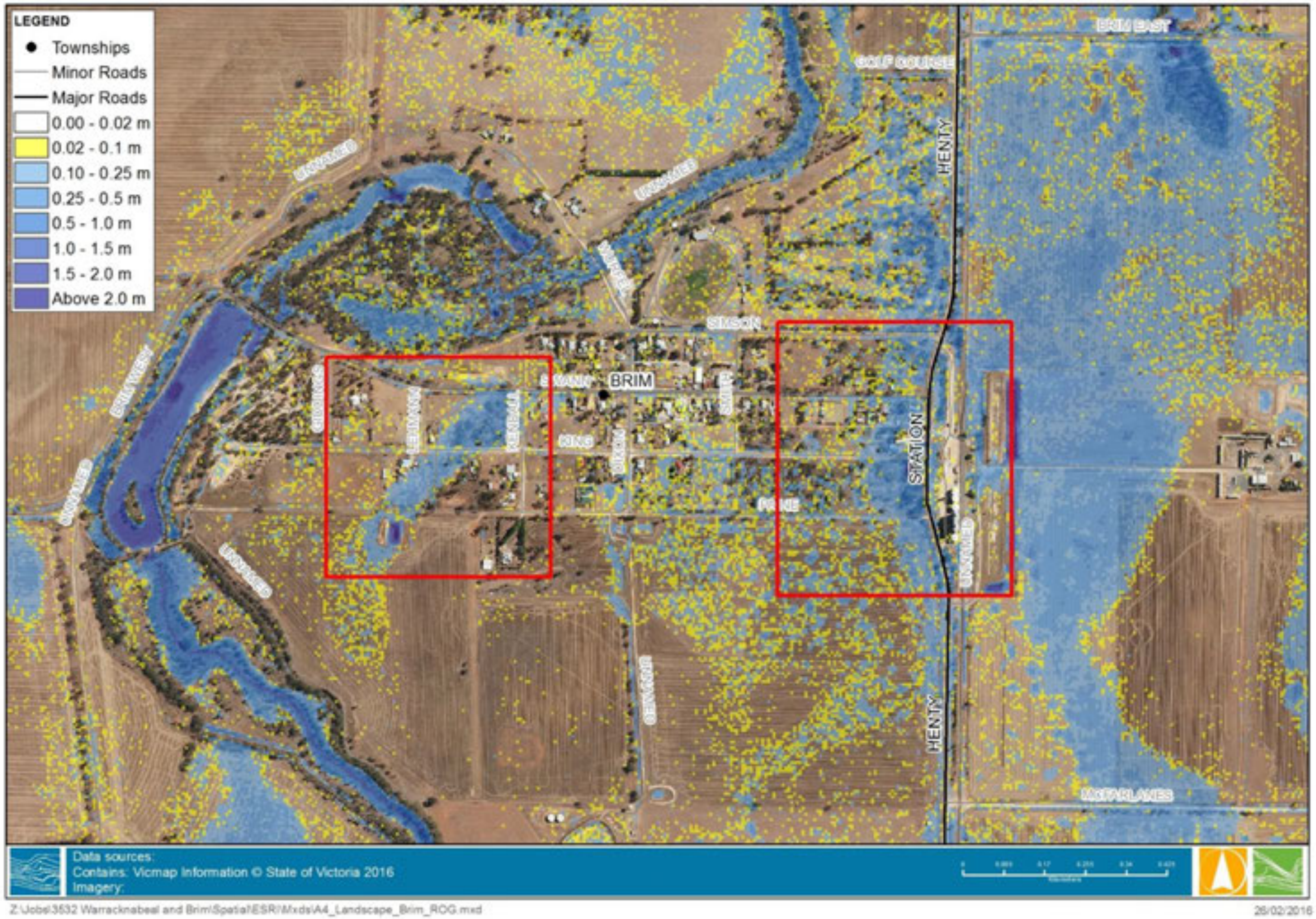


Figure 9-44 Brim problem areas - 1% AEP 2hr Duration Flood Event Inundation

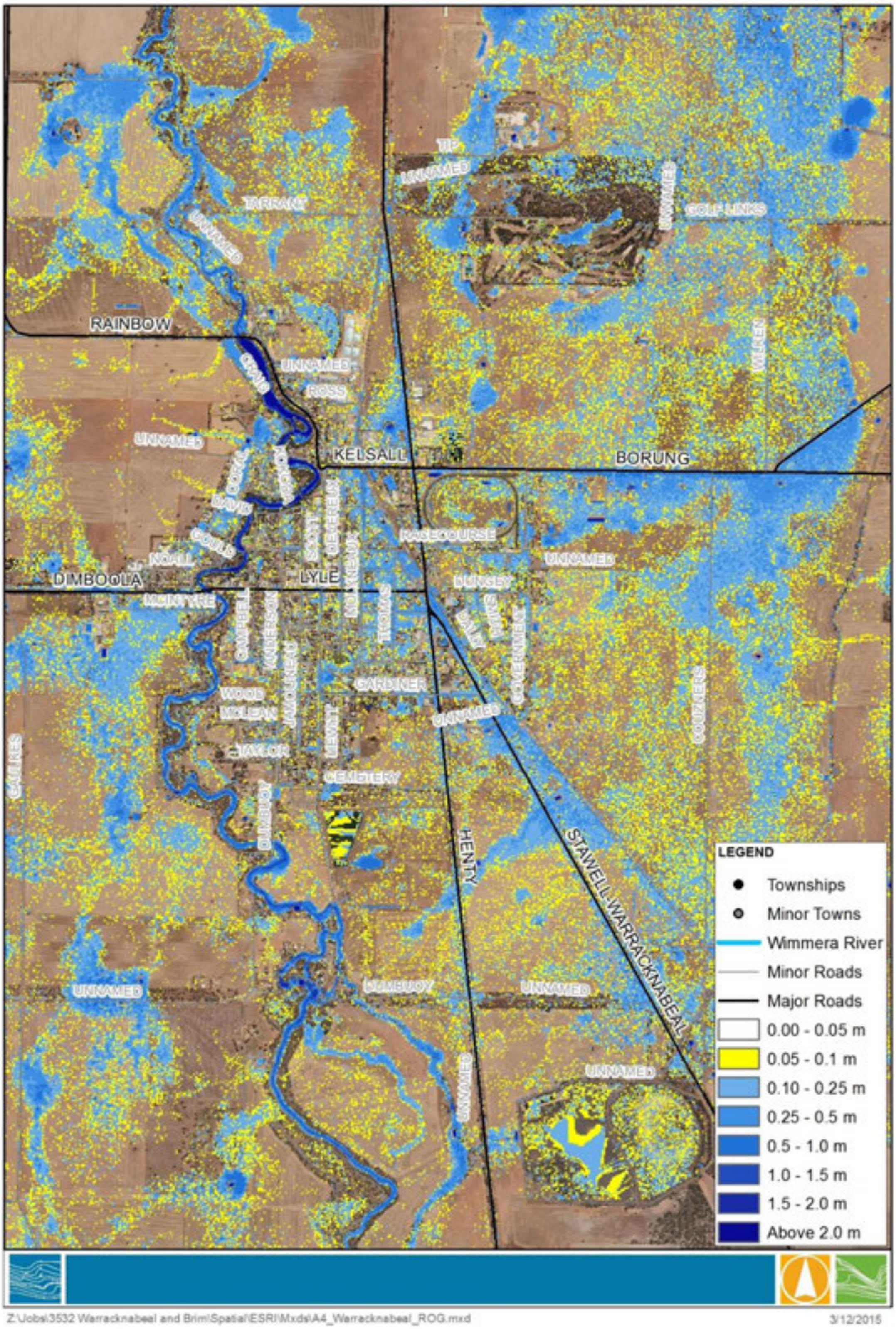


Figure 9-45 Warracknabeal township - 1% AEP 2hr Duration Flood Event Inundation

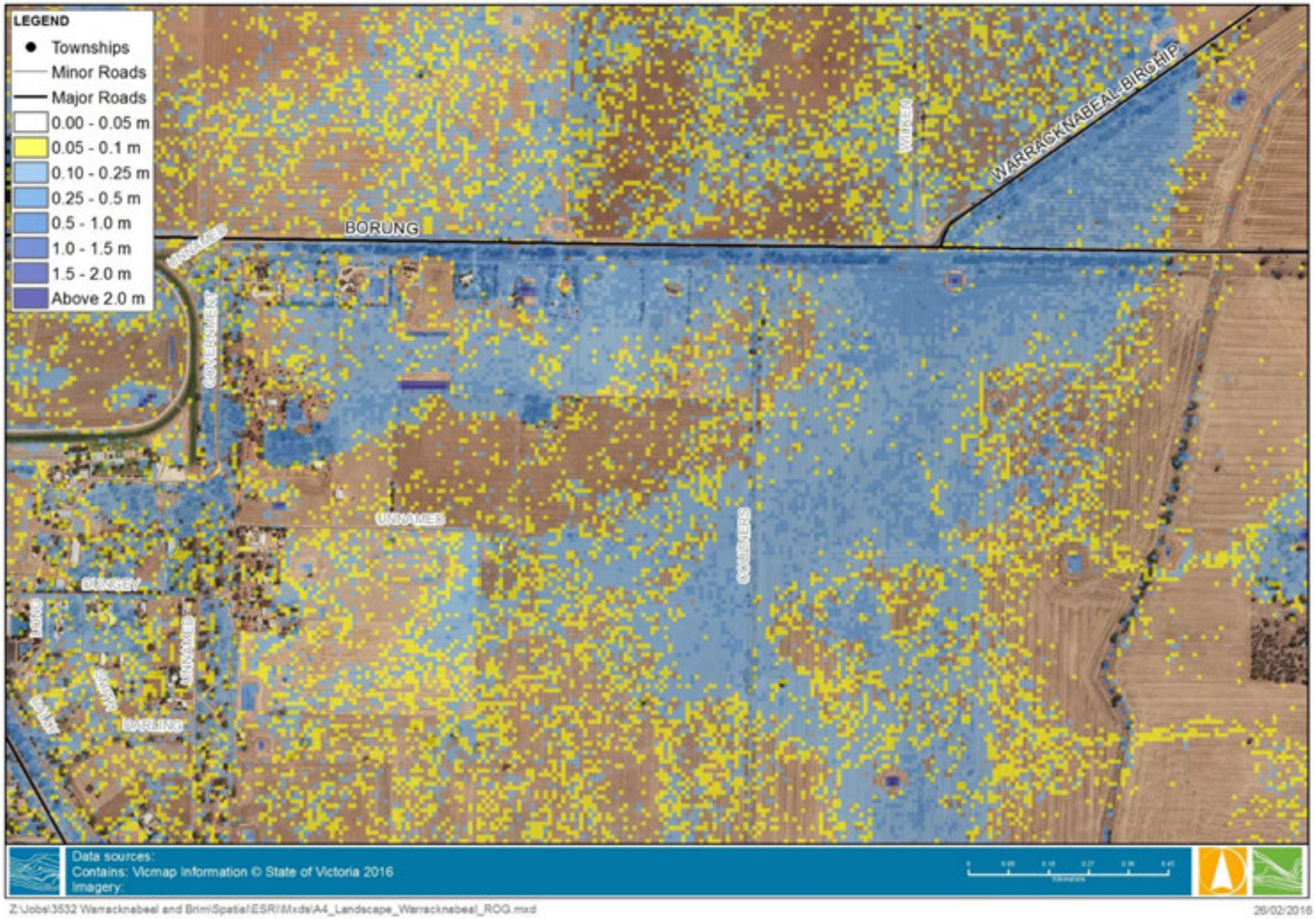


Figure 9-46 Warracknabeal problem areas Borong Highway - 1% AEP 2hr Duration Flood Event Inundation

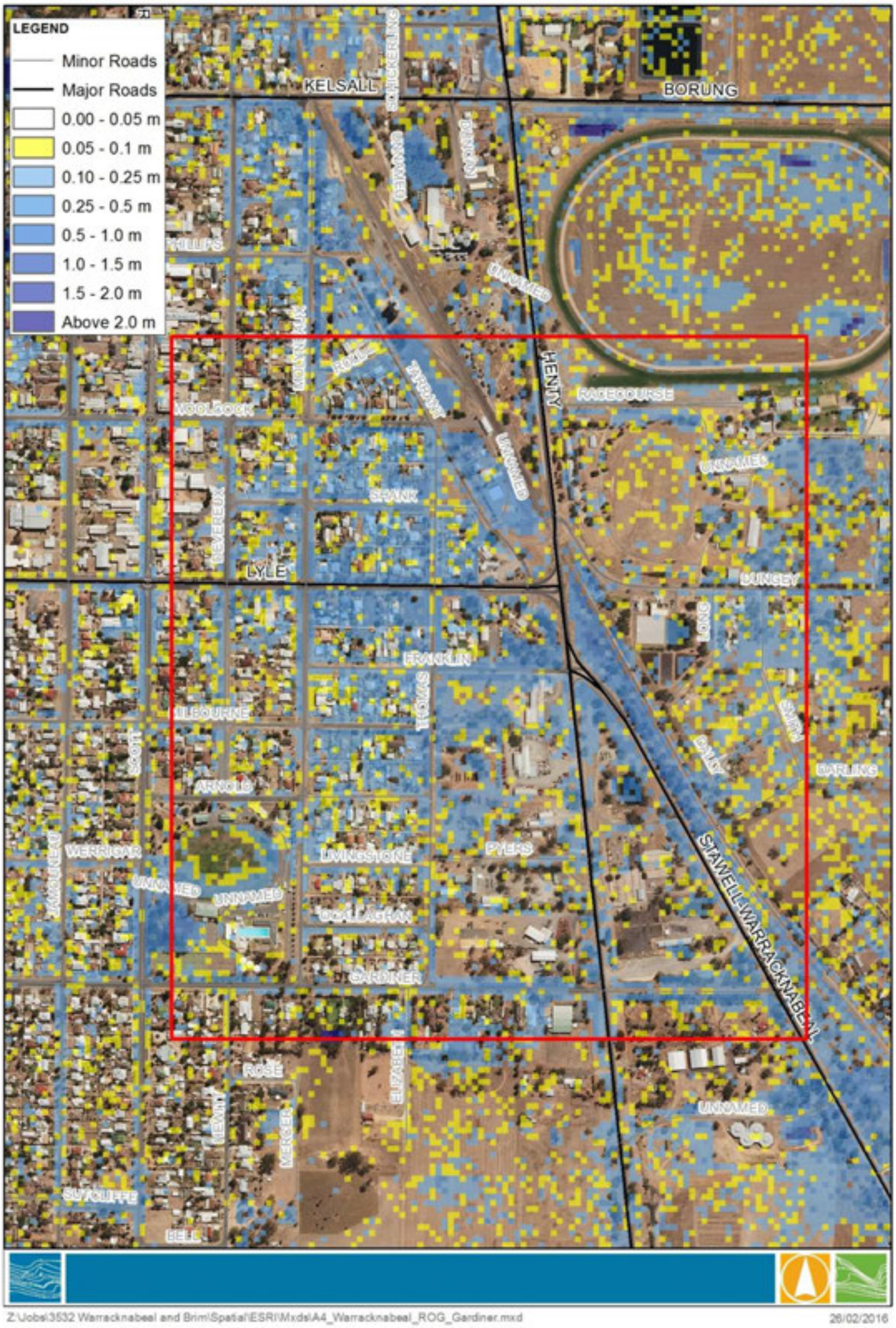


Figure 9-47 Warracknabeal problem areas north of Gardiner Street - 1% AEP 2hr Duration Flood Event Inundation

Discussion and Recommendations

Storm water issues for Brim are relatively minor with two buildings impacted below floor on the Henty Highway between Swann and King Streets, and one garage flooded on the corner of King Street and the Henty Highway. Pooling of inundation is caused by water unable to flow north west by the Henty Highway. To alleviate the issue the culvert capacity under the Henty Highway could be increased and the culvert monitored during a flood event. There is a high chance the culvert could block given the upstream catchment characteristics, this occurred during January 2011.

It is recommended YSC and VicRoads review the size of the current culvert under the Henty Highway in consultation with local residents and determine if a capacity increase is necessary.

Stormwater inundation on the southern side of the Henty Highway is caused by a lack of available drainage under the Highway from south to north. A large catchment area drains to this point and currently it runs along the roadside drainage to the west where it passes underneath the Borung Highway in Canning Canal.

Additional culverts or banks of culverts are required to prevent this water from backing up, allowing it to flow north. The general fall of the topography is from east to west so some thought on the roadside and drainage arrangements either side of the Borung Highway would be required. Some potential example locations are shown in Figure 9-48.

It is recommended further investigation be completed to determine the optimum culvert locations, sizes and channel arrangements. This could be completed using a more site specific hydraulic model of the Borung Highway covering the area shown in Figure 9-48, using the model to assess the required culvert capacities and channel arrangements.

Stormwater inundation in Warracknabeal itself is difficult to remedy due to the very low grade between areas of inundation and Yarriambiack Creek. The inundation observed during January 2011 provides a good guide for the worst impacted areas and should be used as a reference additional to the modelling completed in this project.

It is recommended YSC consult with residents who were impacted by stormwater inundation north of Gardiner Street as well as residents of the following streets:

- **Thomas and Molyneaux (between Gardiner and Woolcock)**
- **Arnold, Milbourne, Franklin, Lyle and Shank (between the Henty Highway and Devereux Street)**

It is recommended the frequency of flooding in these areas be reviewed and the potential for upgrades be considered.

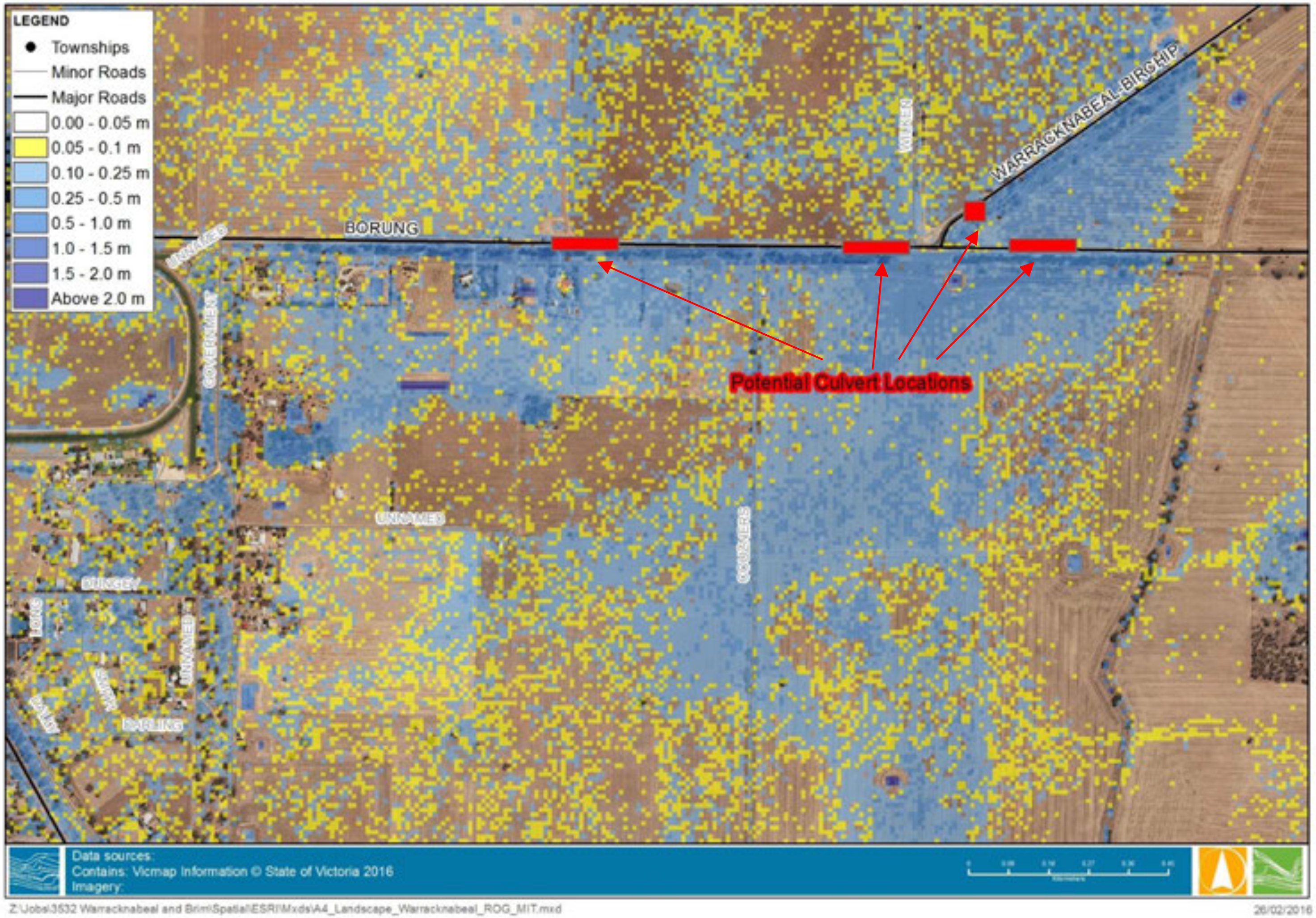


Figure 9-48 Borung Highway, example culvert locations - 1% AEP Flood Event Inundation

9.7 Modelling 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 during the project:

- Model Calibration
  - Wimmera Highway gauge model was constructed and attempts were 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 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 Modelling
  - 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 ratio 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.
  - 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.
  - Hydraulic modelling was completed using a uniform Manning's 'n".
  - No initial conditions were applied to the Yarriambiack Creek.
  - No infiltration/evaporation losses were applied to Yarriambiack Creek.

10. FLOOD MITIGATION

10.1 Overview

Flood risk and flood damages along Yarriambiack Creek can be reduced via both structural and non-structural mitigation. Non- structural mitigation measures ensure that development doesn't occur in high flood risk areas and that the community is aware of the potential impact a given flood may have and how best to be prepared. Structural mitigation options are engineering solutions focused on reducing flood extent, depth and damage.

The 1% AEP flood inundation extent and properties flooded below and above floor for the two major population centres, Brim and Warracknabeal are shown in Figure 10-1 and Figure 10-2 respectively.

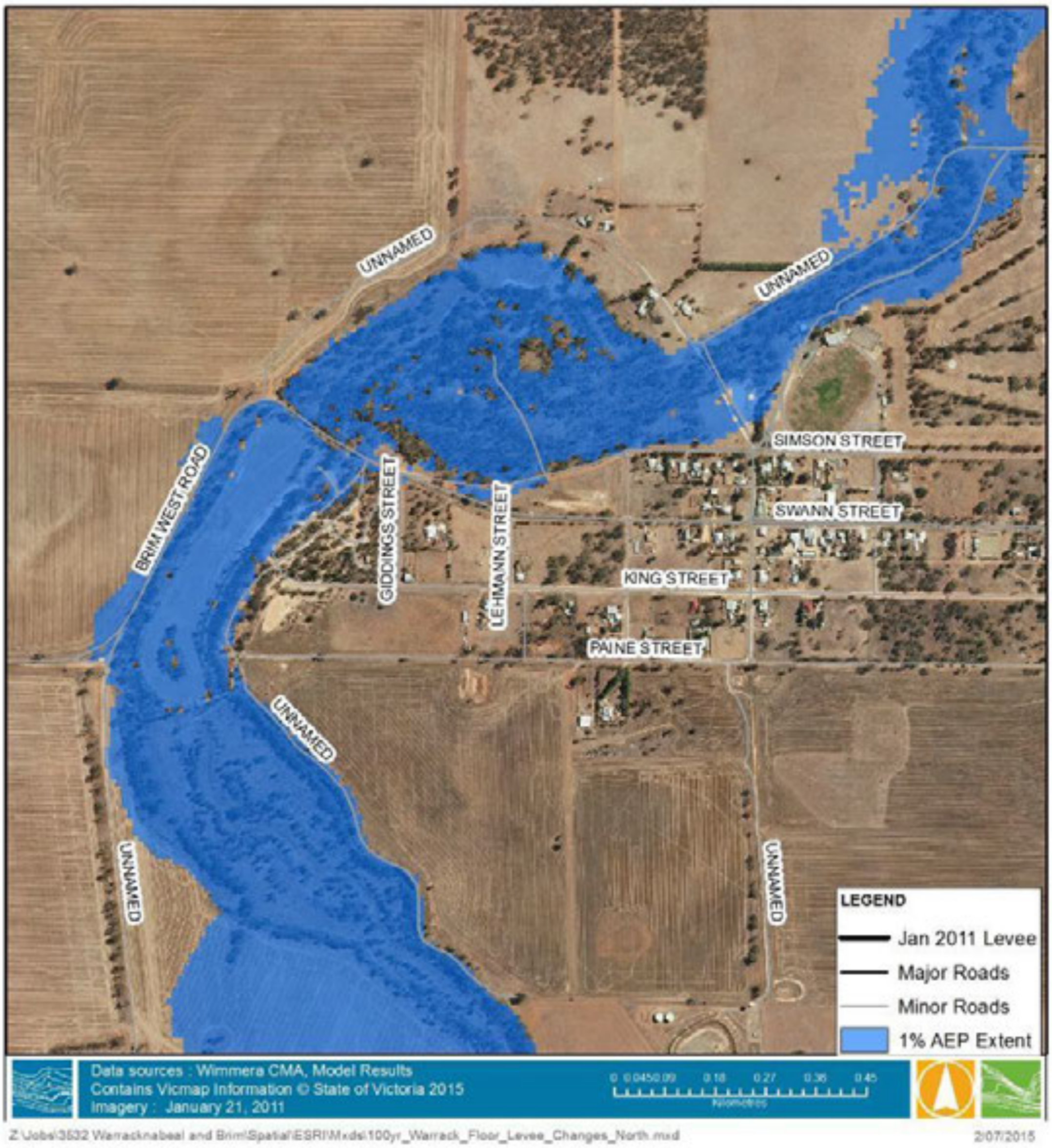


Figure 10-1 Yarriambiack Creek 1% AEP flood extent at Brim (no buildings inundated by riverine flooding)

Figure 10-2 Yarriambiack Creek 1% AEP flood extent and impacted buildings at Warracknabeal

10.2 Non Structural Mitigation Options

10.2.1 Overview

There are a range of non-structural mitigation options possible to reduce flood damages, these include:

- Land use planning
- Flood warning and response
- Flood awareness.

During this project sub-consultants Planning and Environmental Design and Molino Stuart were engaged to assist with reviewing the current non-structural flood mitigation arrangements for the land use planning and flood warning, response and awareness respectively.

The below sections summarises their individual reports, if further detail is required, please refer to:

- Planning and Environmental Design (2015), Planning Scheme Amendment Documentation – Warracknabeal and Brim Flood Investigation, Wimmera CMA
- Molino Stewart (2015), Warracknabeal and Brim Flood Investigation - Flood Warning Assessment and Recommendations Report, Wimmera CMA

10.2.2 Land Use Planning

The Victoria Planning Provisions (VPPs) contain a number of controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), and the Urban Floodway Zone (UFZ).

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

Guidance for applying flood con
Environment, Land, Water and
Development's (DPCD)) Practice N

Planning Schemes can be view
recommended that the planning s
this project's study area (Jung to
Brim) is amended to reflect the
identified by this project.

Figure 10-4 shows proposed FO ar
consideration into such an amend
draft planning scheme map is bas
'Advisory Notes for Delineating F
(NRE, 1998), with three a
considered.

Flood frequency - Appendix A
advisory notes suggest areas wl
frequently and for which the con
of flooding are moderate or hig
generally be regarded as floodway

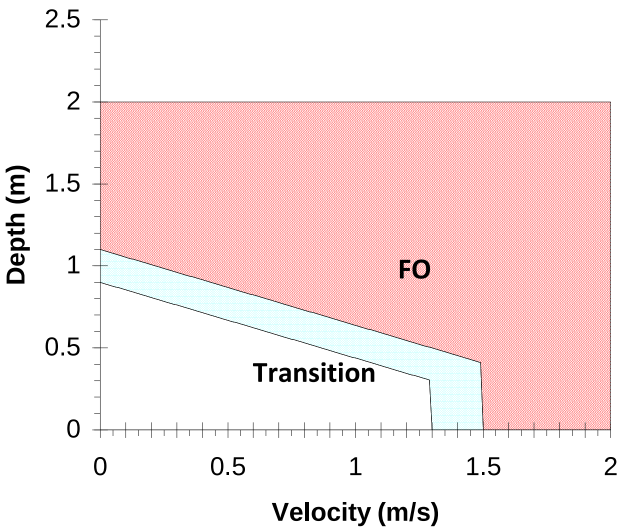


Figure 10-3 Flood Hazard Delineation of FO

Land Subject to Inundation Transition Zone Floodway adopted the 10% AEP as areas that flood frequently.

Flood hazard - Combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 10-3 for delineating the floodway based on flood hazard. The flood hazard for the 1% AEP event was considered appropriate for this study.

Flood depth - Regions with a 1% AEP flood depth greater than 0.5 m were considered as FO based on the flood depth criteria in the advisory note.

Using the flood hazard chart in Figure 10-3, the flood hazard criteria can be simplified. As the depth criteria already covers areas with a depth greater than 0.5m, the only area remaining in the hazard criteria is areas with a velocity greater than 1.5 m/s.

Therefore, to define areas of FO, all that is required is to envelope the 10% AEP extent with areas of the 1% AEP of depth greater than 0.5 m and areas of the 1% AEP of velocity greater than 1.5 m/s. Figure 10-4 shows the proposed FO for the entire study area, and Figure 10-5 and Figure 10-6 for Warracknabeal and Brim respectively.

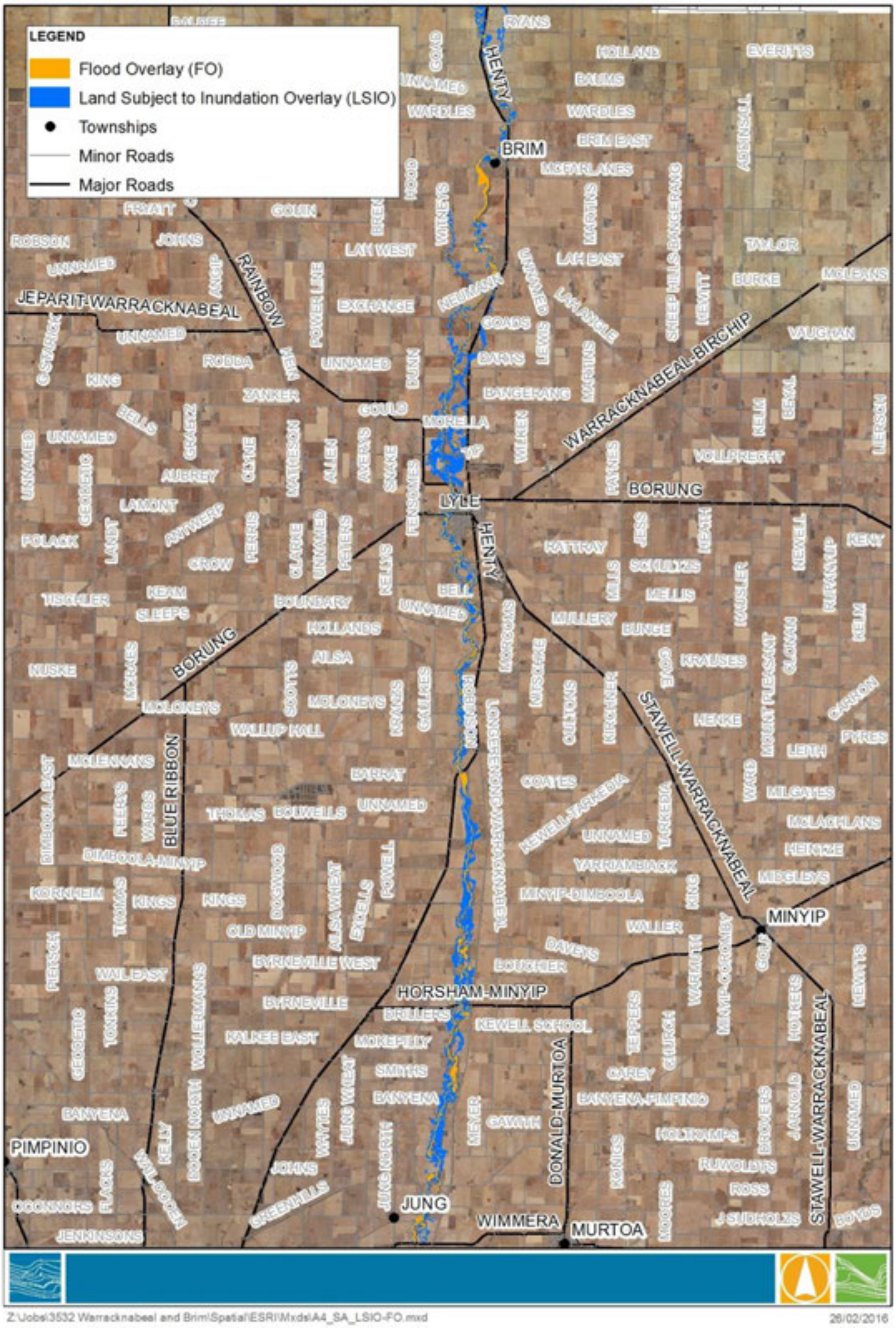
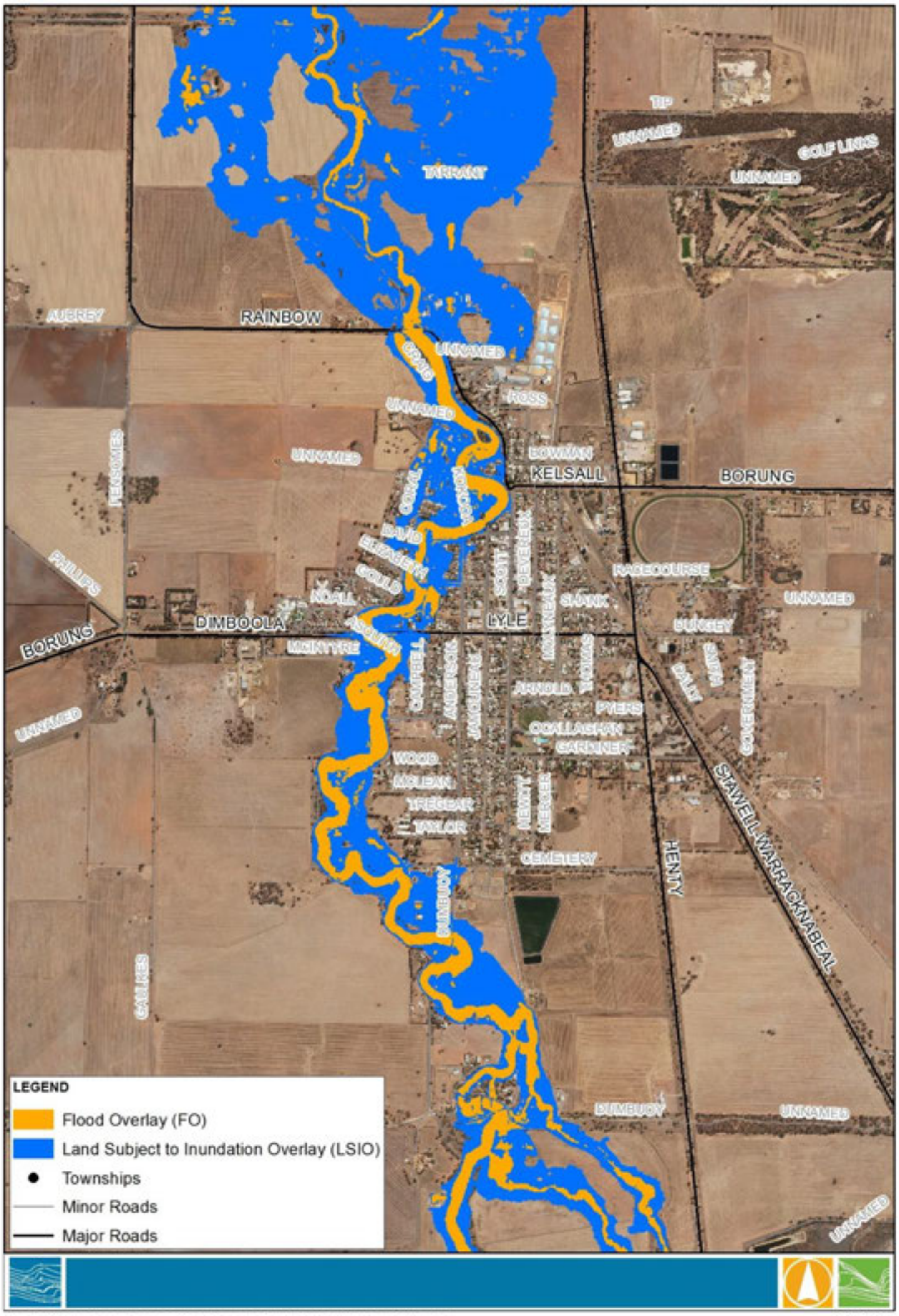


Figure 10-4 Draft LSIO and FO Map for Existing Conditions for the entire study area



Z:\Jobs\3532 Warracknabeal and Brim\Spatial\ESRI\Mxds\A4_Warrack_LSIO-FO.mxd 26/02/2016

Figure 10-5 Draft LSIO and FO Map for Existing Conditions for Warracknabeal

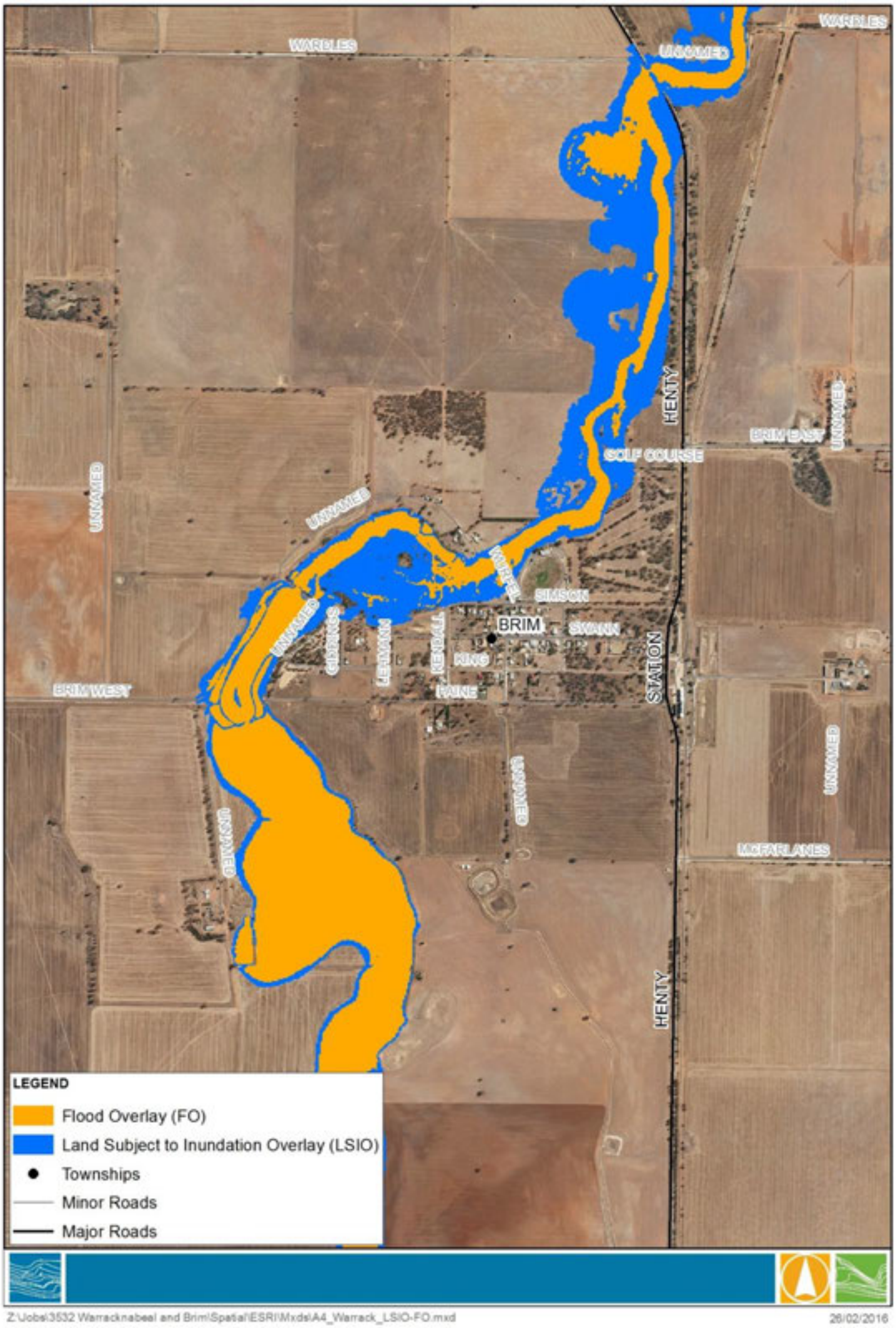


Figure 10-6 Draft LSIO and FO Map for Existing Conditions for Brim

10.2.3 Flood Warning

Overview

"Flood warning systems are developed with the fundamental aim of increasing safety and reducing the harmful effects of floods (referred to as 'damages' or 'losses'). The extent of losses avoided as a result of a warning is therefore the key measure of warning system effectiveness."[22]

In practice, flood warning systems provide individuals and communities with time to carry out actions to protect themselves, and if possible, aspects of their properties including stock and pets.

In Australia, the concept of the 'total flood warning system' (TFWS) has been used to describe the full range of elements that must be developed if flood warning services are to be provided effectively. The lead guiding document for the development of the TFWS in Australia is Manual 21 – Flood Warning[23].

According to Manual 21 (page 6), at its simplest, the TFWS consists of six components:

1. Prediction - Detecting changes in the environment that lead to flooding, and predicting river levels during the flood.
2. Interpretation - Identifying in advance the impacts of the predicted flood levels on communities at risk.
3. Message Construction - Devising the content of the message which will warn people of impending flooding.
4. Communication – Disseminating warning information in a timely fashion to people and organisations likely to be affected by the flood.
5. Response - Generating appropriate and timely actions from the threatened community and from the agencies involved.
6. Review - Examining the various aspects of the system with a view to improving its performance.

When designing a TFWS, Manual 21 (pages 7-8) advises that the following points need to be addressed:

- The system must meet the needs of its clients including identifying:
    - levels of flooding at which warnings are required
    - the impacts at the different levels of flooding
    - warning time that the community requires and that can be provided
    - appropriate subject matter content for warning messages
    - the ways in which warning messages are to be disseminated
    - the frequency of warning updates
- The system must be part of the emergency management arrangements established by the relevant State or Territory as defined in disaster or emergency management plans.
- The review of the system must be carried out by all emergency agencies and by the community itself.
- The roles of the emergency agencies must be clearly defined for each component of the system.
- The system must be incorporated into the wider floodplain management.
- The system should be regularly tested and maintained.

[22] Molinari, D. and Handmer, J. (2011) A behavioural model for quantifying flood warning effectiveness, Journal of Flood Risk Management, Vol. 4, pp. 23-32.
[23] Attorney-General's Department (2009) Manual 21 Flood Warning, Australian Emergency Manuals Series, Commonwealth of Australia

Within this project the following tasks were undertaken to understand the current flood warning arrangements, how they meet the community's requirements and provide a direction for future management of flood warning for the study area:

1. Conduct an assessment of the existing total flood warning system (TFWS) for the investigation area
2. Recommend improvements to the existing TFWS based on the assessment.

The TFWS used in this project is shown below in Figure 10-7.

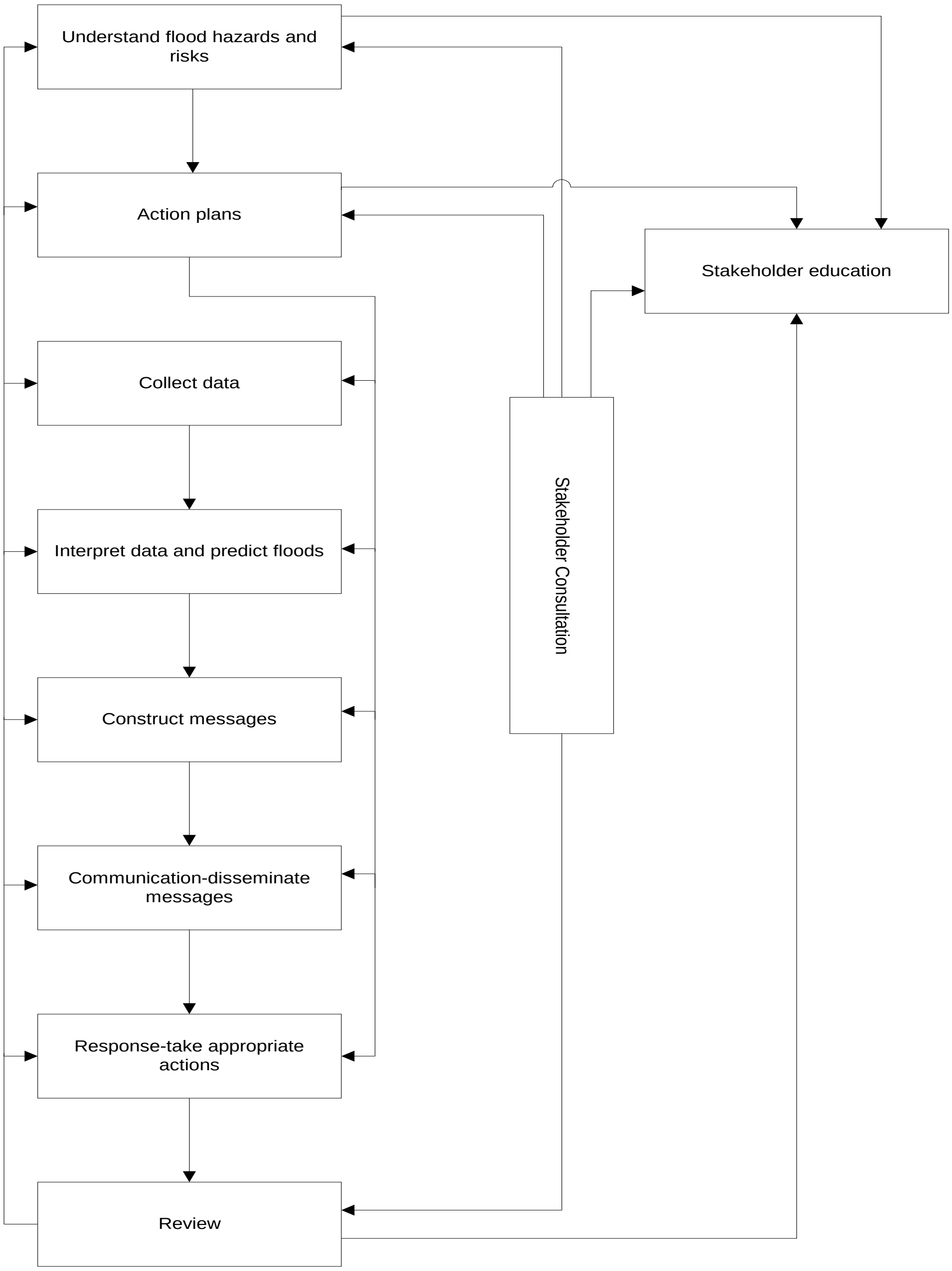


Figure 10-7 The Total Flood Warning System (source: Molino et al[24])

[24] Molino, S., Dufty, N., Crapper, G. and Karwaj, A. (2011) Are warnings working? Achievements and challenges in getting communities to respond, paper presented to the Floodplain Management Association Conference, Tamworth NSW, February 2011.

Study Area Community and Current Flood Education

Warracknabeal is the principal service centre followed by Brim. According to the 2011 census data[25], Warracknabeal had a population of 2,745 in 2011 comprised of approximately 51.0% females and 49.0% males, whereas Brim had a population of 26. With little observable urban growth, there will probably have been little population change since 2011 for either community.

The indicators from the 2011 census that have direct relevance to the community aspects of this project are shown in Table 10-1.

Table 10-1 2011 census data for Warracknabeal and Brim

Data Type	Warracknabeal	Brim
Age	Average age 48	Average age 43
Language	97% English at home	96.1% English at home
Household size	2.2 people	2.5
Type of living	96% permanent residents	96% permanent residents
Internet connection	36% have no internet connection	30% have no internet connection
Assistance Required	10% require some form of core assistance	6% require some form of core assistance
Volunteerism	28% volunteer in some way	55% volunteer in some way

Community flood education helps people learn how to prepare for and respond to floods (including to flood warnings). The prime outcome is public safety, with a secondary outcome being protection of property.

According to VICSES, up to now there has not been a concerted effort of community education and engagement around floods in Warracknabeal and Brim[26]. Activities to date include:

- The occasional feature in the local paper during FloodSafe week.
- A pamphlet titled 'Flood Information Warracknabeal' produced in 2008 by Wimmera CMA which includes a table relating flood probability to impact on the town. The table is related to the Water Technology (2007) report.

The 2008 pamphlet provides the following advice to the community about flood warning:

"Flood information including generalised flood forecasts, road closures and advice on evacuations and property protection will be broadcast over local TV and AM radio station ABC 594."

"It is likely that you will have several days' notice of a coming flood. You should use this time to prepare your business and family home. Don't leave precautions until it is too late."

After the January 2011 flood, Yarriambiack Shire Council organised a town celebration and acknowledgement of effort. Four interpretive signs were erected around Yarriambiack Creek to describe the community response to the 2011 flood, including the construction of the temporary levee. An example of these signs is shown in Figure 10-8.

[25] Australian Bureau of Statistics (2012), 2011 Census data for Warracknabeal and Brim.
[26] Pers. Comm. VicSES

Figure 10-8 2011 Floods Warracknabeal interpretive signage

Assessment and potential improvements to the existing TFWS

Using the community and other stakeholder consultation and the available data sources, the TFWS components were assessed based on the TFWS framework, each of these components is shown in Table 10-2, along with an assessment of the existing system and potential improvements.

Table 10-2 TFWS components, assessment of and areas of potential improvement

Data Type	Summary and assessment of current component	Potential Improvements
Understanding the flood risk	As a result of this investigation, there is a good agency and council understanding of flood risk, including with the construction of a permanent levee at Warracknabeal	Flood risk needs to be communicated to local residents including current and prospective landowners. Wimmera CMA should provide all flood maps and reports on their web site so the details of property flood risk will be available to the community. Yarriambiack Shire Council should provide a link on their website to this site. Yarriambiack Shire Council should undertake a planning scheme amendment which once completed will provide details of the Land Subject to Inundation Overlay (LSIO) on the landholders' Section 32 certificate. Community education (below) should also inform the communities in the study area of their flood risk
Emergency management planning	Flood intelligence cards for Warracknabeal are based on the Warracknabeal and Beulah Flood Study. The Warracknabeal Caravan Park located on Yarriambiack Creek has an emergency response plan based on triggers from the Warracknabeal and Beulah Flood Study.	The MFEP should be based on VICSES's current MFEP template (this is an output to this study). The MFEP and the existing flood intelligence should be updated based on this study. The MFEP should include a section on flood relief and recovery arrangements.
Community flood education	Community education and engagement regarding floods in Warracknabeal and Brim to date has included: • The occasional feature in the local paper during FloodSafe week • A pamphlet titled 'Flood Information Warracknabeal' produced in 2008 by Wimmera CMA which includes a table relating flood probability to impact on the town, related to the Warracknabeal and Beulah Flood Study (Water Technology, 2008).	Plan a suite of education and engagement activities to accompany a Local Flood Guide. This could include providing home emergency kit guides, local newspaper features, and a launch of the Guide which could include a variety of events such as a community barbeque. Community education activities should include • An understanding of flood risk (with and without a permanent levee at Warracknabeal) • Details of local triggers (e.g. gauge heights) and what people should do at these levels

Data Type	Summary and assessment of current component	Potential Improvements
	• Yarriambiack Shire Council organised a town celebration and acknowledgement of effort after the January 2011 flood. Four interpretive signs erected.	• An understanding of evacuation routes and the location of evacuation centres • A map showing the location of local streamflow gauges • Background to flood warnings issued by the BoM and other services • An understanding of the range of ways that warning messages are sent to the communities in the study area including for those without internet access • Messaging related to not driving in floodwaters • Stock food and water to be isolated for 72 hours • Encouragement to help others including neighbours and those requiring assistance • If the permanent levee at Warracknabeal is built, an understanding that levees can be overtopped and fail and that this should be considered in personal response • Encouragement to participate in the establishment and review of the TFWS
Data collection including location and use of rain gauges and stream gauges	Several streamflow gauges provide information on the inundation potential along Yarriambiack Creek. The gauge most specific to the study area is Yarriambiack Creek at Murtoa (Wimmera Highway) followed by Wimmera River at Glenorchy (Tail Gauge). Good information on these gauges is available through this study.	To improve the reliability and accuracy of flood predictions and warnings in the study area, Wimmera CMA has investigated in liaison with the BoM, the installation of a new streamflow gauge at the Ailsa Road crossing of Yarriambiack Creek, approximately 8.5 kilometres upstream (south) from Warracknabeal. The BoM has undertaken a radio path test and found there is no need for another repeater station. Installation of this gauge would allow a better understating of event travel times and allow for updated warnings.

Data Type	Summary and assessment of current component	Potential Improvements
Prediction	BoM maintains and funds the prediction services for the locations defined in the BoM Service Level Specification for Flood Forecasting and Warning Services. Maintenance includes continually improving prediction techniques. As part of its prediction services, the BoM issues Flood Watches and Flood Warnings. For the study area, the BoM currently uses the Murtoa river height gauge on Yarriambiack Creek and the Glenorchy gauge to provide flood predictions including flood warnings.	The BoM is regularly improving its forecasting capabilities and no recommendations are made here other than those for data collection.
Interpretation	The Yarriambiack Shire Council Flood Response Plan, coupled with data from this study, provides flood intelligence that links flood peaks at the Glenorchy streamflow gauge to impacts in the study area. This information can be used by the ICC to interpret flood predictions prior to the issuing of Flood Bulletins and other warning information. An issue that was raised in the community consultation was the perceived lack of use of local knowledge by the agencies in interpretation and on-ground emergency operations such as sandbagging.	As acknowledgement of local knowledge was an issue raised in community consultation, it would be prudent to further develop the community flood observers program in the study area. This crowdsourcing program would allow people to provide real-time flood height data to the ICC as one way to participate in the TFWS. It also helps those in the ICC to check real-time data against flood data including models.
Message construction	Warning messages are released by the BoM as Severe Weather Warnings, Flood Watches and Flood Warnings. VICSES through the ICC release messages as Flood Bulletins that provide details of the likely impacts on communities and what people should do.	No recommendations are made for this component of the TFWS.
Message communication	General warnings are communicated by VICSES through the appropriate level ICC using One Source One Message (OSOM) which links to the media, emergency service websites, the VICSES Flood and Storm Information Line and social media. Specific warnings are communicated by the ICC using Emergency Alert (providing location warning messages to mobile phones and	Message communication is being improved at a state level including the transfer to the EM-COP system and recent upgrades to Emergency Alert. The idea suggested at the Brim community consultation of a ‘phone tree’ or similar localised communication method for isolated

Data Type	Summary and assessment of current component	Potential Improvements
	landlines). VICSES (or delegated authority such as the Country Fire Authority) also use local and personal communication methods such as doorknocking, community meetings, and community bulletins. All of these communication mediums were used in the study area during the January 2011 flood event. From the community consultation, most local residents believed that they received good warning information during the flood. This enabled them to prepare themselves, and to help others if required. However, two issues were identified: • A local resident living outside the floodplain received an Emergency Alert message to evacuate. It should be noted that the precision of Emergency Alert in reaching flood-prone residents has improved since January 2011. • A local resident from Brim noted that he did not own a computer or smartphone and thus did not access warning information from the internet. This concern is supported by analysis of Census data that shows that approximately one-third of residents in the study area do not have internet access (although this rate may have decreased since the 2011 census).	properties should be supported to augment the other warning communication mediums. There also may be merit in using the Warracknabeal CFA siren as an extra warning mechanism although it is viewed as a 'dumb' warning (i.e. it does not provide information, only heads-up of an emergency). The community would need to be made aware that the siren was going to be used for dual purposes if this decision was made.
Response	In the January 2011 flood event, the Warracknabeal community worked together to construct a temporary levee that in the end protected the town from floodwaters. From community consultation, temporary levees and sandbags were used to protect individual houses outside of the town's temporary levee. A smaller levee was also constructed in Brim.	Yarriambiack Shire Council should ensure that all people requiring assistance are in its Vulnerable Persons Register as required by the Vulnerable People in Emergencies Policy. Lah gauge boards should be moved to a location that can be viewed during time of flood, ensuring the height of the gauge boards are left unchanged so correlation to historic floods can continue.

Data Type	Summary and assessment of current component	Potential Improvements
	Some people informed Wimmera CMA that the gauge boards at Lah are difficult to view during a flood. They are attached to the side of the culverts on the southern side of the crossing.	
Community participation	There was little evidence found that community members had participated in any aspects of the establishment and operation of the TFWS in the study area. This was due to them assisting their friends and neighbours in the management of the flood and the large section of levee that was constructed largely by members of the community.	Possible processes for this to occur include by crowdsourcing flood observations, through community membership of existing committees (e.g. Yarriambiack Shire Council Flood Response Plan Sub-Committee) and through community workshops or forums.
Review of the TFWS	Outside of this flood investigation, there was no evidence that the TFWS was being reviewed regularly (e.g. through a system monitoring and evaluation process) in the study area. There also was no evidence of a process (e.g. flood warning committee, community meetings/forum) to show that the local communities were participating in the review of the local TFWS.	Future reviews of the TFWS in the study area should be undertaken through the centralised process outlined in the Revised Draft Victorian Floodplain Management Strategy.
Integration of the TFWS components	There was no strong evidence (e.g. in the Yarriambiack Shire Council Flood Response Plan) found that the linkages across the components of the TFWS were well understood for the study area. An example of how this could be visualised is provided in Figure 7 (page 47) of the Revised Draft Victorian Floodplain Management Strategy	There is a need to understand how the components of the TFWS are integrated.

Recommendations

From this assessment, the following recommendations are made to improve the TFWS in the study area:

- ***Recommendation 1:*** Provide readily available details to local communities of their flood risk through the Wimmera CMA website, Section 32 certificates (via planning scheme) and ongoing community education.
- ***Recommendation 2:*** The Yarriambiack Shire Council Flood Response Plan and Municipal Flood Emergency Plan should include the outcomes and flood intelligence reporting from this project.
- ***Recommendation 3:*** The Warracknabeal Caravan Park emergency plan be updated to include reference to the latest flood study.
- ***Recommendation 4:*** Educate the communities in the study area about aspects of the TFWS including their flood risk, local flood warning triggers for action and the warnings that they will receive if a flood is imminent.
- ***Recommendation 5:*** A new streamflow gauge with telemetry be installed at the Ailsa Road crossing of Yarriambiack Creek, this should be installed and maintained by WCMA and YSC.
- ***Recommendation 6:*** BOM provide flood forecasting at the Jung and Ailsa Rd (when installed) gauges and, in the interim, provide detailed information to all agencies to determine flood forecasting using charts that relate stream height to AEP, and timing of flood flows to AEP.
- ***Recommendation 7:*** Combine the old Jung gauge rating (for low flows) with new modelled rating (for flood flows). DELWP and BoM to adopt this rating curve for water quantity measurement and flood forecasting.
- ***Recommendation 8:*** Further develop the community flood observers crowdsourcing program to enable people to provide real-time flood height observations to the ICC.
- ***Recommendation 9:*** Establish a 'phone tree' or similar localised communication method for isolated properties in the vicinity and downstream of Brim.
- ***Recommendation 10:*** Explore the possibility of Warracknabeal CFA siren as an extra warning mechanism.
- ***Recommendation 11:*** Explore the possible uptake of a localised smartphone flood warning app for the study area.
- ***Recommendation 12:*** Move the gauge boards at Lah to a location that can be viewed during time of flood.
- ***Recommendation 13:*** Ensure that all people requiring assistance in Yarriambiack Shire are in the Vulnerable Persons Register.
- ***Recommendation 14:*** Engage (e.g. by doorknocking) with all people in the Brim community if a flood is imminent.
- ***Recommendation 15:*** Identify and implement ways for community members in the study area to participate in the establishment, operation and review of the TFWS.
- ***Recommendation 16:*** Describe the integration of the local TFWS at least in the new Yarriambiack MFEP.
- ***Recommendation 17:*** Ensure that the integration of the TFWS is included as part of future TFWS reviews in the study area.

10.3 Structural Mitigation

10.3.1 Overview

As discussed in Section 7, a list of structural mitigation options was developed during community meetings, Project Steering Committee meetings and general discussion. A prefeasibility assessment was conducted on the list of mitigation options, which narrowed down the options to be tested further in the hydraulic model. The mitigation options suggested were focused on reducing flood damages in Warracknabeal, as this area has the highest flood risk, out of bank inundation plus many residents and infrastructure. Mitigation options were also suggested for the whole project study area from the Wimmera Highway at Jung to Galaquil Road north of Brim. Each and every mitigation option suggested over the course of the project was assessed based on its potential to reduce flood damages.

Given the number of mitigation options suggested the mitigation assessment was separated into four stages, these were as follows:

- Prefeasibility Assessment - to determine the potential for a mitigation option to reduce flood damage at reasonable cost and feasibility
- Detailed Hydraulic Modelling Assessment - to determine what reduction in flood levels and extents could be achieved
- Damages Assessment – to determine the reduction in damages that could be achieved by the chosen mitigation options
- Cost Benefit Analysis – to compare the reduction in flood damage and costs of the chosen mitigation options over a period of time to assess the economic performance of the options
- Concept design of the recommended mitigation option.

Mitigation solutions were described separately for Warracknabeal, Brim and regional properties. Discussion of levee options for Warracknabeal was included in more detail given the number of properties involved. The full list of suggested mitigation measures is summarised below in Table 10-3.

Table 10-3 Suggested mitigation options

Option No.	Detail	Source
Warracknabeal		
1	Removal of remnant levee formalised by YSC (See Figure 9-36)	Steering committee/Community
2	Construction of a permanent levee that protects Warracknabeal in a 1% AEP flood event in a similar alignment to that constructed during January 2011 (See Figure 9-36)	Steering committee/Community
3	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed during January 2011 with a combination of both temporary and permanent sections.	Steering committee
4	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal Weir	Community
5	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	Steering Committee
6	Improved drainage to the east of Warracknabeal to reduce stormwater flooding (See Figure 10-10)	Wimmera CMA/Council
7	Pump to transport water around Warracknabeal	Steering Committee
8	A levee upstream of Warracknabeal along Ailsa Road or Moloneys Road acting like a retarding basin to reduce the peak flow rate.	Community
Brim		
9	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal Weir	Community
10	Improved drainage to the east of Brim to reduce stormwater flooding	Community
Rural areas		
11	Improve roads/crossings/access to reduce isolation and cut off road connection to residential buildings.	Wimmera CMA

10.3.2 Prefeasibility Assessment

Each mitigation option was assessed against a number of criteria; potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 10-4 below. The reduction in flood damage was the most heavily weighted criteria as this is really the main objective for all flood mitigation. Table 10-5 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the more appropriate mitigation solutions for each location. While these options were reviewed and recorded individually it is important to consider a combination of options when developing a flood mitigation scheme.

Table 10-4 Prefeasibility assessment criteria

Score	Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact
Weighting	**2**	**1**	**0.5**	**0.5**
5	Major reduction in flood damage	Less than $50,000	Excellent (Ease of construction and/or highly feasible option)	None
4	Moderate reduction in flood damage	$50,000 – $100,000	Good	Minor
3	Minor reduction in flood damage	$100,000 – $500,000	Average	Some
2	No reduction in flood damage	$500,000 – $1,000,000	Below Average	Major
1	Increase in flood damage	Greater than $1,000,000	Poor (No assess to site and/or highly unfeasible option)	Extreme

Each of the suggested mitigation options was assessed using the outlined assessment criteria, and is discussed in Table 10-5.

Table 10-5 Prefeasibility assessment criteria

No.	Mitigation Option	Criteria				Score	
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
Warracknabeal							
1	Removal of remnant levee formalised by YSC	1	1	5	5	Removal of the remaining levee would increase flood damages and increase the work required to construct a similar levee in the future. However it may increase the amenity of Yarriambiack Creek for some Warracknabeal residents. (See Figure 9-36)	8
2	Construction of a levee that protects Warracknabeal 1% AEP flood event in a similar alignment to constructed during January 2011 (See Figure 9-36)	5	1	2	4	Replicating the January 2011 levee for Warracknabeal would offer the same level of protection, reducing the number of properties inundated significantly. However a permanent levee along the full length would be expensive given the lack of space along the required levee alignment and would likely involve major road works. (See Figure 9-36)	14
3	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed during January 2011 with a combination of both temporary and permanent sections.	5	2	3	4	Replicating the January levee along Yarriambiack Creek then leaving road crossings and other areas where a permanent levee is expensive or has an adverse impact on amenity of Yarriambiack Creek will reduce the number of properties inundated significantly. It will also be cheaper than a full permanent levee scenario. However, it will leave YSC with a large amount of flood response work preceding a flood event which could be time consuming and expensive. (See Figure 9-36)	15.5

No.	Mitigation Option	Criteria				Score	
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
4	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal weir	2	4	2	1	Removal of vegetation and large debris along Yarriambiack Creek and around the Warracknabeal weir is unlikely to have a significant impact on flood levels. The weir is the largest influencing factor on water levels and the capacity increases post January 2011 have reduced its impact. Vegetation removal would be required on a large scale to have any noticeable impact on flood levels and this is unlikely to be approved by Council, CMA, DELWP or the Community.	9.5
5	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	3	4	5	4	Asquith Reserve is impacted by a stormwater catchment to the south west. This could be directed into Yarriambiack Creek. Since January 2011, YSC have completed localised stormwater improvement works. The potential to reduce flood damages through improved drainage will be assessed conceptually as part of the Warracknabeal stormwater modelling.	14.5
6	Improved drainage to the east of Warracknabeal to reduce stormwater flooding	3	4	5	4	East of Warracknabeal the Borung Highway causes a significant restriction to overland flow to the north. During the January 2011 event extensive inundation was caused. Improved conveyance from south to north of the Highway would reduce stormwater flood damage. This will be assessed conceptually as part of the Warracknabeal stormwater modelling (See Figure 10-9)	14.5
7	Pump to transport water around Warracknabeal	2	3	1	5	The 1% AEP flow at Warracknabeal is around 50 m^3/s, this flowrate could not be passed around Warracknabeal via a pump as it is too large.	10

No.	Mitigation Option	Criteria				Score	
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
8	A levee upstream of Warracknabeal along Ailsa Road or Moloneys Road acting as a retarding basin.	4	2	2	4	A levee running along either Ailsa or Moloneys Road with a flow control structure limiting flow in Yarriambiack Creek has the potential to reduce flood damage in Warracknabeal, however it would increase agricultural flood damage upstream of the levee. The size of the bank required to reduce the flow significantly would be very large.	12.5
Brim							
9	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal Weir	2	4	2	1	There are very low flood damages for Brim with no dwellings flooded above or below floor for the 1% AEP event. Vegetation removal is expected to cause a minimal change to flood levels and would not be well accepted by the community.	9.5
10	Improved drainage to the east of Brim to reduce stormwater flooding	3	4	4	5	Improving stormwater drainage to the east of Brim would reduce flood damage. A stormwater catchment south of the township is unable to discharge under the Henty Highway to the north due to what appears to be undersized culverts. The potential to reduce flood damages through improved drainage will be assessed conceptually as part of the Brim stormwater modelling	14.5
Rural Areas							
11	Improve roads/crossings/ access to reduce isolation and cut off road connection to residential buildings.	2	3	3	5	There are several properties that are isolated during a major flood event and one property flooded above floor. Improving access will not reduce flood damage for these properties but could improve the ability to assist others and allow people to evacuate prior to the peak of a flood.	13

Using the prefeasibility assessment above, the 11 mitigation options were ranked by weighted score. Their ranking is shown below in Table 10-6.

Table 10-6 Weighted prefeasibility mitigation scores

Rank	Option No.	Mitigation Option	Weighted Score
1	**3**	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed during January 2011 with a combination of both temporary and permanent sections.	15.5
2	**5**	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	14.5
3	**6**	Improved drainage to the east of Warracknabeal to reduce stormwater flooding	14.5
4	**10**	Improved drainage to the east of Brim to reduce stormwater flooding	14.5
5	**2**	Construction of a levee that protects Warracknabeal from a 1% AEP flood event in a similar alignment to constructed during January 2011	14
6	**8**	A levee running along either Ailsa or Moloneys Road with a flow control structure limiting flow in Yarriambiack Creek has the potential to reduce flood damage in Warracknabeal, however it would increase agricultural flood damage upstream of the	12.5
7	**11**	Improve roads/crossings/ access to reduce isolation and cut off road connection to residential buildings.	11
8	**4**	Removal of vegetation and large debris along Yarriambiack Creek and upstream of the weir	9.5
9	**9**	Removal of vegetation and large debris along Yarriambiack Creek and upstream of the weir at Brim	9.5
10	**7**	Pump to transport water around Warracknabeal	8
11	**1**	Removal of remnant levee formalised by YSC	8

Based on the above ranking, a levee option for flood mitigation in Warracknabeal was identified as viable and considered for further investigation. Several localised drainage options were also highlighted for further consideration at part of the projects conceptual stormwater modelling. These options were assessed separately and were not assessed in the flood damages assessment.

The top five options are discussed in more detail in the following sections.

10.3.3 Stormwater Inundation improvements

Two of the proposed mitigation options were related to inundation via stormwater. These options were at Asquith Reserve and south of the Borung Highway east of Warracknabeal and are shown in Figure 10-9. Stormwater inundation at Asquith Reserve has been alleviated by drainage enlargements and the installation of one way stormwater outlets post the January 2011 event[27]. These changes will be reviewed during the stormwater modelling component of this project.

Stormwater inundation south of the Borung Highway is largely caused by a blockage to overland flow at the highway. The inundation observed during January 2011 event is shown in Figure 10-10. There may be options to add additional drainage culverts under the highway and improving the passage of overland flow. This will be assessed as part of the Warracknabeal stormwater modelling.

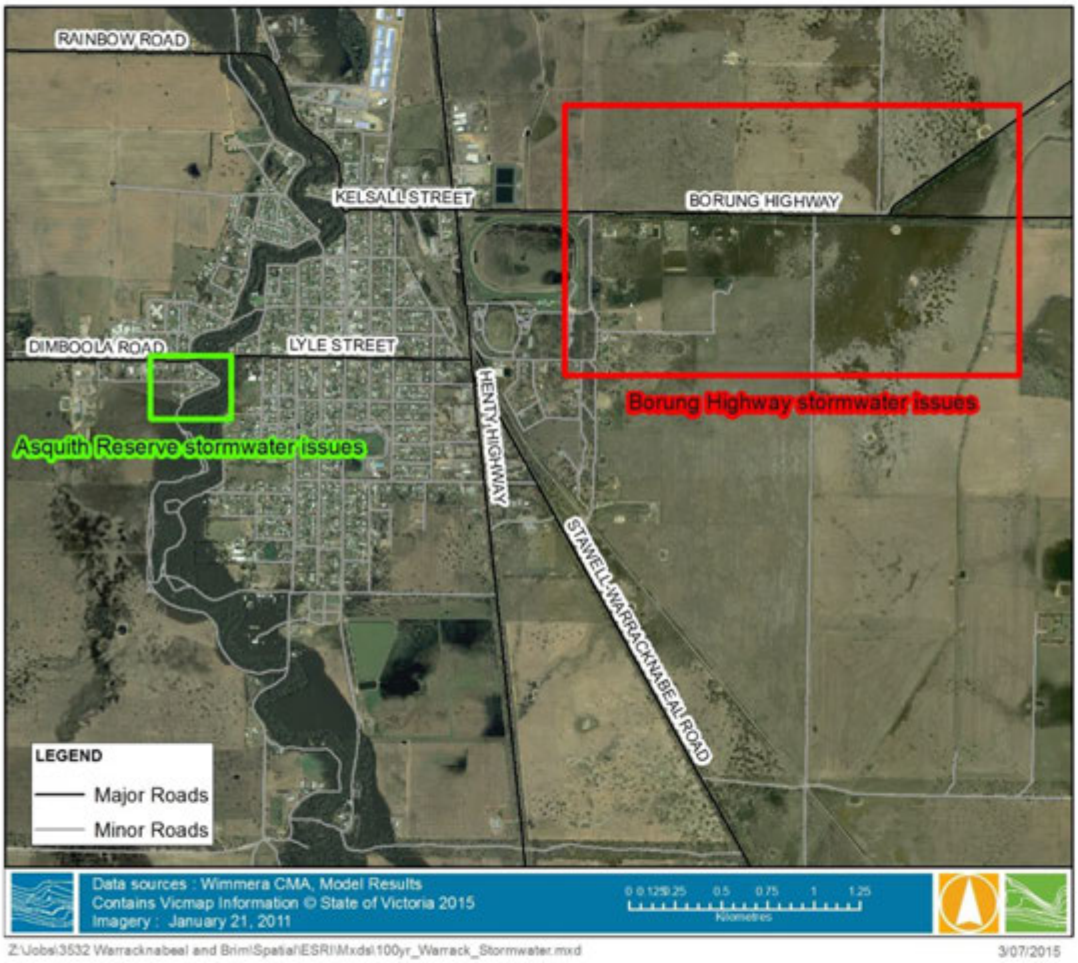


Figure 10-9 Warracknabeal stormwater issues

[27] Pers. Com. Yarriambiack Shire Council – Bernie Naylor

Figure 10-10 Inundation east of Warracknabeal during the January 2011 event caused by the Borung Highway restricting overland flow

10.3.4 Warracknabeal Levee

Overview

The highest flood risk within the study area is in Warracknabeal. There are several regional properties outside of Warracknabeal that are impacted above and below floor, however these properties are a significant distance from other built assets and individual mitigation (i.e. private levees) at these properties is unlikely to cause adverse flood impacts. The existing conditions design modelling and the January 2011 event showed no properties are impacted above or below floor in Brim, resulting in no requirement for flood mitigation.

Within the study area Warracknabeal is the only real location where a mitigation scheme will benefit numerous properties. As a result the mitigation modelling undertaken in this project focused on the Warracknabeal township. This is not to say that rural dwellings outside of Warracknabeal can't be protected by individual levees, but levees protecting individual buildings in a rural setting are not likely to negatively impact adjacent landholders or be funded by State Government and therefore have not been assessed in this study. If a landholder wishes to protect an individual building with a levee or other mitigation options, advice must be sort from Yarriambiack Shire Council and Wimmera CMA.

January 2011 Mitigation

As mentioned in Section 9.6.2, a significant levee was constructed during January 2011, protecting Warracknabeal, with portions of this levee formalised and included in the design modelling.

To test the impact of the levee constructed during January 2011 during a 1% AEP flood event, the levee was incorporated into the 1% AEP flood model. In the Warracknabeal existing conditions modelling (with current remnant levees), of the commercial and residential buildings surveyed there are 11 buildings flooded above floor, and 166 below floor (this does not include multiple buildings on one allotment).

By including the entire January 2011 levee in the modelling, this was reduced to just 1 building flooded above floor and two below, as shown in Figure 10-11. The total levee as constructed in January 2011 significantly reduced the extent of inundation through the Warracknabeal township. The levees acted to reduce the flow area available to convey floodwater through the township so water levels inside the levees along Yarriambiack Creek is increased. A difference between the existing and January 2011 water levels was determined to understand these increases, Figure 10-12. This was calculated as:

Difference in Water Level = January 2011 Levee Scenario – Existing Conditions Scenario

The result shows positive values where there is an increase in water level and negative values where there is a decrease. The difference between the January 2011 Levee and Existing Conditions model scenarios is shown in Figure 10-12.

Implementing the full January 2011 levee alignment in a 1% AEP event results in a maximum increase in water levels of 0.2 m immediately downstream of the Warracknabeal Weir, where several industrial buildings are protected, as shown in Figure 10-13. This localised increase does not appear to impact on any buildings. There is also a maximum increase between the levee banks of 0.15 m, as shown in Figure 10-14.

Increases in water levels downstream of Lyle Street (north) have impacted on the bowling green and the caravan park. Floor levels for these locations were not surveyed as part of the original Warracknabeal and Beulah Flood Study[6]. There are no permanent buildings at the caravan park and several buildings at the bowling green. The bowling green club room floor level was captured by the additional floor level survey from this project. This floor level information showed the bowls club would be inundated below floor, with a freeboard of 0.28 m.

The one building (shed) remaining flooded above floor in Wood Street has a water level increase of 0.03 m. During January 2011 this property is understood to have been protected by a private levee. This has not been included in the January 2011 levee scenario. There is no increase in water levels at the two buildings flooded below floor.

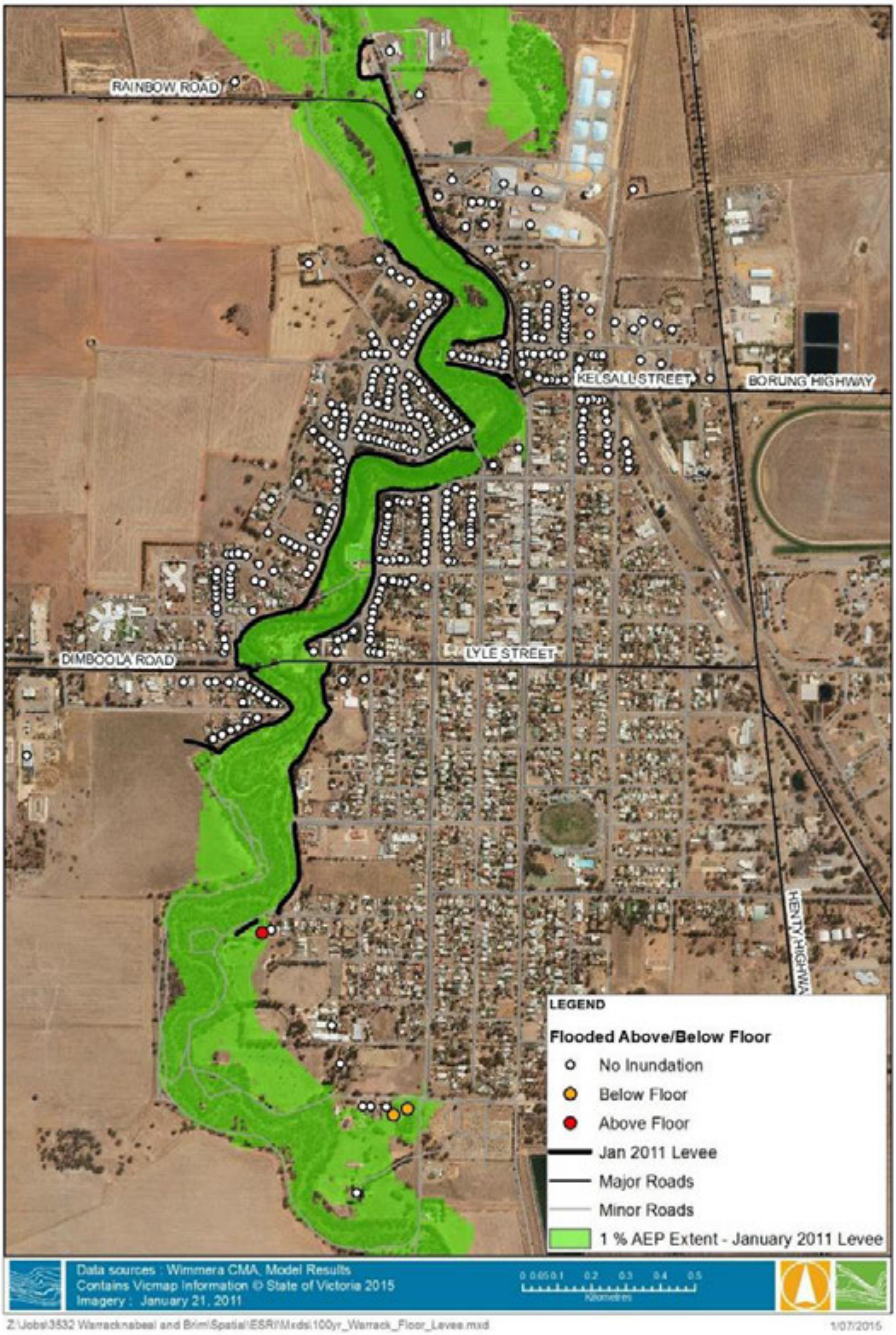


Figure 10-11 Yarriambiack Creek 1% AEP flood event with the January 2011 Levee

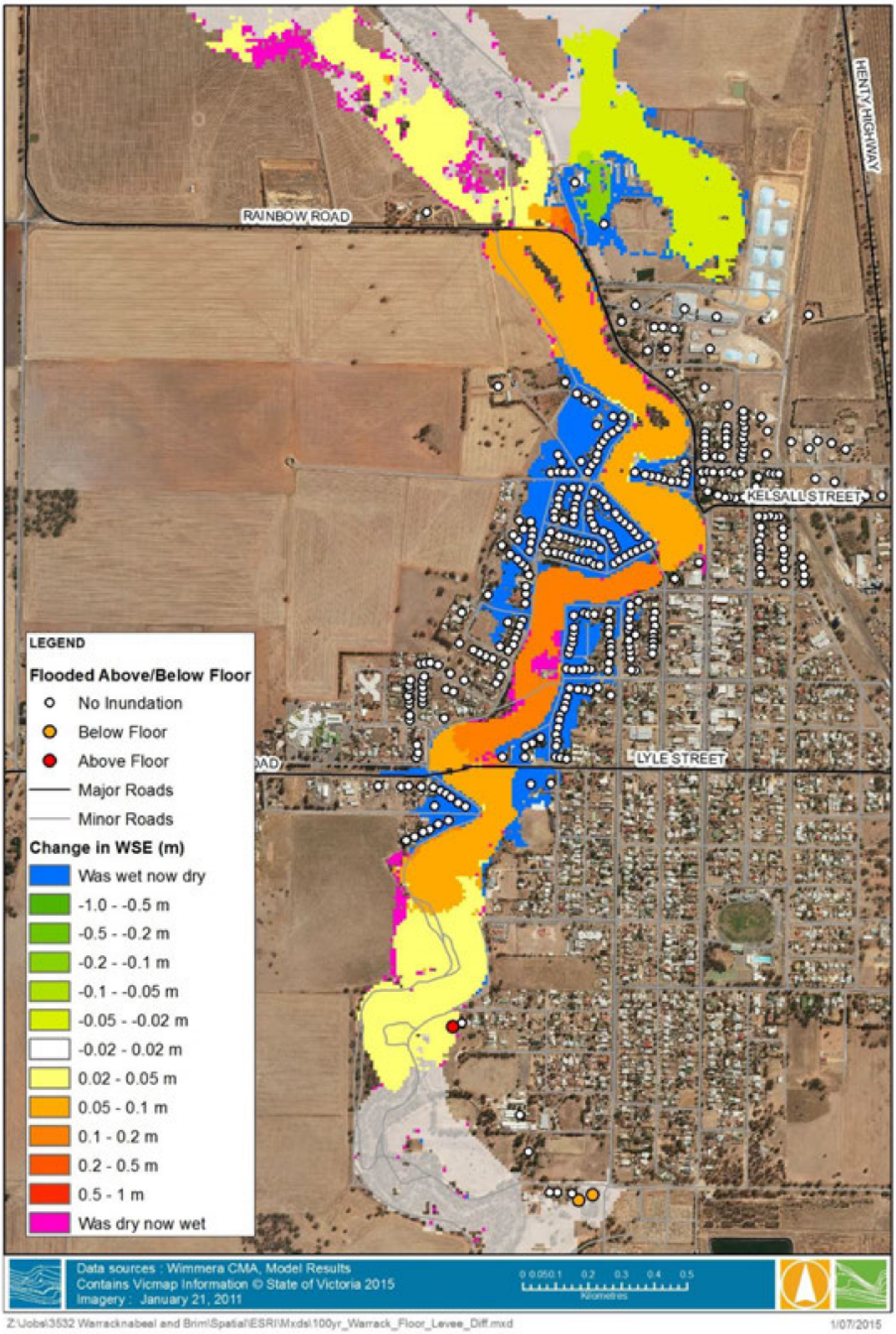


Figure 10-12 Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment

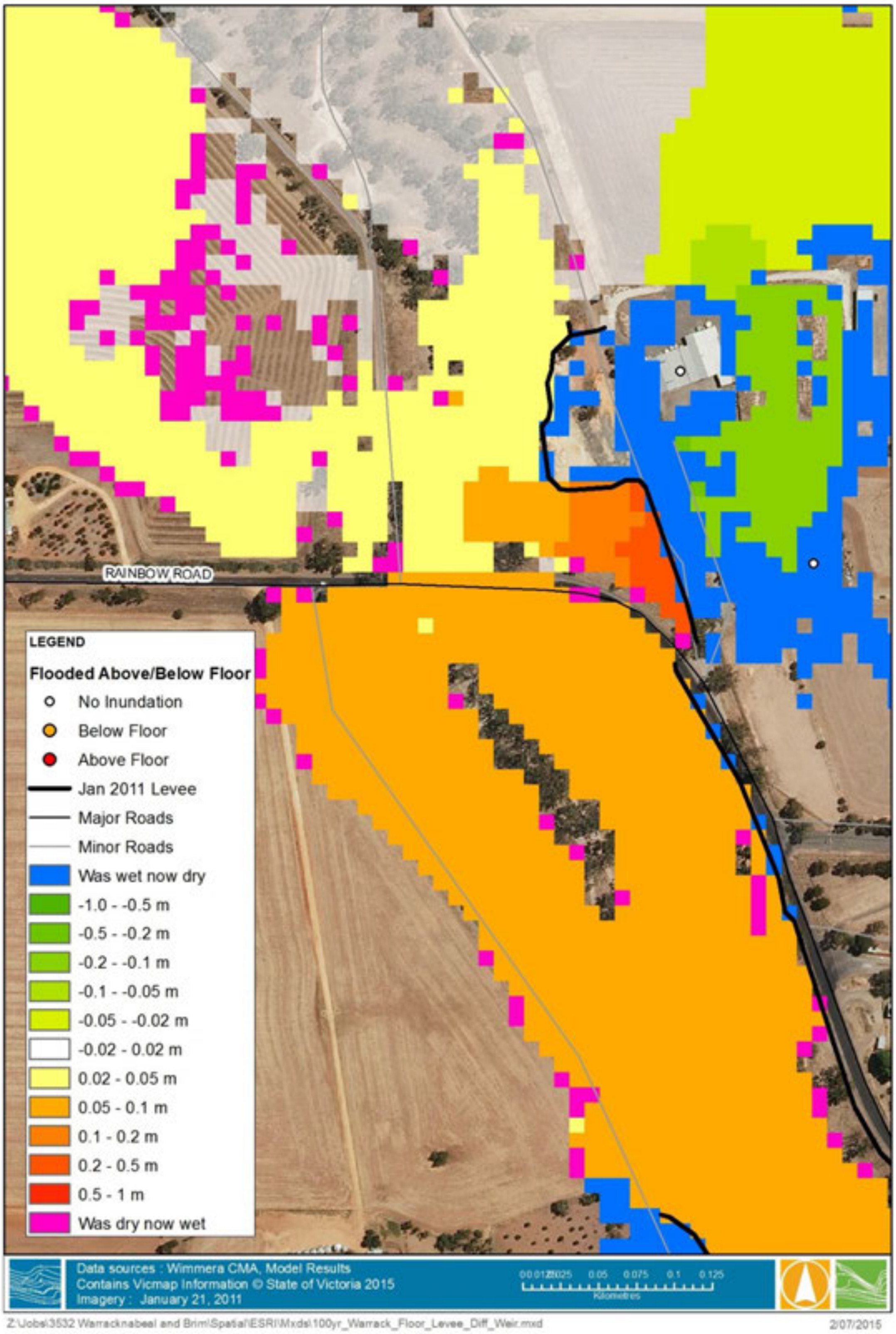


Figure 10-13 Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment, downstream of Warracknabeal Weir

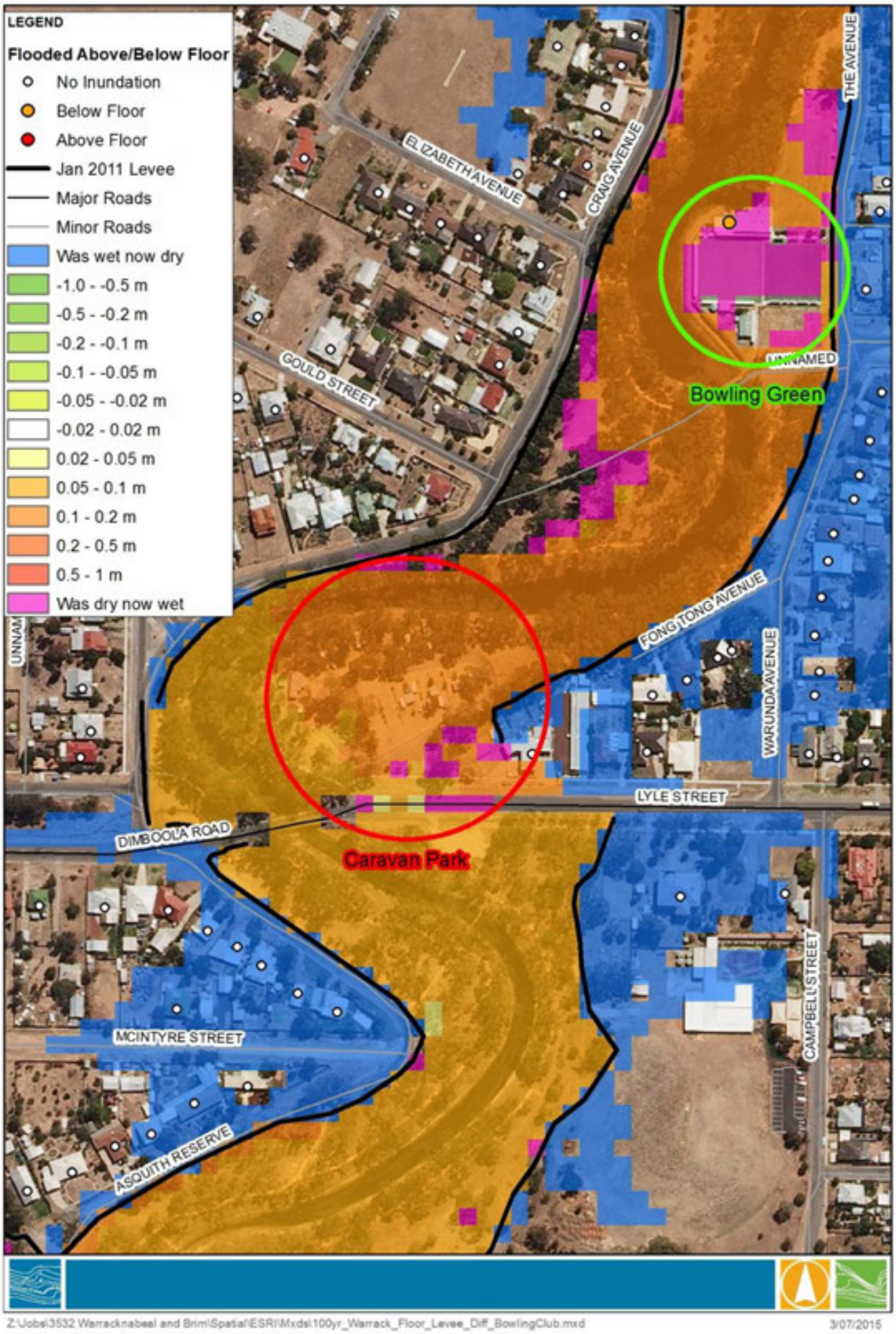


Figure 10-14 Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment, downstream of Lyle Street

Mitigation option assessment

Overview

The water level comparison between the existing and January 2011 levee scenario assisted in understanding potential for improvements in the levee alignment. A series of potential options for improvement were developed by the Project Steering Committee, Wimmera CMA and Water Technology, these potential improvements are shown below:

- Changing the levee alignment to include the Warracknabeal Bowls Club (Figure 10-15)
- Increase the levee length to better protect the industrial area north of Warracknabeal (Figure 10-16)
- Private levee for single building flooded above floor (Figure 10-17)
- Private levee for two buildings flooded below floor (Figure 10-18)
- Structure capacity increases

The options were assessed using the calibrated hydraulic model to determine their impact on the properties they protect and those that remain unprotected.

Several other scenarios were run as a sensitivity test to determine their impact, these were:

- Blocking several major structures on Yarriambiack Creek
- A reduction in floodplain storage downstream of Warracknabeal Weir

Each model scenario is discussed in the following sections.

Figure 10-15 Yarriambiack Creek 1% AEP flood event – Potential levee option at the Warracknabeal Bowling Club

Figure 10-16 Yarriambiack Creek 1% AEP flood event – Potential levee option north of Warracknabeal

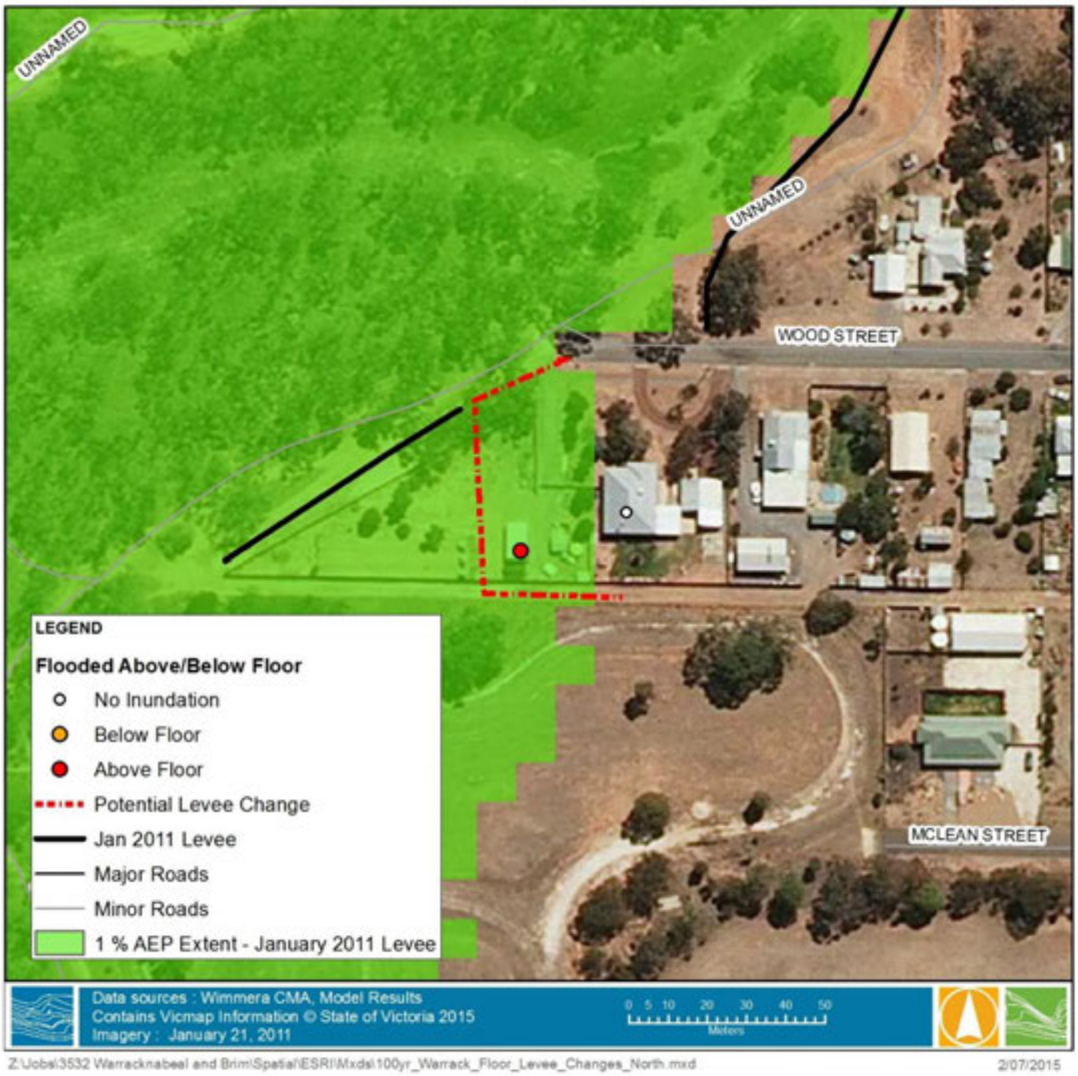


Figure 10-17 Yarriambiack Creek 1% AEP flood event – Potential levee changes at the building flooded above floor

Figure 10-18 Yarriambiack Creek 1% AEP flood event – Potential levee changes at the buildings flooded below floor

Removal of remnant levees

Removal of the remnant and formalised Yarriambiack Shire Council levees was modelled to understand the impact of the remaining levees. The modelling was used to determine what a flood could look like without any mitigation measures in place (excluding the size increase at the Warracknabeal Weir).

A comparison of the existing conditions (remnant levees remaining) and removed remnant levee scenarios is shown in Figure 10-19 with a closer perspective of the southern and northern levees shown in Figure 10-20 and Figure 10-21 respectively.

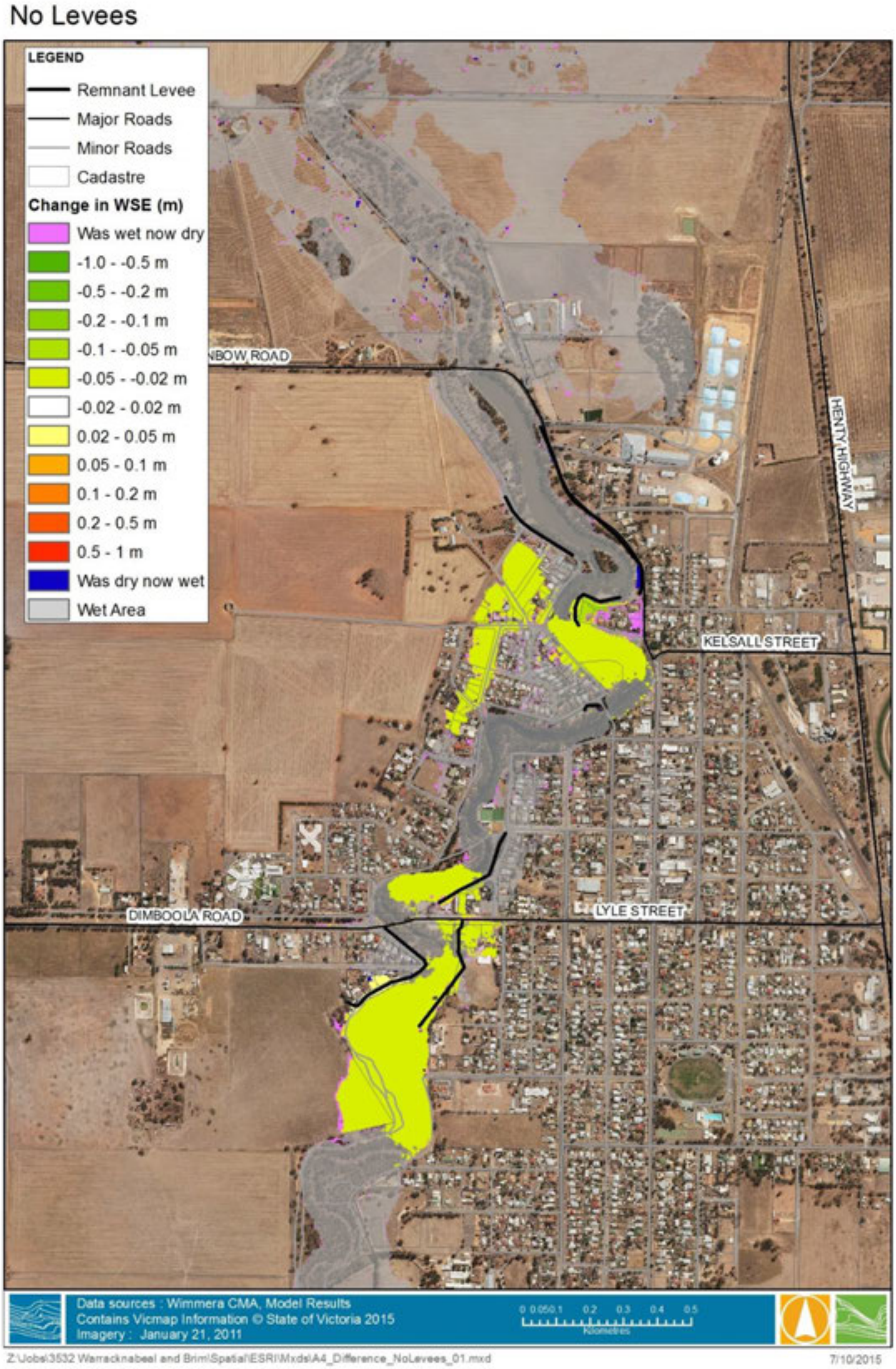


Figure 10-19 Change in water levels as a result of removing the remnant levees

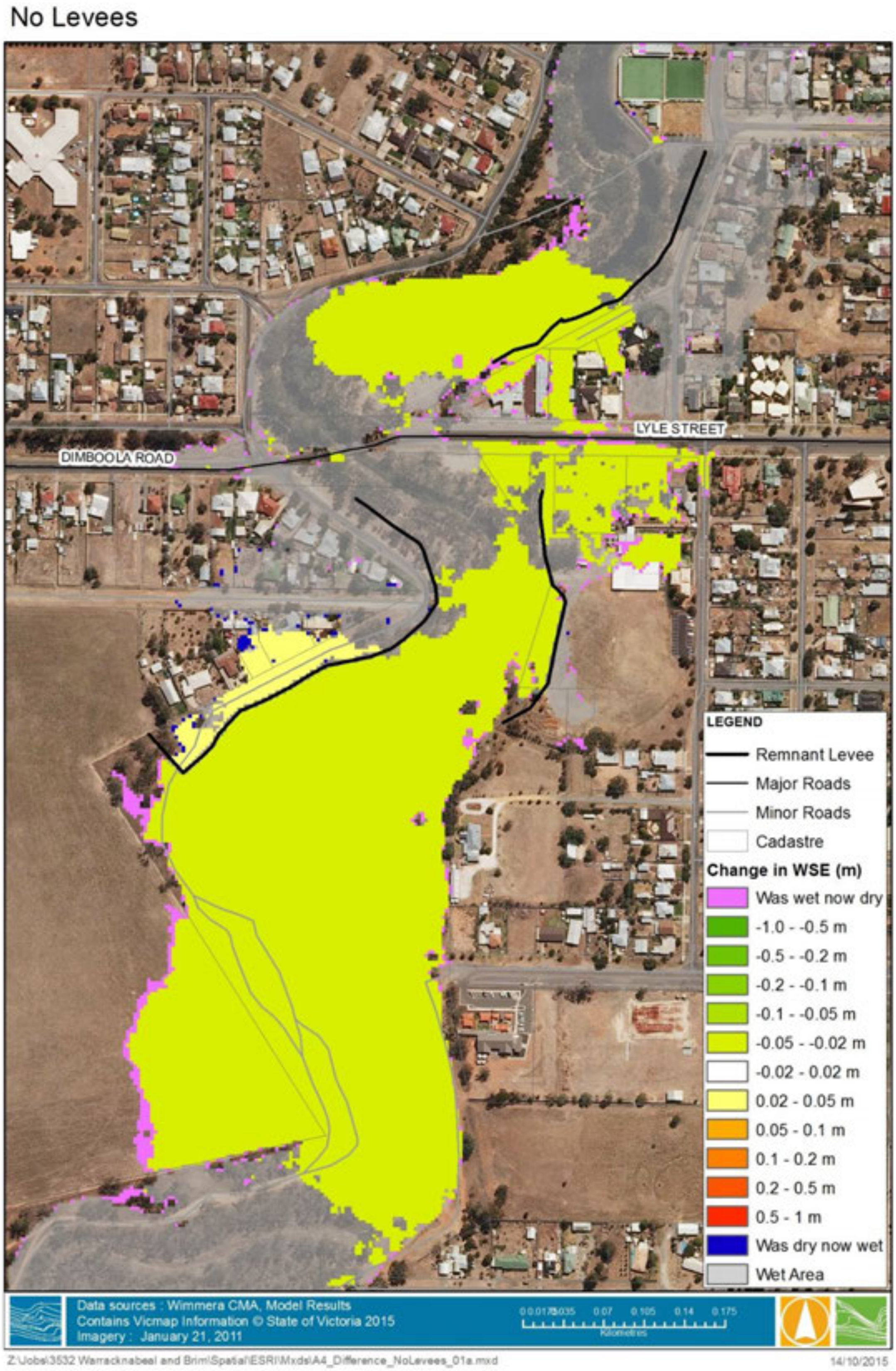


Figure 10-20 Change in water levels as a result of removing the remnant southern levees

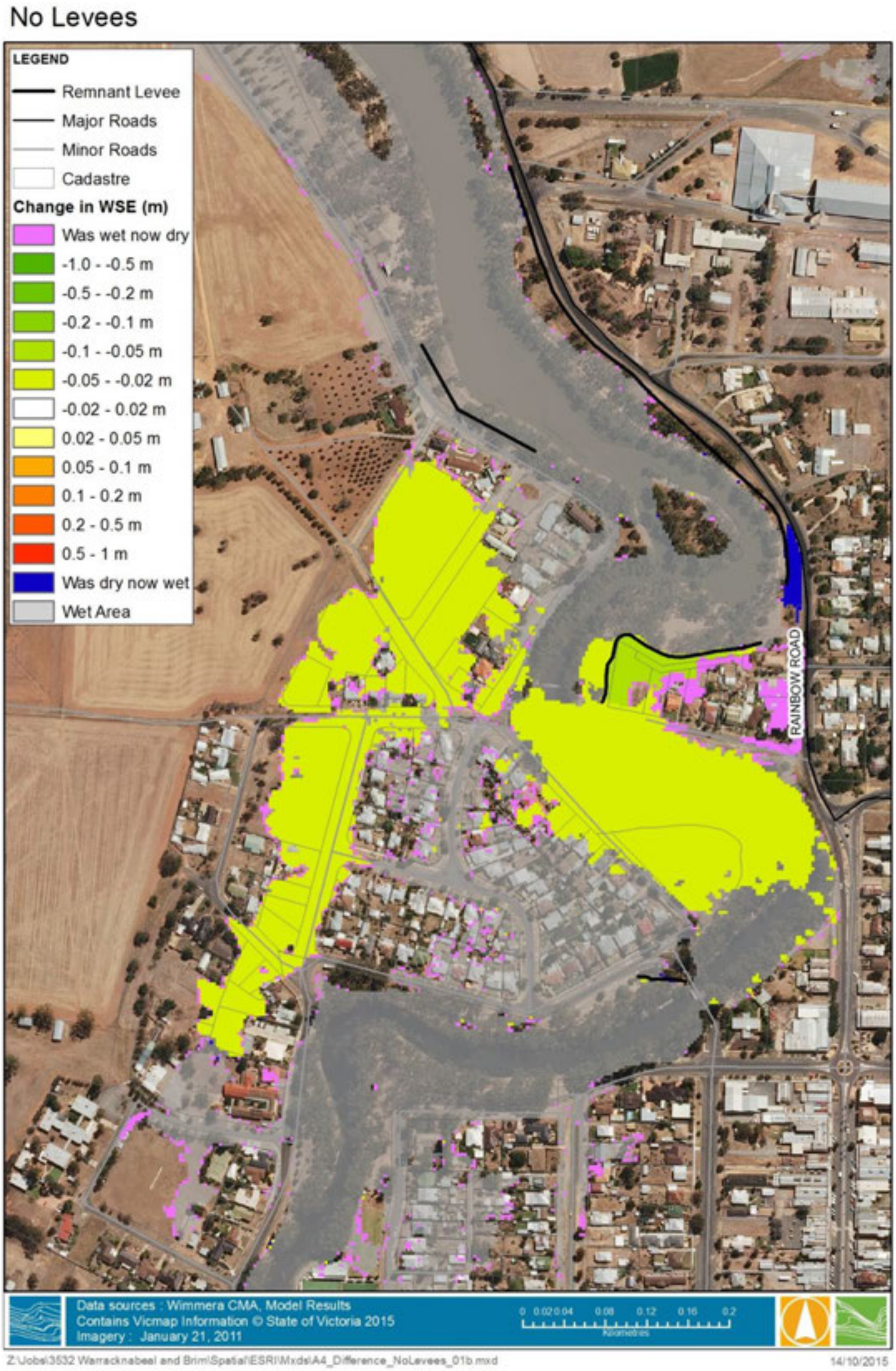


Figure 10-21 Change in water levels as a result of removing the remnant northern levees

The removal of the remnant levees has resulted in a general reduction in water levels in Yarriambiack Creek and the floodplain. This is due to the remnant levee system having gaps in it, with water outflanking the existing remnant levees. These remnant levees are currently not providing full protection and when water outflanks them it gets trapped behind them, so removing them actually lowers water levels. The majority of the remnant levees are also not high enough to prevent overtopping of the 1 % AEP event.

Bowling Club Levee

The Warracknabeal Bowling Club in not inundated during the 1% AEP design modelling, however modelling with the inclusion of the January 2011 levee has shown the constriction the levee causes increases flood levels in this area, as shown in Figure 10-14 exacerbating inundation. The increase in water levels causes an increase in inundation extent with the bowling green now inundated. There are two buildings at the Bowling Club, north and south of the greens. The northern building is around 190 mm lower than the southern building and is shown as flooded below floor (100 mm below floor level).

To protect the Bowling Club from inundation a levee was modelled along the edge of Yarriambiack Creek. The inclusion of the levee only caused a minor increase in water levels upstream when compared to the January 2011 levee scenario of 0.025 m. When compared to the existing conditions scenario an increase of 0.133 m was observed immediately upstream of the Bowling Club.

A comparison of the modelled water levels with the inclusion of the Bowling Club levee (as a modification to the January 2011 level) and the existing condition is shown in Figure 10-22.

The lack of increase in water levels upstream of the Bowling Club is due to the lack of floodplain conveyance across the site when it is inundated.

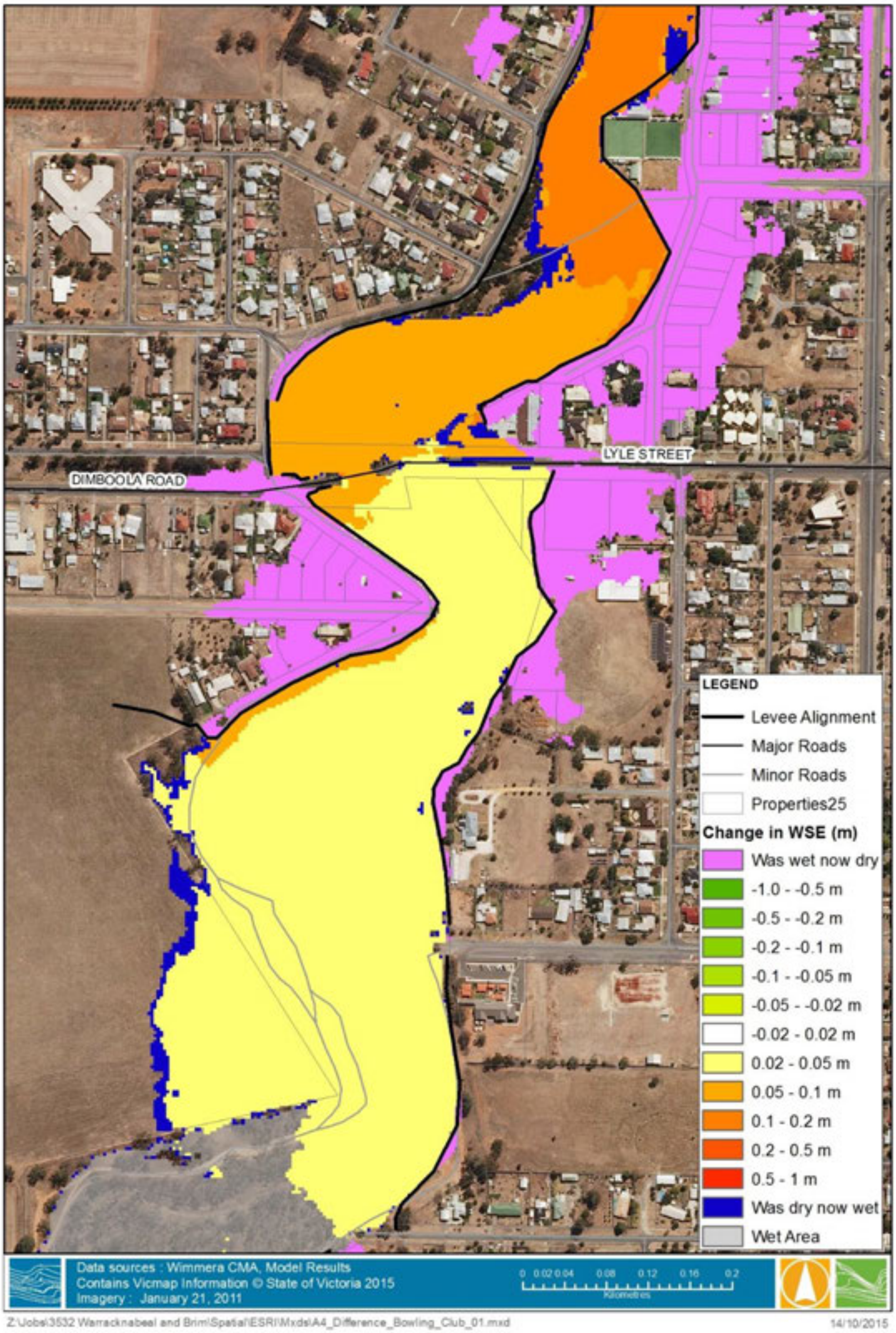


Figure 10-22 Change in water levels - The inclusion of a levee around the Bowling Club as a modification to the January 2011 levee compared to existing conditions

Joinery Levee

The joinery downstream of the Warracknabeal weir is inundated by water breaking out from Yarriambiack Creek and flowing into a low area across the site.

A levee was modelled along the western side of an unnamed road running east of Yarriambiack Creek. The levee then changed direction to the east to run along an existing internal road.

The levee alignment and change in water levels with the addition of the levee protecting the joinery is shown in Figure 10-23.

The proposed levee prevents inundation of the joinery with water now breaking out of Yarriambiack Creek to the west and flowing around the levee at the northern end. Similar to the January 2011 levee there is an increase in water levels in the immediate vicinity of the levee, however the increases are only relatively isolated. Upstream of the Warracknabeal Weir the increases are marginally over 0.02 m and decrease to zero.

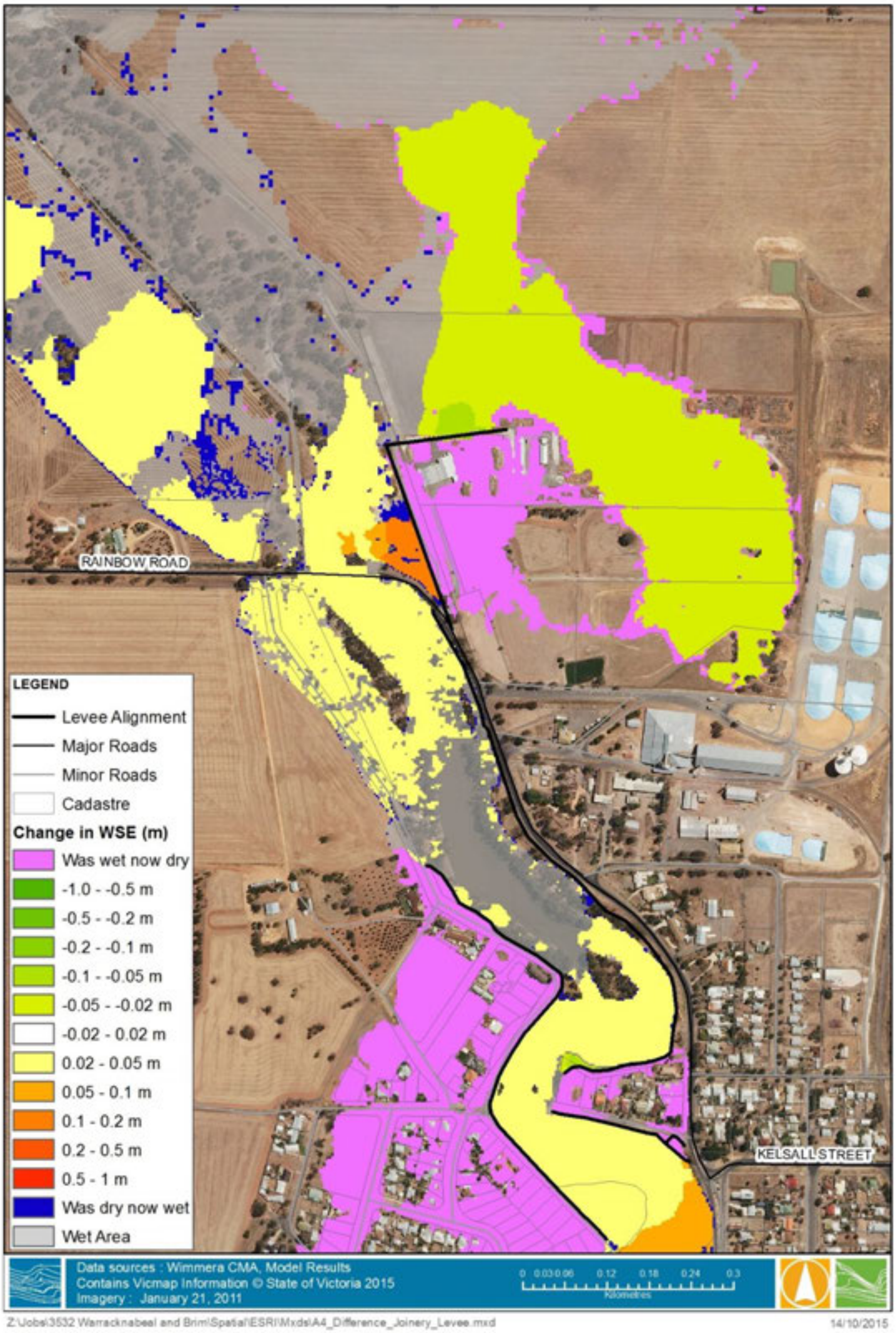


Figure 10-23 Change in water levels - The inclusion of a levee protecting the joinery as a modification to the January 2011 levee compared to existing conditions

Increased Structure Capacity

To test the impact of increasing structure capacity in Yarriambiack Creek through Warracknabeal the two major structures; Dimboola Road and Jamouneau Street were completely removed, simulating the largest possible capacity increase. The Warracknabeal Weir has already undergone significant works to increase its capacity.

The opened structures and change in water levels as a result of the opening is shown in Figure 10-24.

Opening of the Yarriambiack Creek structures at Dimboola Road and Jamouneau Street caused a relatively localised reduction in water levels upstream of each location. In both cases this reduction was around 0.03 m.

Upstream of Jamouneau Street the reduction in flood levels impacts on two buildings flooded above floor, one each in Kokoda Avenue and The Avenue. Both are flooded above floor in excess of 0.15 m and remain flooded above floor on the structure opening scenario.

Upstream of Dimboola Road the reduction in flood levels impact on three neighbouring buildings flooded above floor on Asquith Reserve Road. One of these is a shed inundated by 0.19 m. The other two buildings are dwellings flooded above floor by 0.04 m and 0.02 m. The reduction in flood levels due to opening Dimboola Road is 0.035 m, alleviating above floor flooding at one property. However, practically speaking, with the reduced flood level only marginally below the floor level, it is likely to be impacted to above floor level by wave action from traffic.

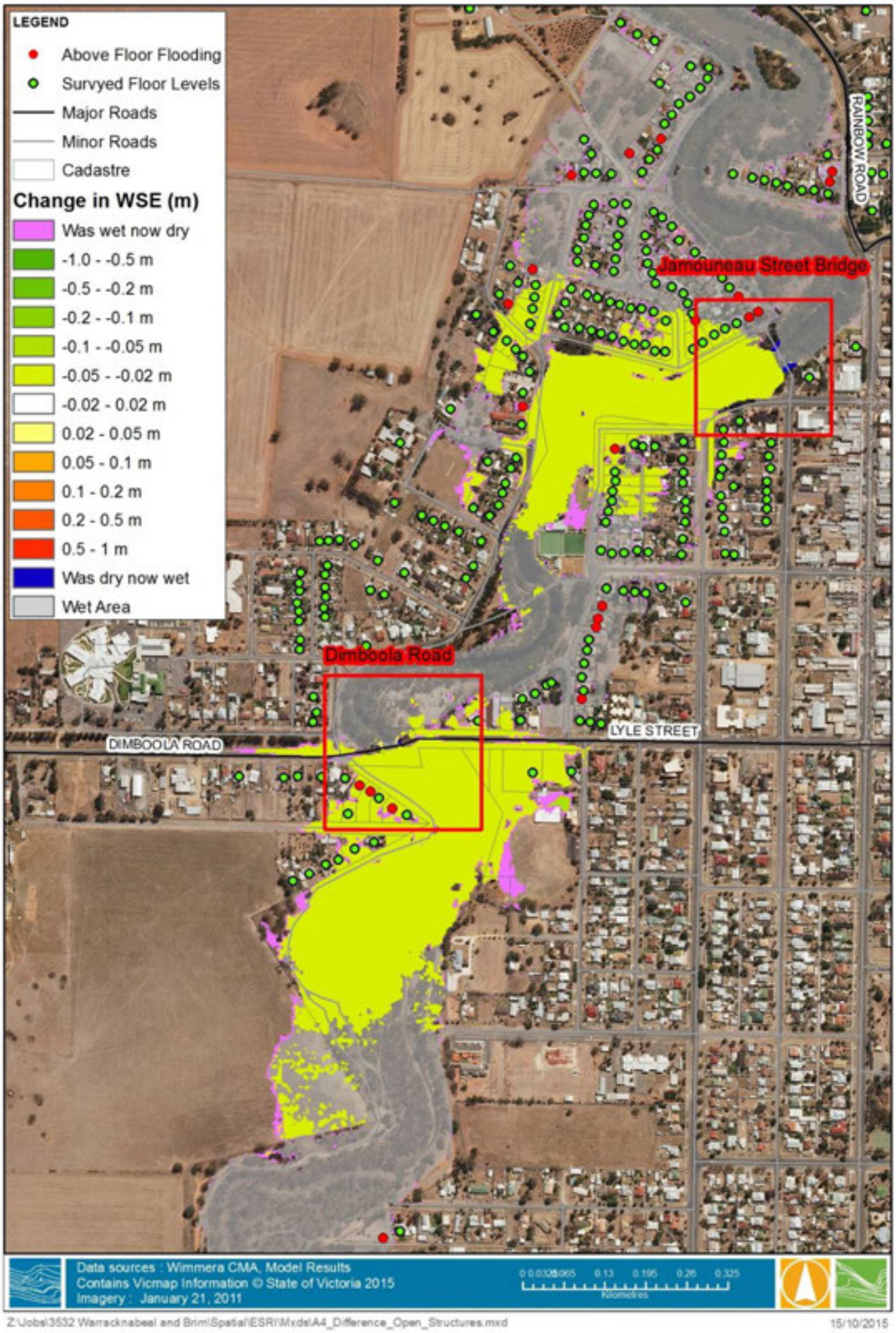


Figure 10-24 Change in water levels – Opening Yarriambiack Creek structures in Warracknabeal

Reduction in Floodplain Storage DS of Warracknabeal Weir

To assist in understanding the impact that uncontrolled levee construction could have on floodplain water levels and extents a reduction in floodplain storage was modelled north of Warracknabeal Weir. In this section of Yarriambiack Creek there has been some levee construction in the past in an attempt to prevent inundation of agricultural land. The reduction in storage was modelled as a levee either side of Yarriambiack Creek.

The levee alignments and the change in water levels due to the loss of floodplain storage downstream of the Warracknabeal Weir is shown in Figure 10-25 with a closer perspective of the Warracknabeal township shown in Figure 10-26.

The loss of floodplain storage downstream of Warracknabeal Weir caused an approximate 0.12 m increase in water level immediately upstream of the weir pool. This increase dissipates to zero at around the Bowling Club. The increase in water levels has caused an increase in inundation extent, this is most prominent on the eastern side of Yarriambiack Creek where additional commercial and residential areas are inundated.

Within the area of water level increases there are 13 buildings flooded above floor in the 1% AEP existing conditions results. Each of these buildings is flooded to a greater depth varying from 0.05 to 0.07 m. There are also an additional 13 buildings flooded above floor as a result of the loss of floodplain storage.

The buildings flooded above floor in existing conditions are shown in Figure 10-26 with green markers, additional buildings flooded above floor in the reduction in storage scenario are shown with red markers.

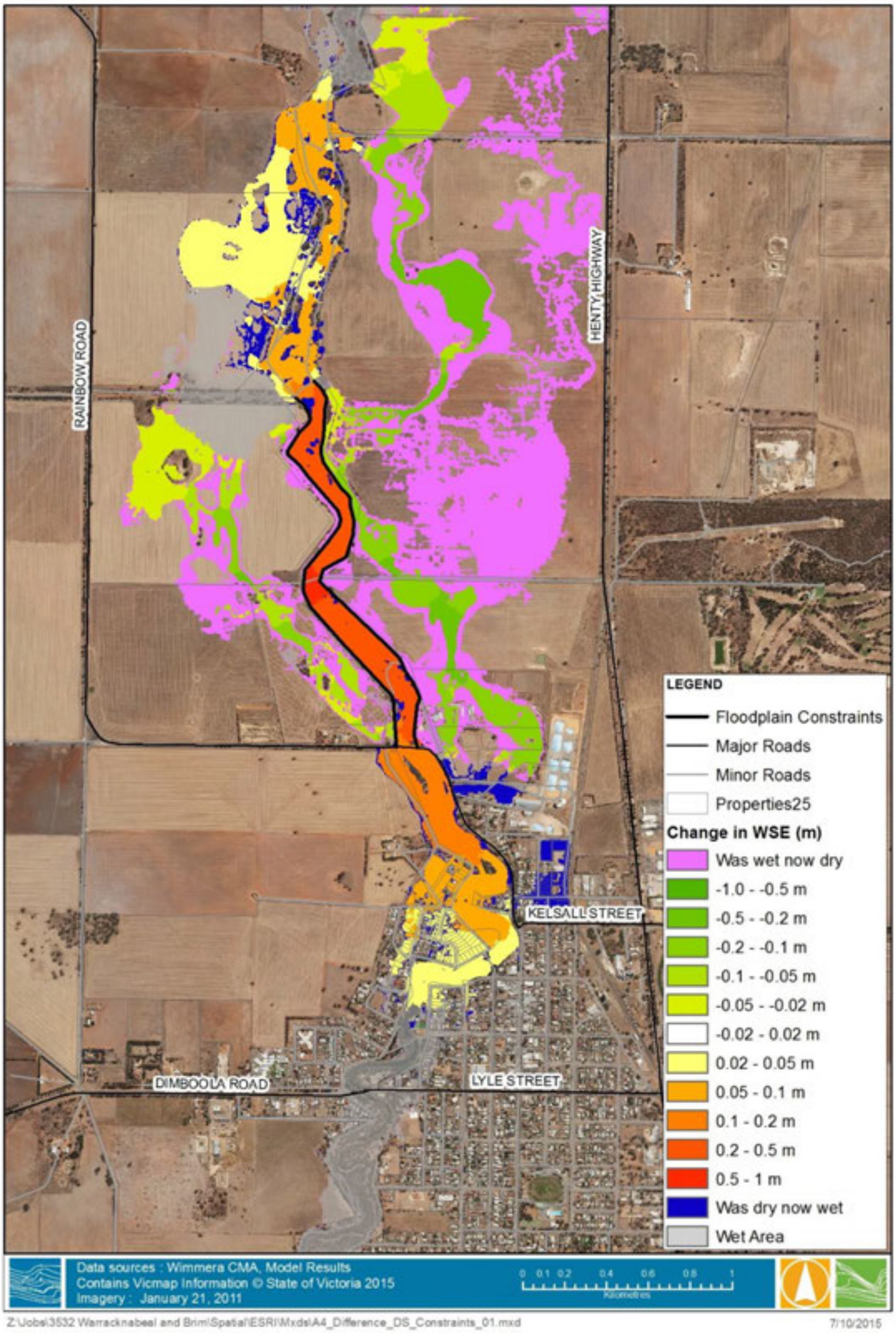


Figure 10-25 Change in water levels – Loss of floodplain storage downstream of Warracknabeal Weir

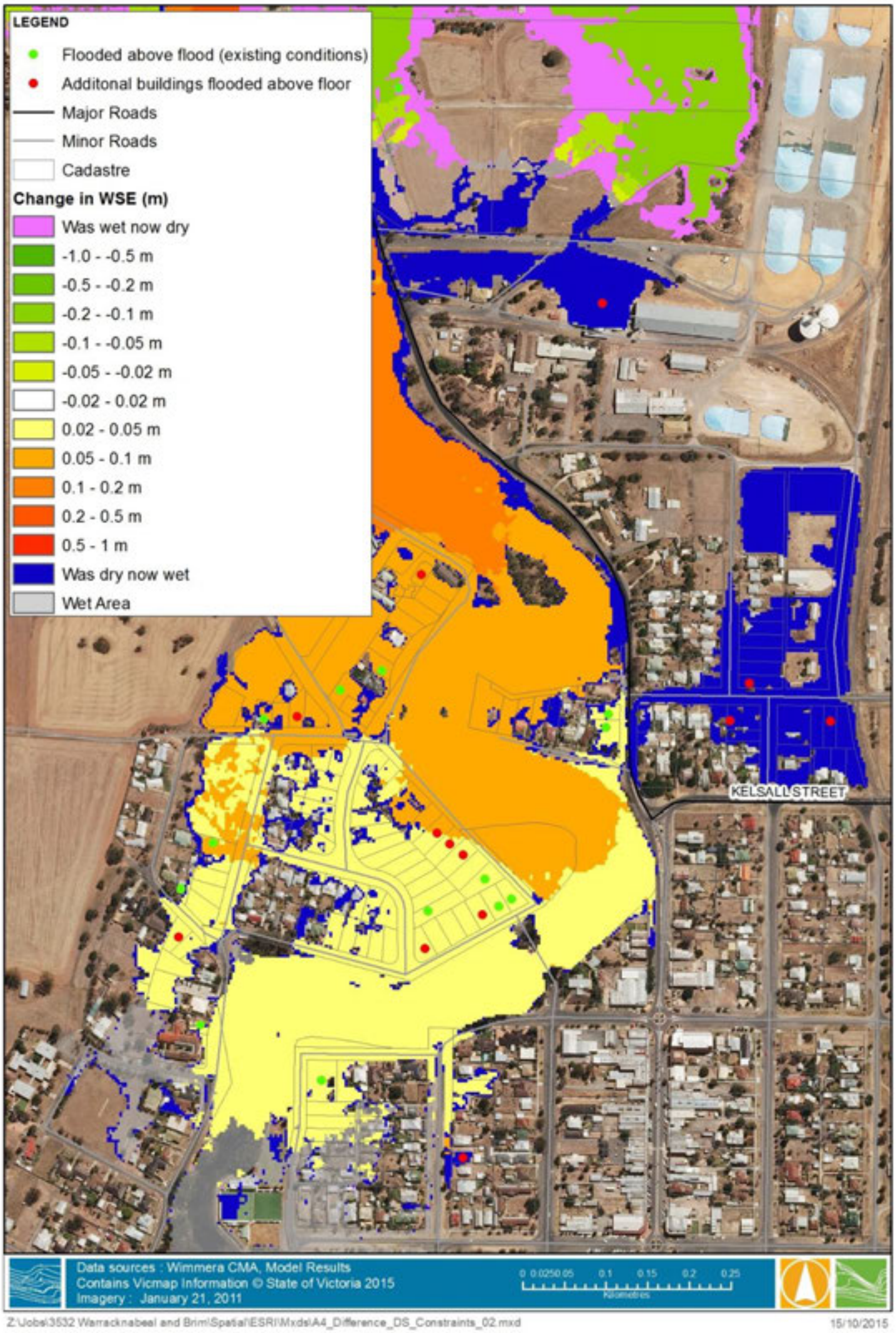


Figure 10-26 Change in water levels in Warracknabeal – Loss of floodplain storage downstream of Warracknabeal Weir

Individual Levee Protection

There are three buildings to the south of Warracknabeal impacted by floodwater in the 1% AEP event with the inclusion of the levee along the same alignment as January 2011. One shed is flooded above floor and two houses below floor. Protecting these properties was modelled with the inclusion of separate levees. The levee alignments and change in water levels due to their construction is shown in Figure 10-27. It is important to note the shed flooded above floor was flooded marginally deeper (less than 0.02 cm) with the January 2011 levee scenario.

The inclusion of private levees reduced the area of inundation, protecting both the shed flooded above floor and the dwellings flooded below floor. The northern levee protecting the shed caused an isolated increase of 0.02 m and a marginal increase in inundation extent. The southern levee did not cause any increase in water levels or extents.

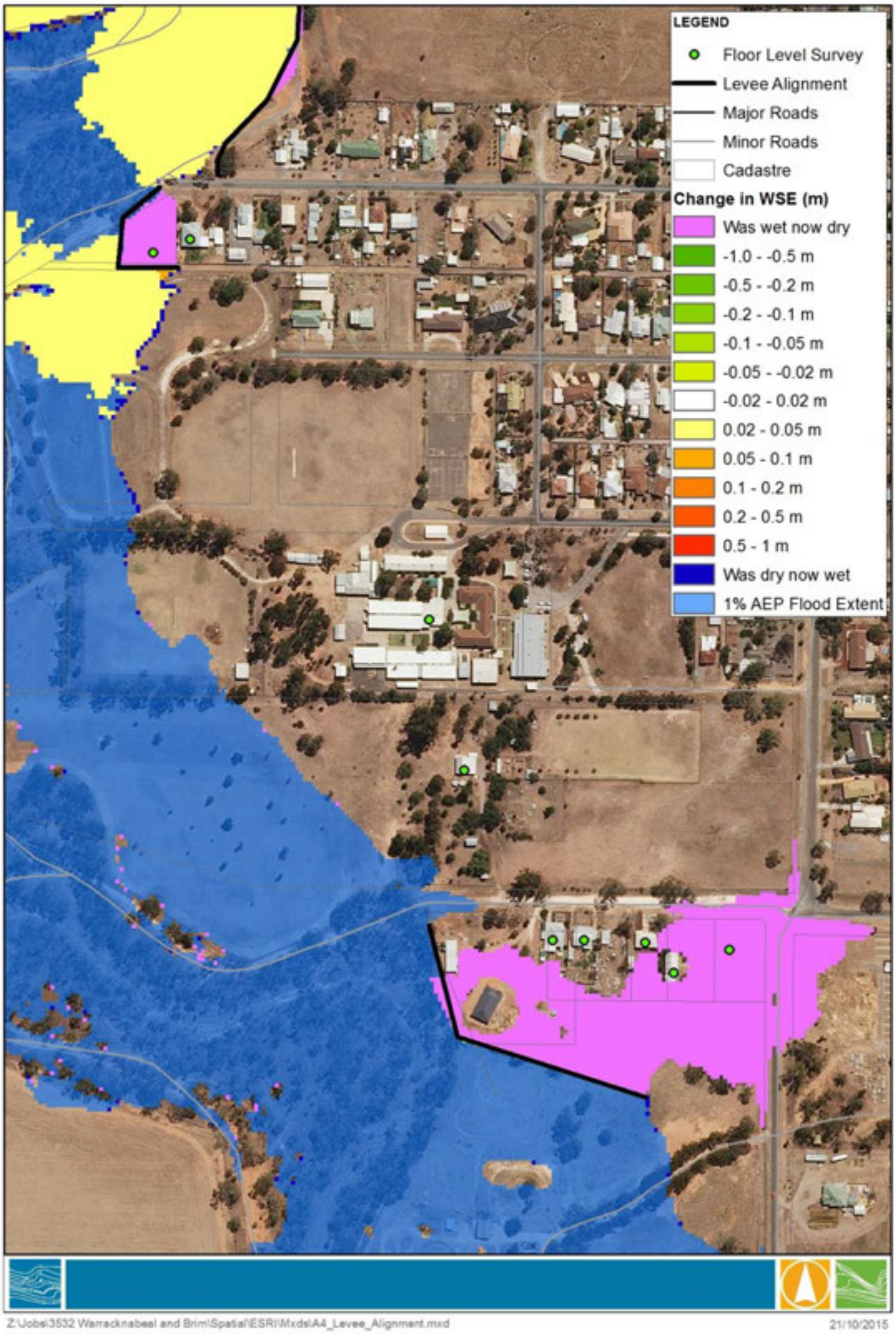


Figure 10-27 Change in water levels – Levees protecting three buildings on the southern edge or Warracknabeal

Combined Mitigation Package

Several of the modelled mitigation measures were combined into a mitigation package. The combined option aimed to not negatively impact any private built assets in Warracknabeal while reducing the number of properties flooded above and below floor to as low as possible.

The combined mitigation package included levees similar to that constructed during January 2011 with the following modifications:

- A levee protecting the industrial area north of Warracknabeal
- Modification to the levee protecting the Bowling Club
- Two private levees protecting the areas south of Warracknabeal

The combined mitigation scenario and 1% AEP inundation extent is shown in Figure 10-28 with a comparison of the combined mitigation package and existing conditions water levels and properties flooded above and below floor in Warracknabeal shown in Figure 10-29.

Under the combined mitigation package no buildings are flooded above or below floor. The Combined Mitigation Package is the recommended mitigation option for Warracknabeal.

More detail around the mitigation package, levee alignments and heights is discussed in Section 10.5.

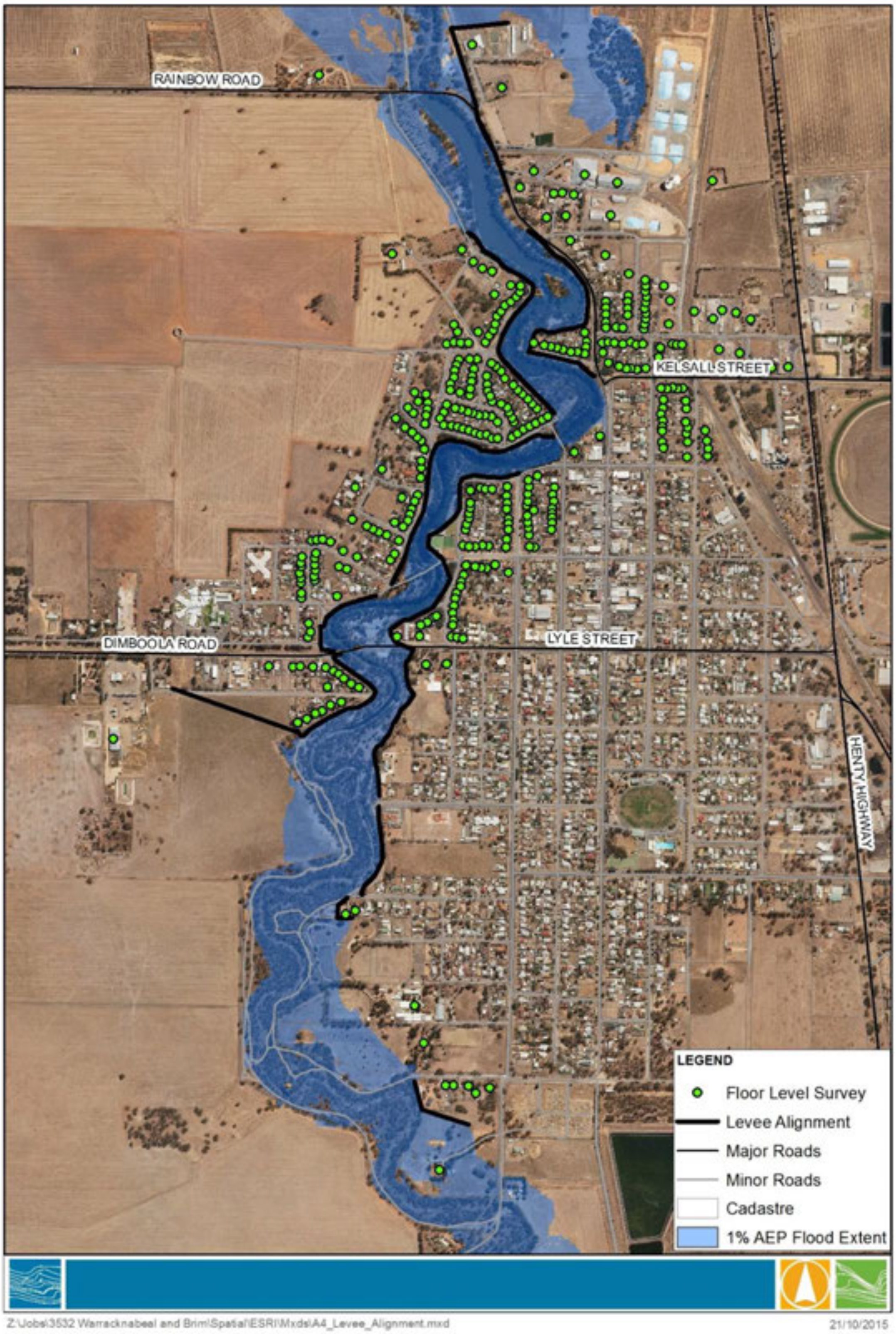


Figure 10-28 Inundation extent and levee alignments for the combined mitigation package

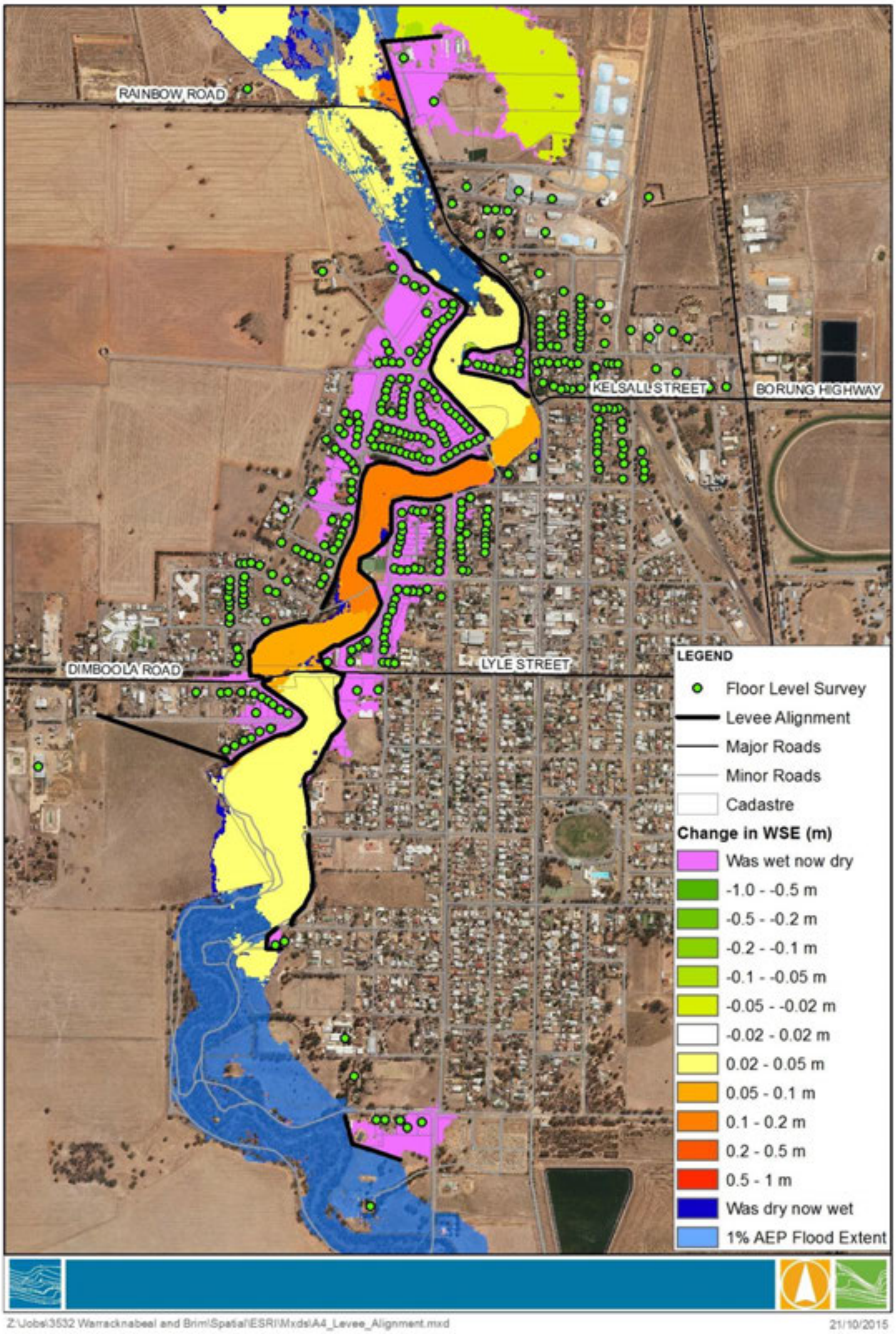


Figure 10-29 Change in water levels – Combined Mitigation Package

Levee Failure

With the construction of any flood protection levee there is a risk the levee may fail. The most likely points of levee failure are on the outside of bends where the velocity is the highest and there is a chance of the river migrating and the bank collapsing, or where there are points of weakness in the levee such as cracks, holes, poorly constructed sections, informal crossings which lower the crest over time, services such as pipes that run through the levee which have not been adequately set in, etc.

The combined mitigation package was reviewed to determine two potential points of failure, one on either side of Yarriambiack Creek. The points of failure were determined on where the levee might fail and where a potential failure could have the highest consequence in terms of property damage. The chosen failure locations and buildings flooded above and below floor in existing conditions are shown in Figure 10-30. Several buildings are flooded above and below floor downstream of each failure location highlighting high consequence for failure in those locations.

The levees were failed along an approximate 15 m length at the peak height of the 1 % AEP event, with an hour duration for the levee failure to breach to ground level. The levee failures were used as a sensitivity test that may assist in understanding the potential result of a levee failure.

The inundation extent and properties flooded above floor for Levee Failure Scenario 01 and 02 are shown in Figure 10-31 and Figure 10-32 respectively.

In the area of Levee Failure 01, the existing conditions results show 10 buildings flooded above floor (see Figure 10-30). Levee Failure Scenario 01 resulted in 29 buildings becoming flooded above floor and 55 below floor. All the building inundation in Warracknabeal was limited to the area of levee failure with flood water unable to re-enter Yarriambiack Creek, being trapped outside of the levee.

In the area of Levee Failure 02, the existing conditions results show 5 buildings flooded above floor (see Figure 10-30). Levee Failure Scenario 02 resulted in 13 buildings becoming flooded above floor and 36 below floor. Similar to Failure Scenario 01, all the building inundation in Warracknabeal was limited to the area of levee failure with flood water unable to re-enter Yarriambiack Creek, being trapped outside the levee.

These results demonstrate the residual risk of living behind a levee. There is a danger that complacency may set in with residents and authorities lulled into a false sense of security, with the assumption that all risk has been removed because they are behind a levee. The reality is that larger events can occur and overtop or outflank a levee, and a levee can fail. For these reasons it is imperative that a levee system is maintained, that flood related planning conditions are in place and that communities are educated to their risk and understand what it means for them.

Figure 10-30 Levee failure locations

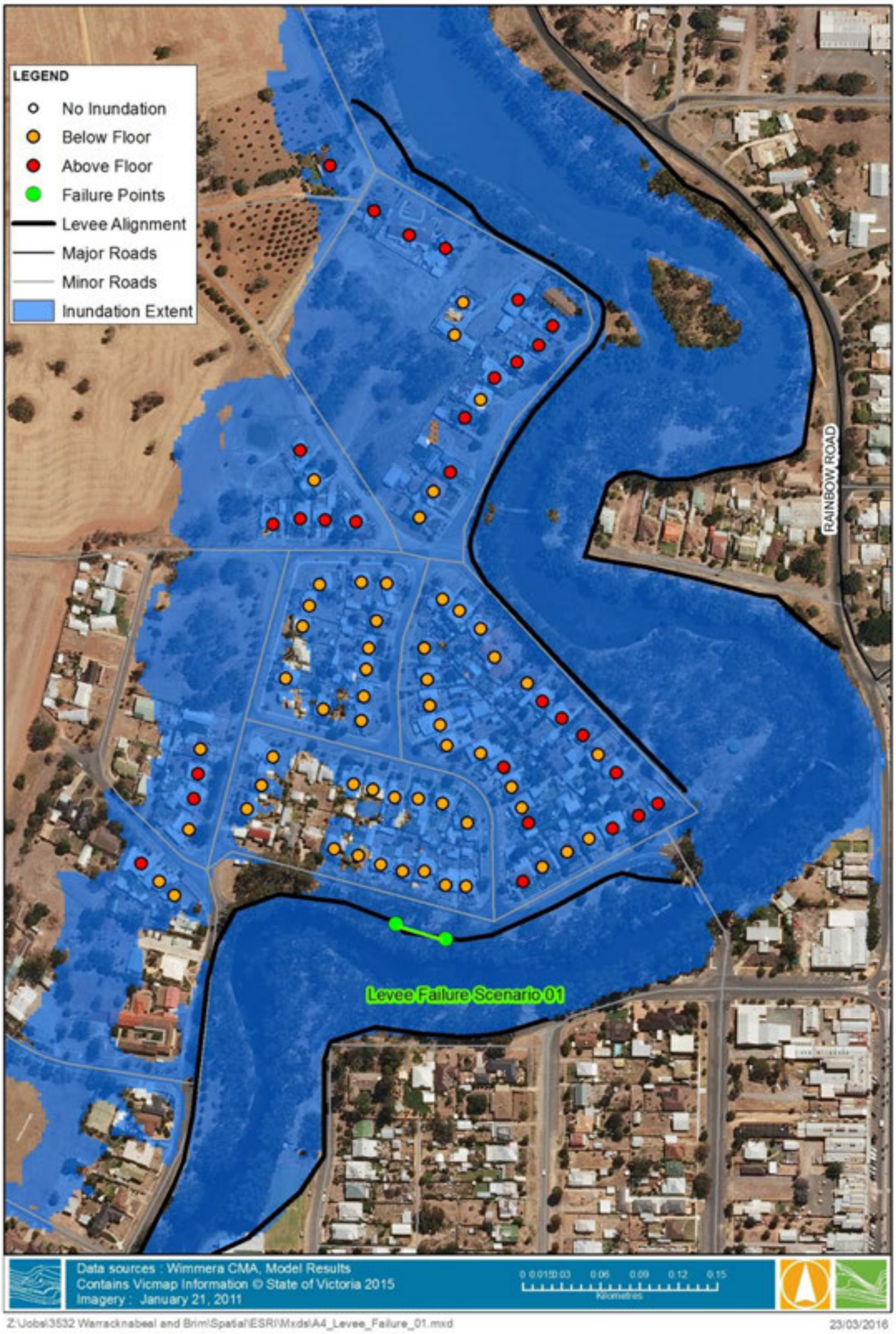


Figure 10-31 Levee Failure Scenario 01 – Inundation extent and properties flooded above floor

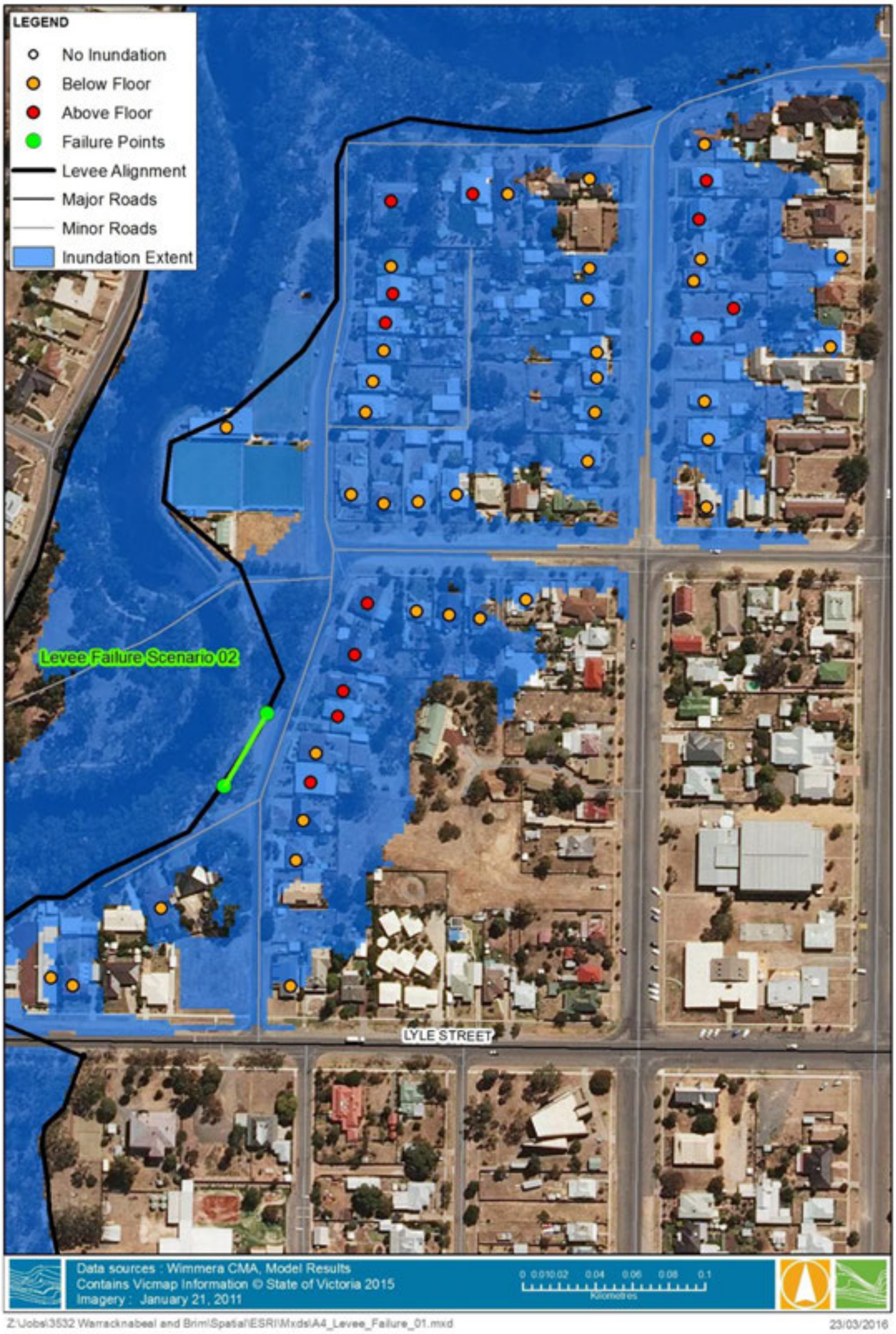


Figure 10-32 Levee Failure Scenario 02 – Inundation extent and properties flooded above floor

Structure Blockage

To assess the potential impact of structure blockage the major Yarriambiack Creek structures were blocked to 100% as a sensitivity test. The blocked structures included Dimboola Road, Jamouneau Street and the Warracknabeal Weir.

The difference in flood level caused by blockage of all three structures is shown in Figure 10-33.

There is a significant increase in inundation extent north of Kelsall Street and with the maximum increase in flood levels observed upstream of the Warracknabeal Weir at around 0.2-0.25 m.

The blockage of all three structures simultaneously and to 100% is over-conservative, but provides a worst case scenario.

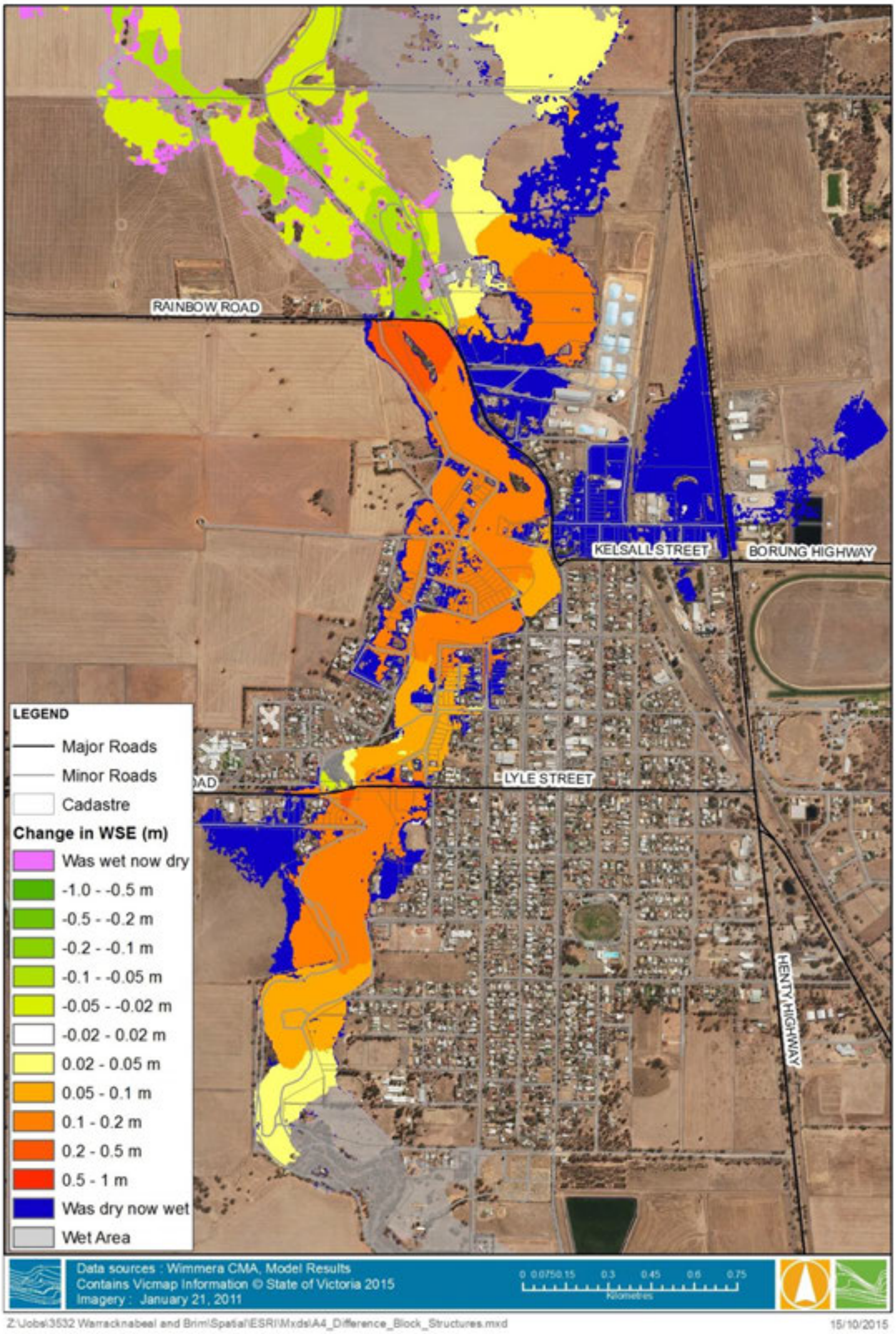


Figure 10-33 Structure Blockage – Change in flood levels as a result of the blockage

10.3.5 Flood Damages Assessment

Overview

A flood damage assessment for the study area was undertaken using the range of design events modelled (20%, 10%, 5%, 2%, 1% and 0.5% AEP design events) for existing conditions (i.e. with current remnant levees). The damage assessment was used to determine the monetary flood damage for the design floods.

The flood damage assessment was also undertaken for Combined Option 01, the recommended mitigation package.

Water Technology has developed an industry best practice flood damage assessment methodology that has been previously utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. The NSW Office of Environment and Heritage stage damage curves are utilised, which represent far superior damage estimates at low depths above floor and below floor than earlier stage damage curves. Water Technology utilises WaterRide to undertake the property inspection and apply the appropriate stage damage curves.

The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths and damages of flood affected roads for each event were also calculated.

Agricultural damages were included in the damages assessment of the entire study area. Agricultural areas were delineated by areas classified as Farm Zone. The predominant agricultural activity along Yarriambiack Creek is broad acre cropping, a damages rate of $150/Ha inundated was applied within the Farm Zone, this value was determined from the Rapid Appraisal Method[28].

The Average Annual Damage (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. This is effectively a measure of the amount of money that must be put aside each year in readiness for when a flood may happen in the future.

The AAD was calculated for the entire study area and within Warracknabeal township alone. This enables the modelled mitigation options for Warracknabeal to be compared to the existing conditions damages in the township alone rather than including the broader study area agricultural damages etc.

The damages assessment shows a slightly different number of buildings flooded above and below floor to that documented in the Flood Intelligence Report and previous discussion of the number of buildings flooded above floor. This is due to the removal of sheds (unless commercial) and multiple buildings on one allotment. The damages estimates are an assessment of the average monetary damage with ancillary buildings included in these averages. The Flood Intelligence Report includes these buildings because they are significant for flood response.

[28] DNRE (2000), Rapid Appraisal Method

Existing Conditions

The flood damage assessment was separated into two areas; the entire study area and the Warracknabeal township. This separation was used to enable easier comparison and assessment for the Warracknabeal township alone.

The flood damage assessment for existing conditions over the entire study area is shown below in Table 10-7. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$144,777.**

The flood damage assessment for existing conditions within the Warracknabeal township alone is shown below in Table 10-8. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$45,000.**

Table 10-7 Existing conditions damages over the entire study area

ARI (years) AEP	200yr 0.5%	100yr 1%	50yr 2%	20yr 5%	10yr 10%	5yr 20%
Residential Buildings Flooded Above Floor	46	11	4	0	0	0
Commercial Buildings Flooded Above Floor	9	3	1	0	0	0
Properties Flooded Below Floor	241	166	76	9	6	4
Total Properties Flooded	**296**	**180**	**81**	**9**	**6**	**4**
Direct Potential External Damage Cost	$884,000	$479,000	$168,000	$15,000	$3000	$3,000
Direct Potential Residential Damage Cost	$2,365,000	$560,000	$181,000	$0	$0	$0
Direct Potential Commercial Damage Cost	$441,000	$15,000	$1,000	$0	$0	$0
Total Direct Potential Damage Cost	**$3,690,000**	**$1,054,000**	**$351,000**	**$15,000**	**$3,000**	**$3,000**
Total Actual Damage Cost *(0.8*Potential)*	**$2,952,000**	**$843,000**	**$281,000**	**$12,000**	**$3,000**	**$3,000**
Rural Damage Cost	**$630,000**	**$487,000**	**$330,000**	**$170,000**	**$115,000**	**$73,000**
Infrastructure Damage Cost	**$1,309,000**	**$899,000**	**$557,000**	**$291,000**	**$212,000**	**$169,000**
Total Cost	**$4,890,000**	**$2,230,000**	**$1,168,000**	**$473,000**	**$329,000**	**$244,000**

Average Annual Damage (AAD)	**$144,777**

Table 10-8 Existing conditions damages over the Warracknabeal township

ARI (years) AEP	200yr 0.5%	100yr 1%	50yr 2%	20yr 5%	10yr 10%	5yr 20%
Residential Buildings Flooded Above Floor	46	11	4	0	0	0
Commercial Buildings Flooded Above Floor	9	3	1	0	0	0
Properties Flooded Below Floor	238	163	73	8	3	3
Total Properties Flooded	**293**	**177**	**78**	**8**	**3**	**3**
Direct Potential External Damage Cost	$857,000	$455,000	$148,000	$13,000	$5,000	$3,000
Direct Potential Residential Damage Cost	$2,365,000	$560,000	$181,000	$0	$0	$0
Direct Potential Commercial Damage Cost	$441,000	$15,000	$1,000	$0	$0	$0
Total Direct Potential Damage Cost	**$3,663,000**	**$1,030,000**	**$331,000**	**$13,000**	**$5,000**	**$3,000**
Total Actual Damage Cost *(0.8*Potential)*	**$2,930,000**	**$824,000**	**$265,000**	**$10,000**	**$4,000**	**$2,000**
Infrastructure Damage Cost	**$441,000**	**$298,000**	**$195,000**	**$73,000**	**$58,000**	**$50,000**
Total Cost	**$3,371,872**	**$1,121,845**	**$459,806**	**$83,641**	**$62,308**	**$52,449**

Average Annual Damage (AAD)	**$45,000**

Combined Mitigation Package

As detailed in Section 10.3.4, the Combined Mitigation Package comprises of a series of levees either side of Yarriambiack Creek ensuring water is held within the waterway. The levees prevent all above floor and below floor inundation within the township during the 1% AEP event.

The flood damage assessment for the Combined Mitigation Package within the Warracknabeal township is shown below in Table 10-9. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$9,000.** The number of properties flooded below floor for is indicative of properties with inundation within their property boundaries, during this assessment damage is attributed to property if it is inundated without regard to the slope of size of the allotment. For this reason actual monetary damages in the mitigation scenario are likely to be lower than that stated in this report.

Table 10-9 Combined Mitigation Package damages over the Warracknabeal township

ARI (years) AEP	200yr 0.5%	100yr 1%	50yr 2%	20yr 5%	10yr 10%	5yr 20%
Residential Buildings Flooded Above Floor	0	0	0	0	0	0
Commercial Buildings Flooded Above Floor	1	1	0	0	0	0
Properties Flooded Below Floor	24	19	15	5	0	0
Total Properties Flooded	**25**	**20**	**15**	**5**	**0**	**0**
Direct Potential External Damage Cost	$93,000	$47,000	$29,000	$0	$0	$0
Direct Potential Residential Damage Cost	$0	$0	$0	$0	$0	$0
Direct Potential Commercial Damage Cost	$19,555	$7,452	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$112,594**	**$54,743**	**$28,000**	**$00**	**$0**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$90,000**	**$44,000**	**$22,000**	**$0**	**$0**	**$0**
Infrastructure Damage Cost	**$221,000**	**$175,000**	**$137,000**	**$77,000**	**$0**	**$0**
Total Cost	**$311,000**	**$219,000**	**$159,000**	**$77,004**	**$0**	**$0**

Average Annual Damage (AAD)	$9,000

10.3.6 Non – Economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, i.e. damages that are easily quantified. In addition to those damages, it is widely recognised that individuals and communities also suffer significant non-monetary damage, i.e. emotional distress, health issues, etc.

There is no doubt that the intangible non-monetary flood related damage in and along Yarriambiack Creek is high. The benefit-cost analysis presented in this report has not considered this cost. Any decisions made that are based on the benefit cost ratios need to understand that the true cost of floods in and along Yarriambiack Creek is far higher than the economic damages alone. The amount of time volunteered and equipment/material cost donated by the community to construct the temporary levees during the January 2011 flood event was also high, and was not factored into the flood damages cost included above. These intangible costs have the effect of increasing the benefit-cost ratio, improving the argument for approving a mitigation scheme at Warracknabeal.

10.4 Benefit-Cost Analysis

A benefit-cost analysis was undertaken to assess the economic viability of the Combined Mitigation Package. An indicative benefit-cost ratio was based on the construction cost estimates below, and Average Annual Damages calculated above.

10.4.1 Mitigation Option Cost

The cost estimate for the permanent sections of the combined mitigation package is shown in Table 10-10 with temporary sections shown in Table 10-11. Water Technology has undertaken many levee functional designs and costings, we have developed standard spreadsheets based on industry rates from Melbourne Water and a variety of material suppliers. A 30% contingency cost was included along with engineering and administration costs. It should be noted that these costs are based on estimated rates and should be checked during the detailed design phase. Site specific issues such as underground services and community negotiations around access to the creek and land compensation may increase the cost and will need to be further considered during detailed design.

The Victorian Levee Guidelines has standard recommendations for levee crest width (2 m), batter slopes (3:1 batter on water side, 2:1 on dry side) and clay core with cut-off trench requirements. Cut-off trench requirements are negotiable depending on the levee material, but if a sandy material is used with no cut-off trench then a wider crest and batter slope is recommended to avoid piping failure. The levee proposed meets these requirements with a 2 m crest width, 3:1 batter slopes on both sides. Further detail is included in Section 10.5.

The levee was designed to the 1% AEP level with the inclusion of a 100 mm freeboard as specified by Yarriambiack Shire Council. This is less than the 0.5% AEP level, and less than the typical freeboard allowance, however Yarriambiack Shire Council will erect temporary sections of levee and an increase in levee height via temporary measures such as sandbagging, if a flood event exceeding a 1% AEP is forecast.

An annual maintenance cost was factored in for the levee works. The annual maintenance allowance includes half a days work to mow the levee and 2 days work to patch up sections that might need seeding or filling of rabbit burrows, etc. Maintenance on this relatively small levee is estimated to be low. An annual allowance of **$3,000** has been made, this is anticipated to be combined with the general Yarriambiack Shire Council Yarriambiack Creek maintenance works.

The cost of the levee has been separated into permanent and temporary portions. Permanent portions were costed with the inclusion of a clay core and cut-off trench, while temporary sections of levee were costed based on standard levee construction rates excluding topsoiling and grassing.

The estimated capital cost of the permanent sections of levee is **$471,780**. The estimated cost of the temporary section of levee is **$163,806.** The temporary levee cost was assumed to occur once within the levee's design life of 200 years. As there are no real engineering/administrative costs for the temporary levee they have been excluded from the costing. The immediate cost of constructing the levee is likely to be paid for by Yarriambiack Shire Council.

Table 10-10 Mitigation Cost Breakdown – Permanent Works

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost
1	230	0.5	522	$16,514
2	117	0.5	254	$8,093
4	511	0.4	933	$30,257
5	824	0.5	1993	$62,658
6	830	0.5	1895	$48,783
9	824	0.5	2300	$70,966
11	694	0.4	1276	$41,255
13	470	0.4	553	$15,161
Culvert and Value allowance				$10,000
Sub-total 'A'				$303,688
'A' x Engineering Fee @ 15%				$45,553
Sub-total 'B'				$349,241
'B' x Administration Fee @ 9%				$31,432
Sub-total 'C'				$380,673
'A' x Contingencies @ 30%				$91,106
FORECAST CAPITAL EXPENDITURE				**$471,780**
ANNUAL MAINTENANCE ALLOWANCE				**$3,000**

Table 10-11 Mitigation Cost Breakdown – Temporary Works

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost
1	230	0.03	131	$4,806
2	117	0.06	75	$2,718
4	511	0.09	361	$12,971
5	824	0.14	683	$24,161
6	830	0.09	568	$42,549
11	694	0.13	565	$20,022
13	470	0.09	335	$76,547
7	150	0.19	156	$3,898
8	238	0.24	179	$4,480
10	727	0.5	1640	$24,930
12	453	0.5	997	$24,930
14	505	0.2	335	$8,367
FORECAST EXPENDITURE				**$163,806**

10.4.2 Benefit-Cost Ratio

The results of the benefit-cost analysis are shown below in Table 10-12 including the cost of the temporary levee and Table 10-13 excluding the cost of the temporary levee. For this analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life. The benefit-cost ratio should ideally be equal to or greater than 1, meaning that the long term benefit of flood mitigation equals or exceeds the long term costs.

Table 10-12 Benefit Cost Analysis – Including temporary levee

	Existing Conditions	Combined Mitigation Package
Average Annual Damage	$45,000	$9,000
Annual Maintenance Cost	-	$3,000
Annual Cost Savings	-	$25,000
Net Present Value	-	$351,560
Cost of permanent mitigation		$471,780
Cost of temporary mitigation		$163,806
Capital Cost of Mitigation	-	$635,586
Benefit-Cost Ratio	**-**	**0.73**

Table 10-13 Benefit Cost Analysis – Excluding temporary levee

	Existing Conditions	Combined Mitigation Package
Average Annual Damage	$45,000	$9,000
Annual Maintenance Cost	-	$3,000
Annual Cost Savings	-	$25,000
Net Present Value	-	$351,560
Capital Cost of Mitigation	-	$471,780
Benefit-Cost Ratio	**-**	**0.98**

10.5 Concept Design

Concept design of the Warracknabeal levee arrangements were completed in consultation with Wimmera CMA, Yarriambiack Shire Council and the Project Steering Committee.

The levee comprises of 14 sections of levee, 9 permanent sections and 5 temporary sections. The section of permanent levee has been set at the 1% AEP level plus a 0.1 m freeboard. The temporary sections of levee are at the 0.5% AEP level, additionally, if an event larger than a 1% AEP event was forecast the levee height would be increased with temporary measures such as sandbags or tipped earth on top of the levee. This is included in the Flood Intelligence Report and costing is undertaken in the Benefit-Cost Analysis.

The concept design and details around each section of levee is detailed using A1 maps in Appendix A. The Appendix A mapping includes levee alignments, type of levee proposed in each section, length, max height and average height. A colour coded map of the levee heights is also included.

In sections of temporary levee it is suggested colour coded posts be installed indicating the height at which the levee should be constructed.

Details around each of the 14 levee sections are shown in Table 10-14, the temporary levee sections are highlighted in green.

Concept levee alignments area also shown in Figure 10-34, a full size A1 drawing of the design is shown in Appendix F.

Table 10-14 Levee details

Levee Number	Length (m)	Max. Height (m) (including 100 mm freeboard on permanent sections)	Average Height (m)	Notes
1	230	0.9	0.5	Permanent earthen levee protecting 2 properties from below floor inundation
2	117	0.7	0.50	Permanent earthen levee protecting one shed from above floor inundation, township levees increase inundation at this location without protection
4	512	0.7	0.40	Permanent earthen levee, school levee exists at a sufficient height
5	825	1.0	0.5	Permanent earthen levee, potential for road level increases, very narrow at the rear of the bowling club
6	830	0.7	0.3	Permanent earthen levee, potential to build into existing road shoulder
7	150	0.3	0.2	Temporary earthen levee, only required for events greater than 1% AEP
8	237	0.5	0.20	Temporary earthen levee, only required for events greater than 1% AEP
9	445	1.2	0.5	Permanent earthen levee, currently partially constructed
10	727	0.8	0.5	Temporary/walking track
11	694	0.9	0.5	Permanent earthen levee, potential to use road median strip
12	450	1.0	0.5	Temporary earthen levee, only required for events greater than 1% AEP
13	470	0.8	0.4	Permanent earthen levee
14	541	0.4	0.1	Temporary earthen levee, only required for events greater than 1% AEP
Total Length of 6,228 m (4,123 m permanent/2,105 m temporary)				

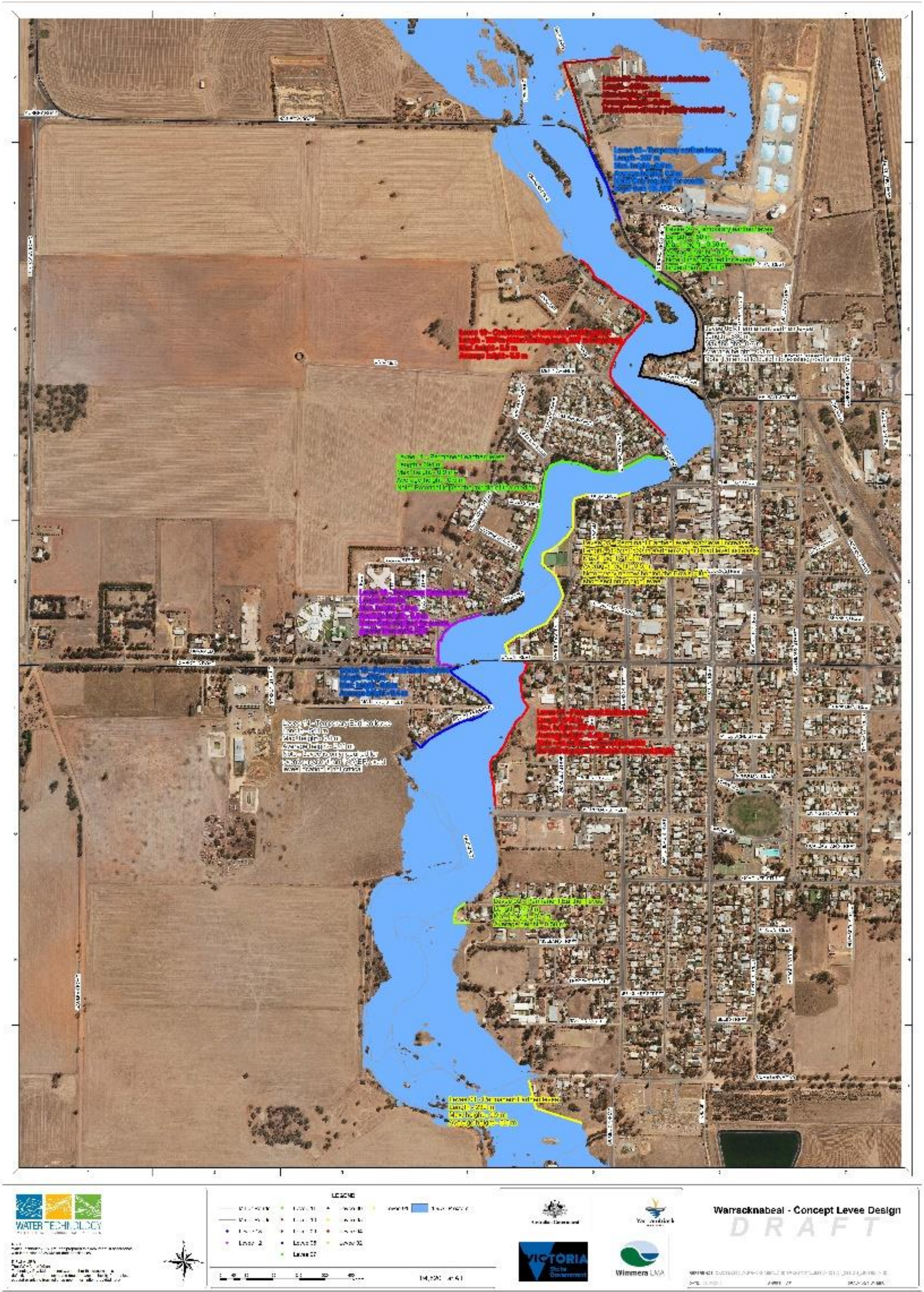


Figure 10-34 Warracknabeal Concept Levee Design (enlarged maps provided separately)

10.6 Detailed Design

Detailed design for the Warracknabeal Levee was completed by Price Merrett Consulting. Their design was based on the concept design above with further consideration to detailed feature survey of roads, community input on levee construction type and exact alignment. This design was provided as a separate document to the Final Report.

11. CONCLUSION AND RECOMMENDATIONS

The Warracknabeal Flood Investigation successfully produced accurate flood mapping and flood intelligence outputs for Yarriambiack Creek from Jung to East Galaquil Road north of Brim. The study produced the following outputs:

- Flood Intelligence reporting, allowing update to the YSC MFEP, improving the ability for YSC and VICSES to respond to a flood event.
- Annual average flood damages, improving the understanding of the cost of flooding to the study area.
- Detailed levee design for the township of Warracknabeal including benefit-cost analysis, providing a solution to reduce flood damages.
- An assessment of the current flood warning systems and recommended changes allowing for an increase in flood awareness and improved response.
- An assessment of the YSC Planning Scheme and recommendations to allow for better control of floodplain development and community understanding of flood risk.
- Design modelling and mapping for the 20%, 10, 5%, 2%, 1% and 0.5% AEP flood events and the Probable Maximum Flood, and a relationship between flows in the Wimmera River at Glenorchy and flooding along Yarriambiack Creek.
- A more informed, aware and resilient community through community consultation meetings, extensive social and print media articles.

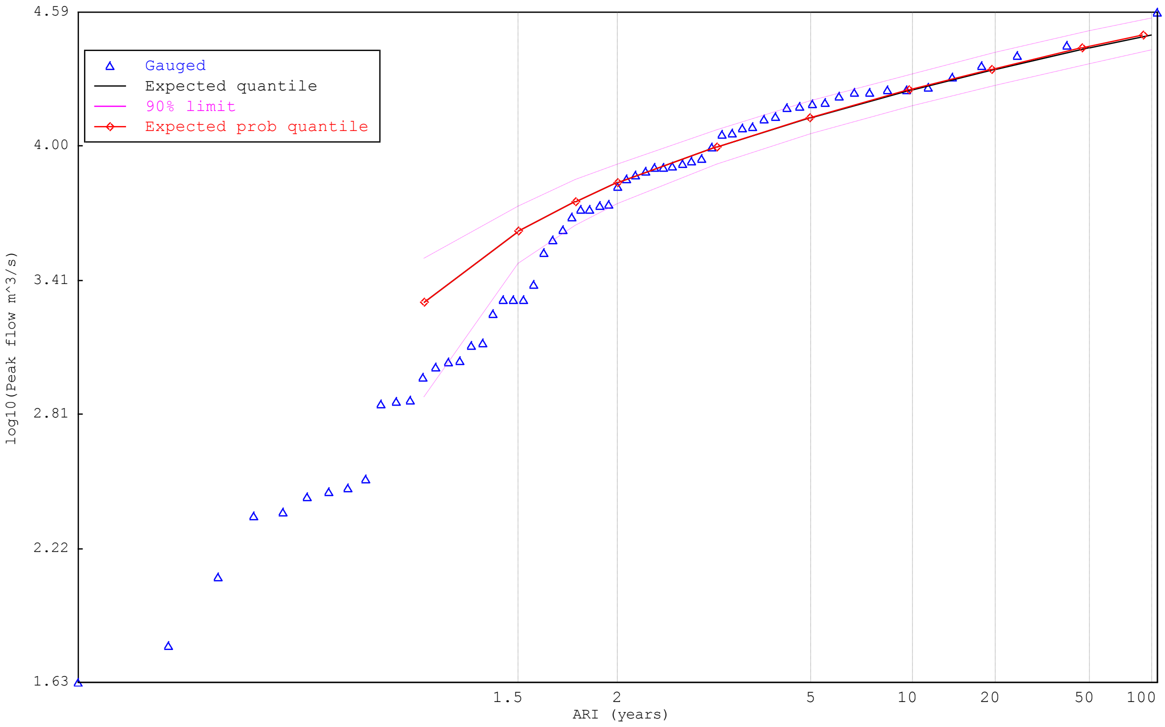
The following list of recommendations are made to allow Wimmera CMA and Yarriambiack Shire Council to continually increase the level of flood preparedness for their community:

- ***Recommendation 1:*** Update the Yarriambiack Creek at Murtoa streamflow gauge rating curve with the modelled water level and flow relationship developed as part of this project. This update should be made with the rating curve information used by DELWP and BoM.
- ***Recommendation 2:*** Update the planning scheme LSIO and FO layers using the mapping products from this investigation.
- ***Recommendation 3:*** Adopt the flood intelligence information produced as part of this project in the YSC MFEP.
- ***Recommendation 4:*** Provide readily available details to local communities of their flood risk through the Wimmera CMA website, Section 32 certificates (via planning scheme) and ongoing community education.
- ***Recommendation 5:*** Educate the communities in the study area about aspects of the TFWS including their flood risk, local flood warning triggers for action and the warnings that they will receive if a flood is imminent.
- ***Recommendation 6:*** Combine the old Jung gauge rating (for low flows) with new modelled rating (for flood flows). DELWP and BoM to adopt this rating curve for flood forecasting and streamflow monitoring.
- ***Recommendation 7:*** A new streamflow gauge with ERRTS telemetry and/or Next G be installed at the Ailsa Road crossing of Yarriambiack Creek. Consideration should be given to whether this gauge is a permanent or temporary unit but it must be specific to the site. This gauge should be tied to AHD and the flood mapping outputs of this study. New gauge boards are also required to be installed and tied to AHD. Wimmera CMA and BOM to review the possibility of providing the Ailsa Rd stream gauge information on their website, developing flood class levels for the Ailsa Road stream gauge that provide flood warning for Warracknabeal and the development of quantitative prediction for Ailsa Rd gauge based upon Warracknabeal flood model.

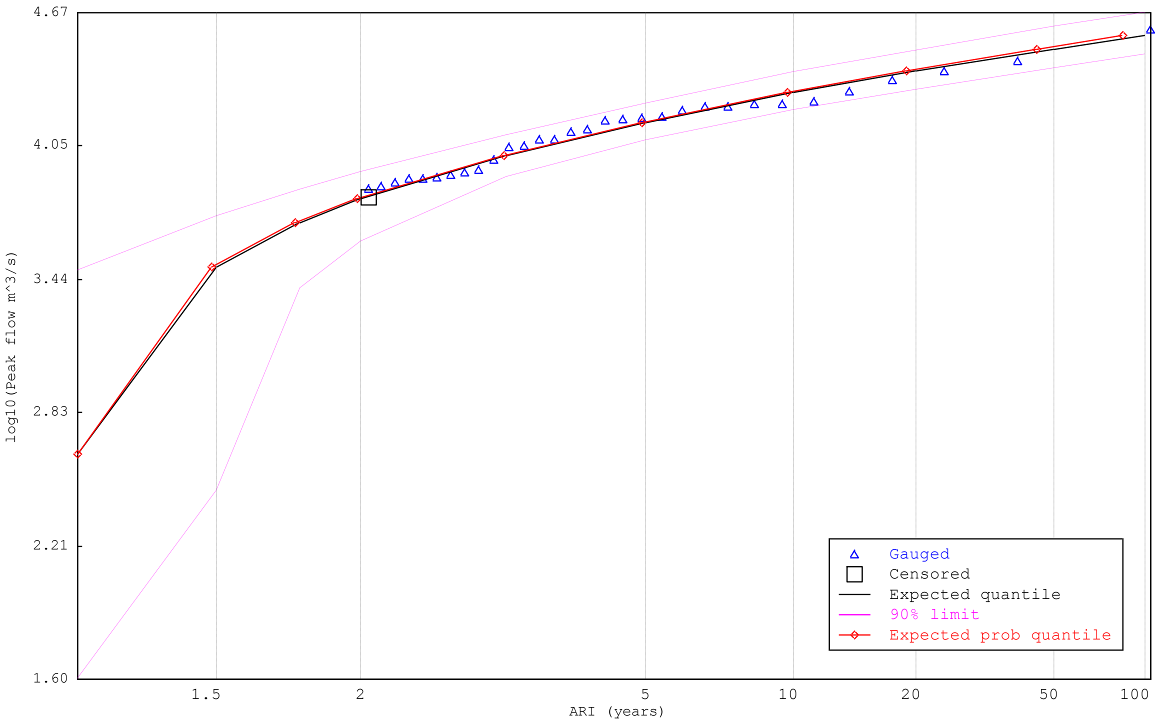
- ***Recommendation 8:*** Wimmera CMA and BoM investigate providing flood forecasting at the Jung gauges and, in the interim, provide detailed information to all agencies to determine flood forecasting using charts that relate stream height to AEP, and timing of flood flows to AEP.
- ***Recommendation 9:*** Further develop the community flood observers crowdsourcing program to enable people to provide real-time flood height observations to the ICC.
- ***Recommendation 10:*** Establish a 'phone tree' or similar localised communication method for isolated properties in the vicinity and downstream of Brim.
- ***Recommendation 11:*** Explore the possible uptake of a localised smartphone flood warning app for the study area.
- ***Recommendation 12:*** Move the gauge boards at Lah to a location that can be viewed during time of flood.
- ***Recommendation 13:*** Review the condition location of all gauge boards along Yarriambiack Creek. All boards should be viewable during a flood. Replace or move gauge boards as required. Install signage next to the all gauge boards that relates the gauge height to a flood magnitude and historical flood levels.
- ***Recommendation 14:*** Establish gauge boards at remaining Yarriambiack Creek crossings relating to AHD with marked levels for design (all AEPs) and historical events.
- ***Recommendation 15:*** Ensure that all people requiring assistance in Yarriambiack Shire are in the Vulnerable Persons Register.
- ***Recommendation 16:*** Engage (e.g. by doorknocking) with all people in the Brim community if a flood is imminent.
- ***Recommendation 17:*** Identify and implement ways for community members in the study area to participate in the establishment, operation and review of the TFWS.
- ***Recommendation 18:*** Ensure that the integration of the TFWS is included as part of future TFWS reviews in the study area.
- ***Recommendation 19:*** Further investigate the potential to upgrade drainage under the Borung Highway east of Warracknabeal
- ***Recommendation 20:*** Further investigate improved drainage under the Henty Highway at Brim
- ***Recommendation 21:*** Contact landholders in Thomas and Molyneaux Streets (between Gardiner and Woolcock) and Arnold, Milbourne, Franklin, Lyle and Shank Streets (between the Henty Highway and Devereux Street) to discuss stormwater issues and impacts during January 2011
- ***Recommendation 22:*** Apply for funding to construct the levee design proposed as part of this project.

APPENDIX A FFA DISTRIBUTIONS

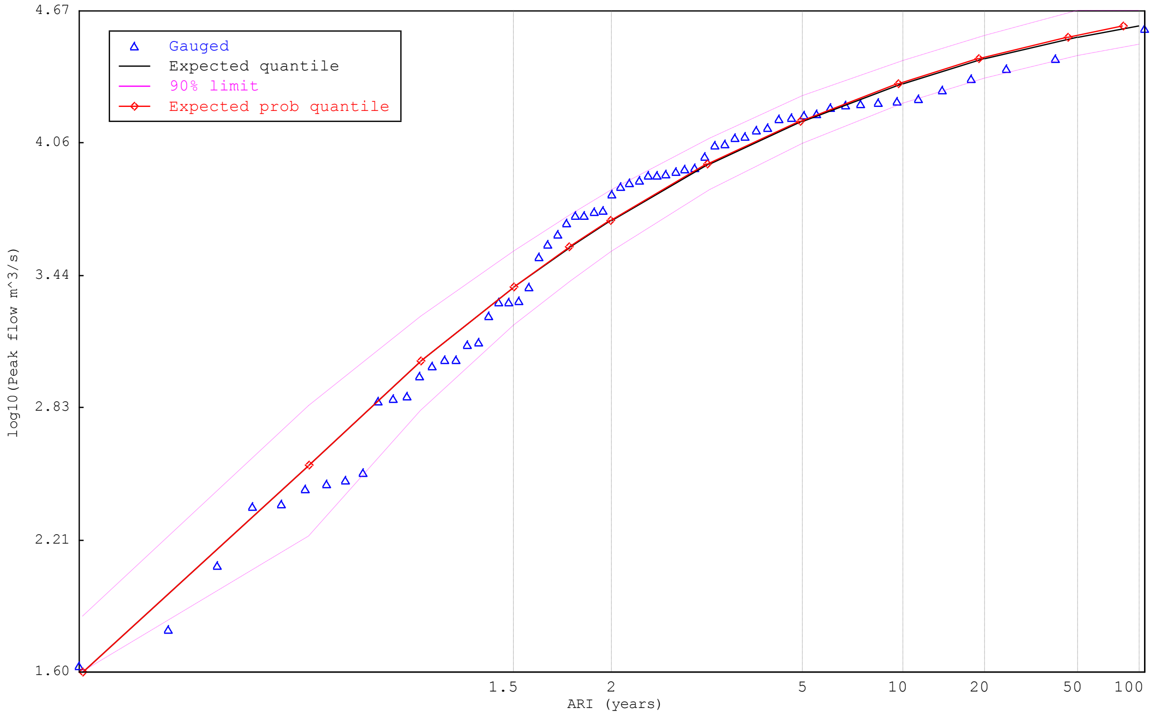
Gumbel – Raw Annual Series



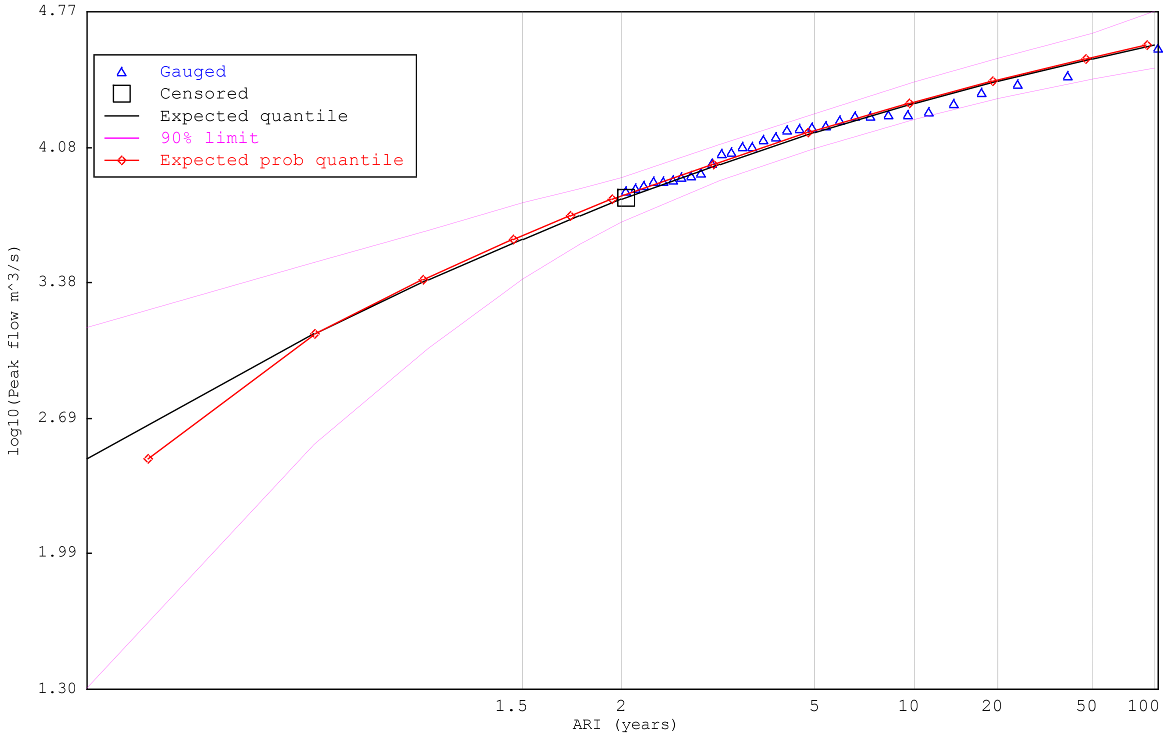
Gumbel – Censored Annual Series



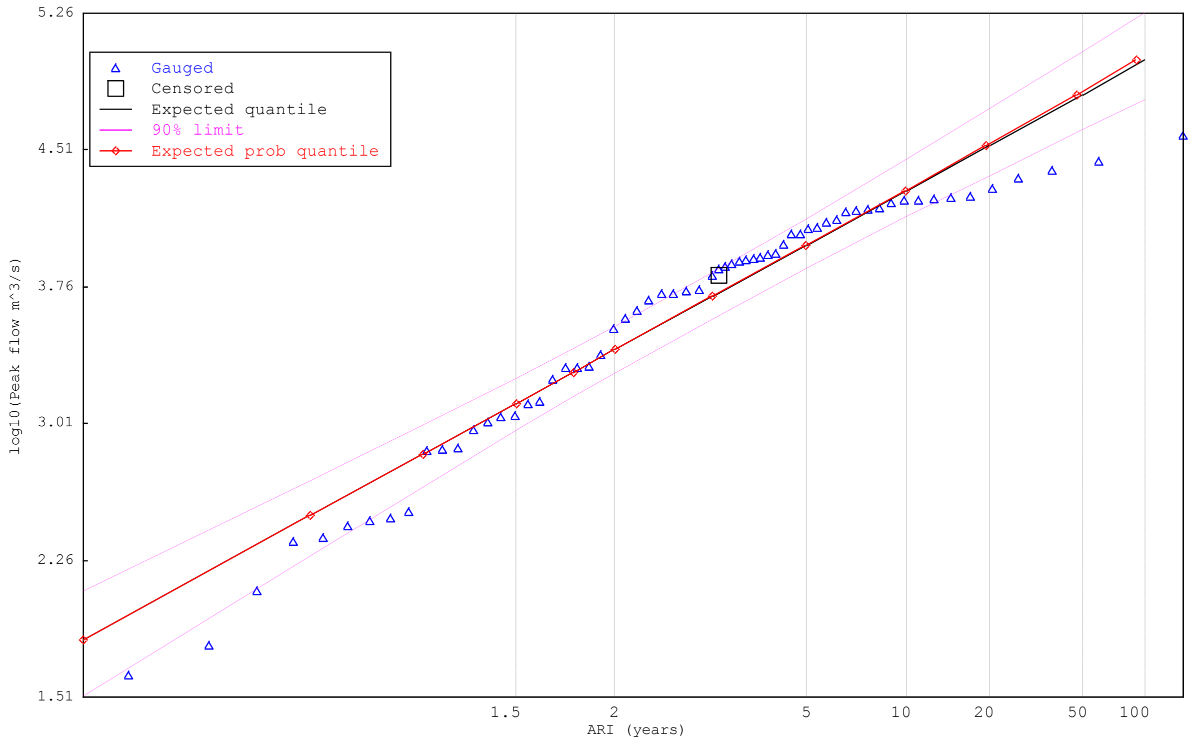
LP3 – Raw Annual Series



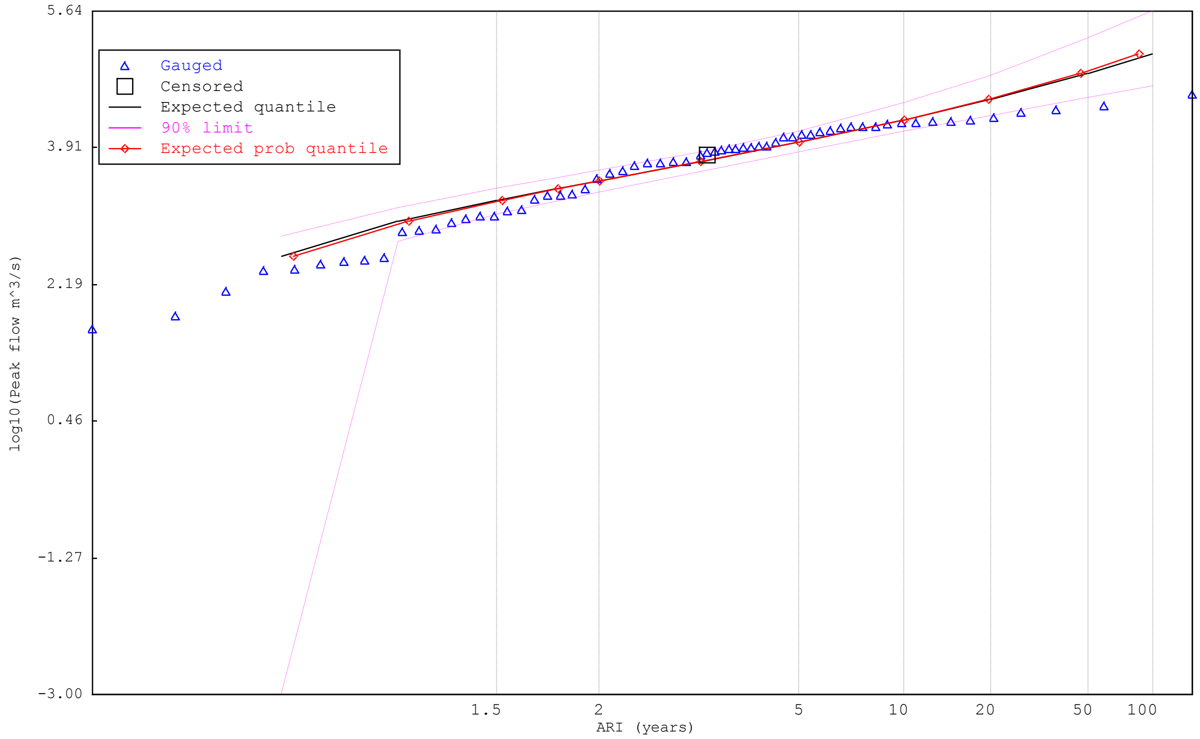
LP3 – Censored Annual Series



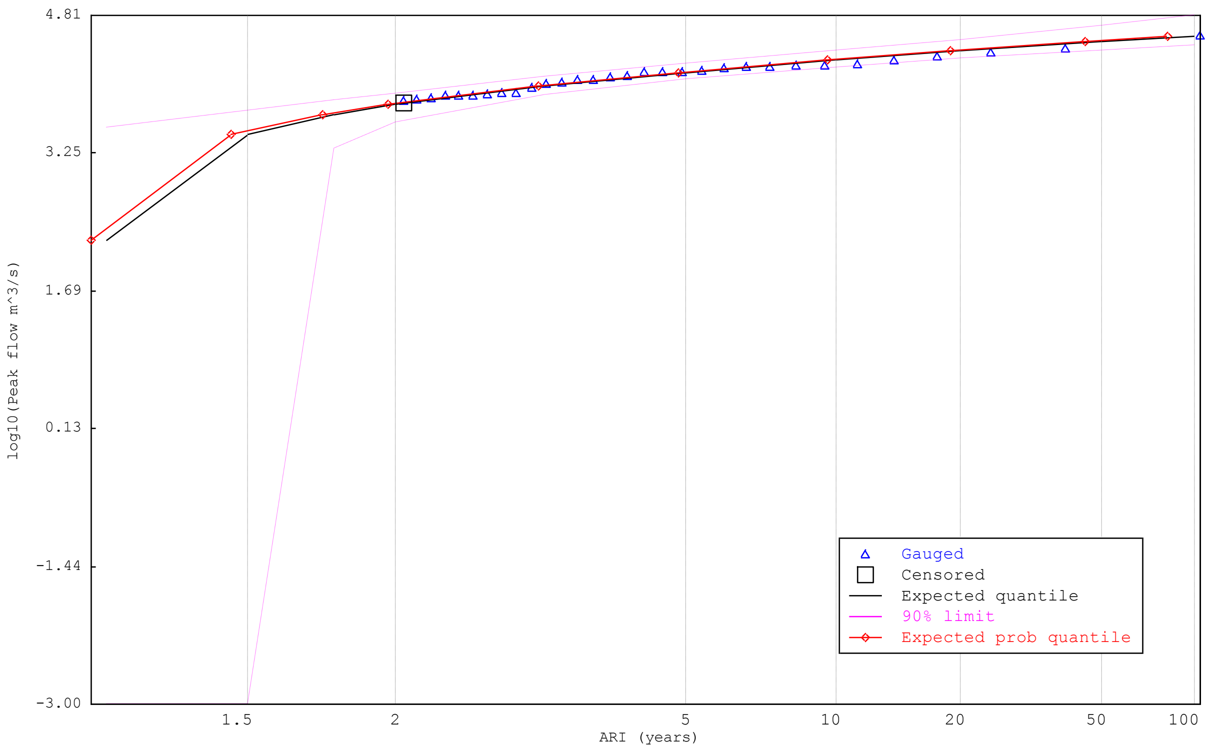
Log Normal – Raw Annual Series



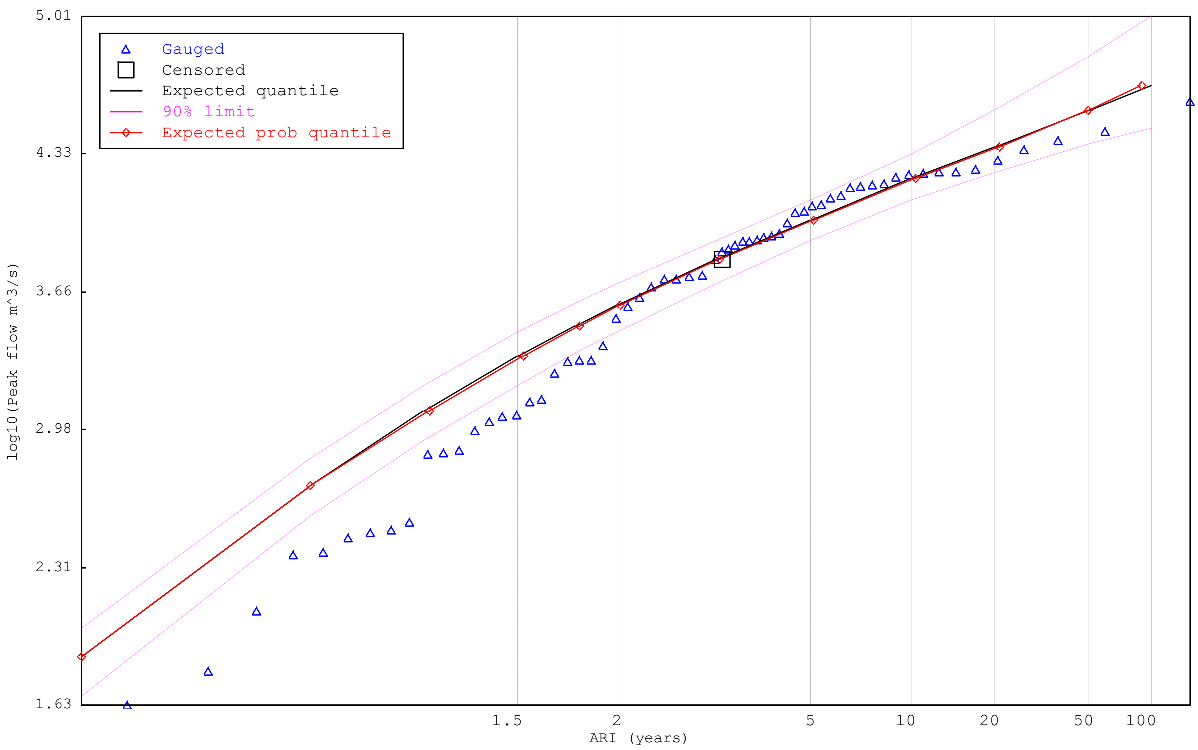
GEV – Raw Annual Series



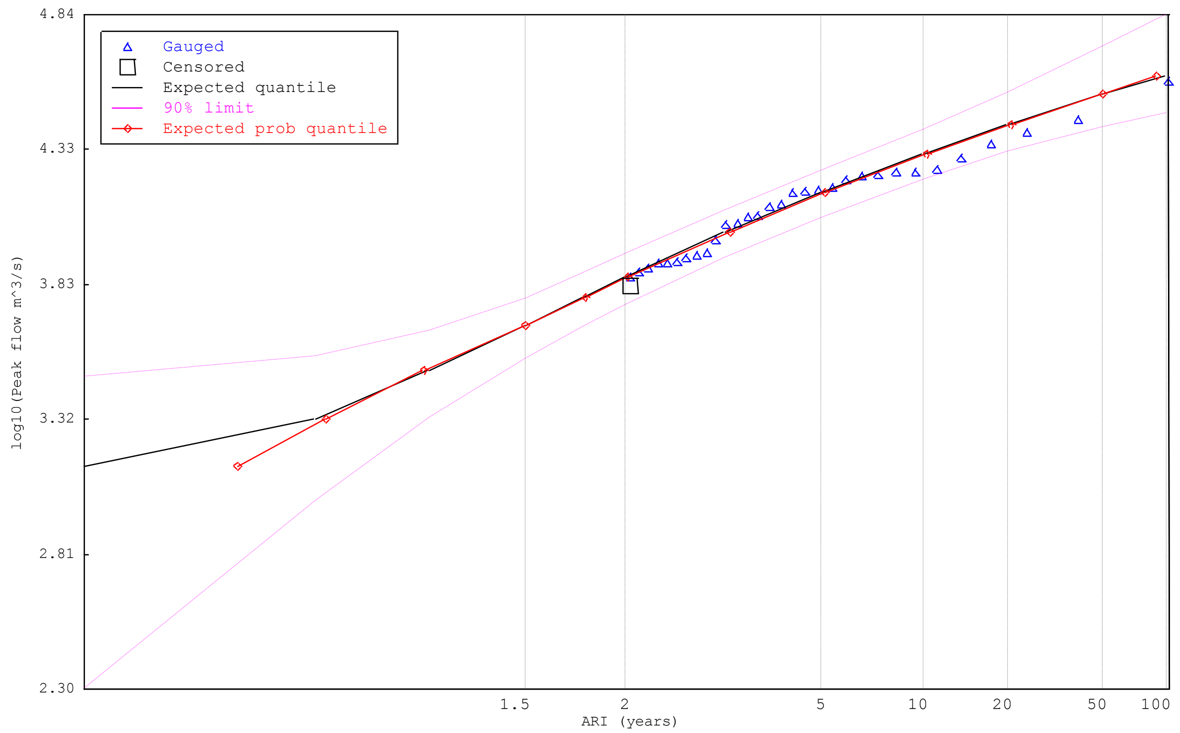
GEV – Censored Annual Series



GP – Raw Annual Series

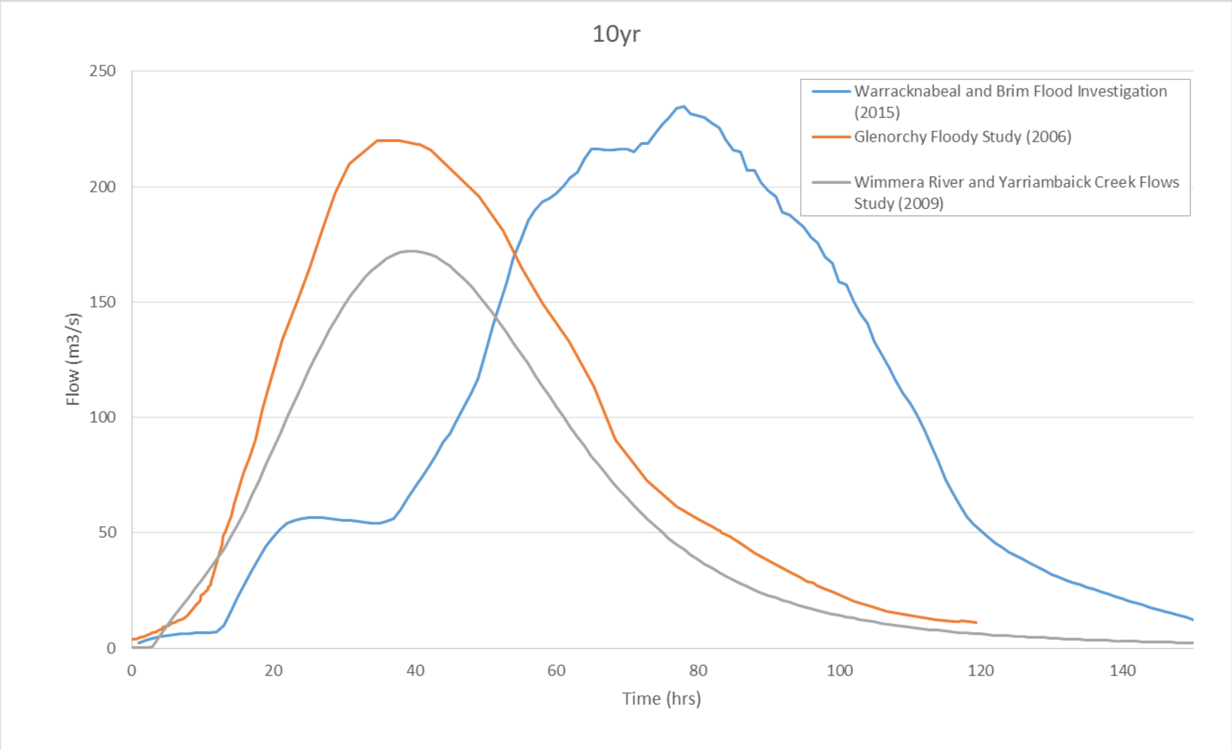


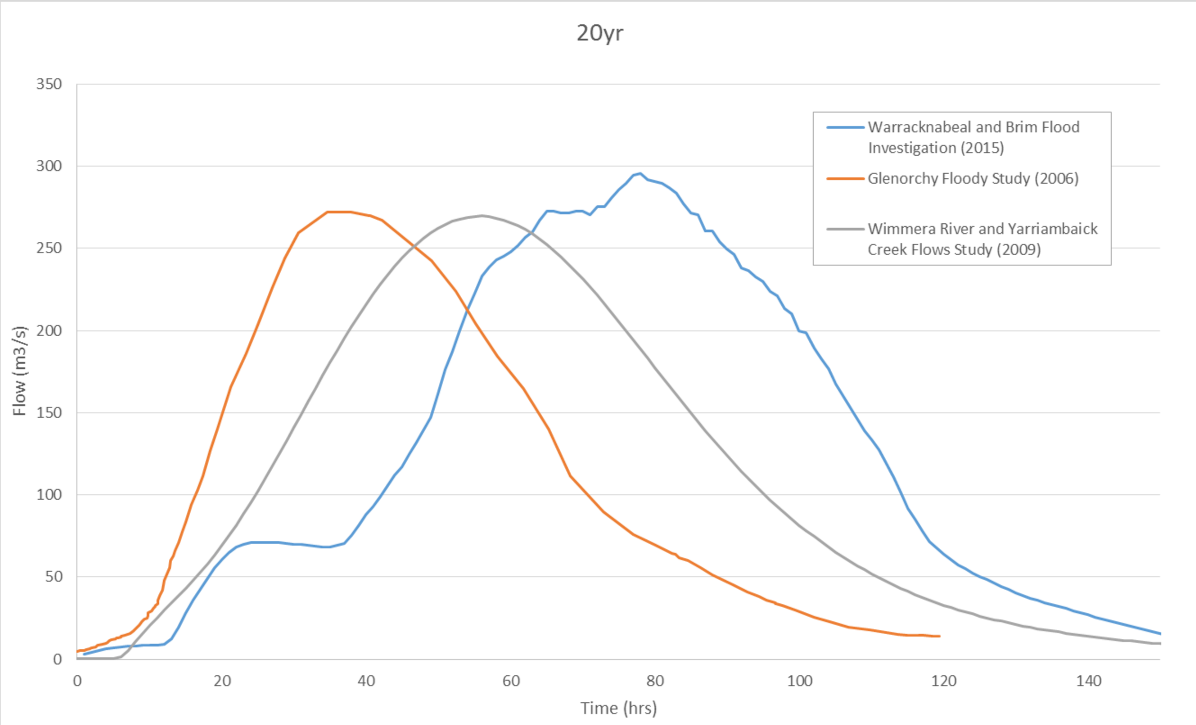
GP – Censored Annual Series

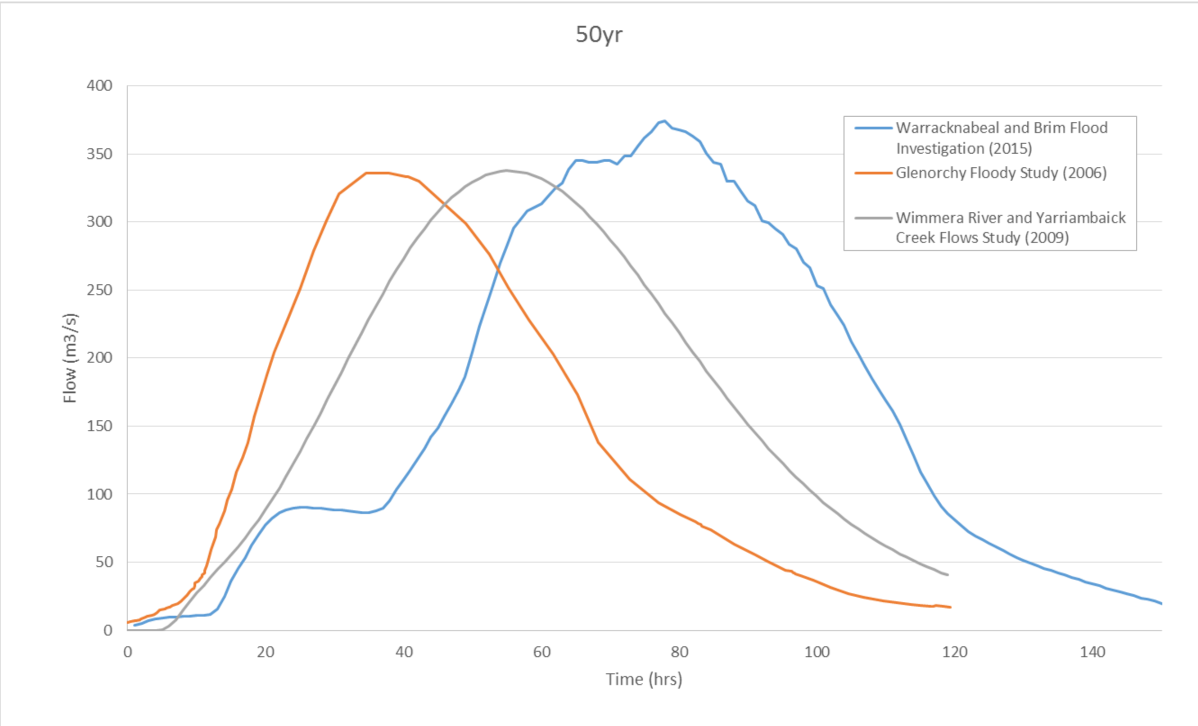


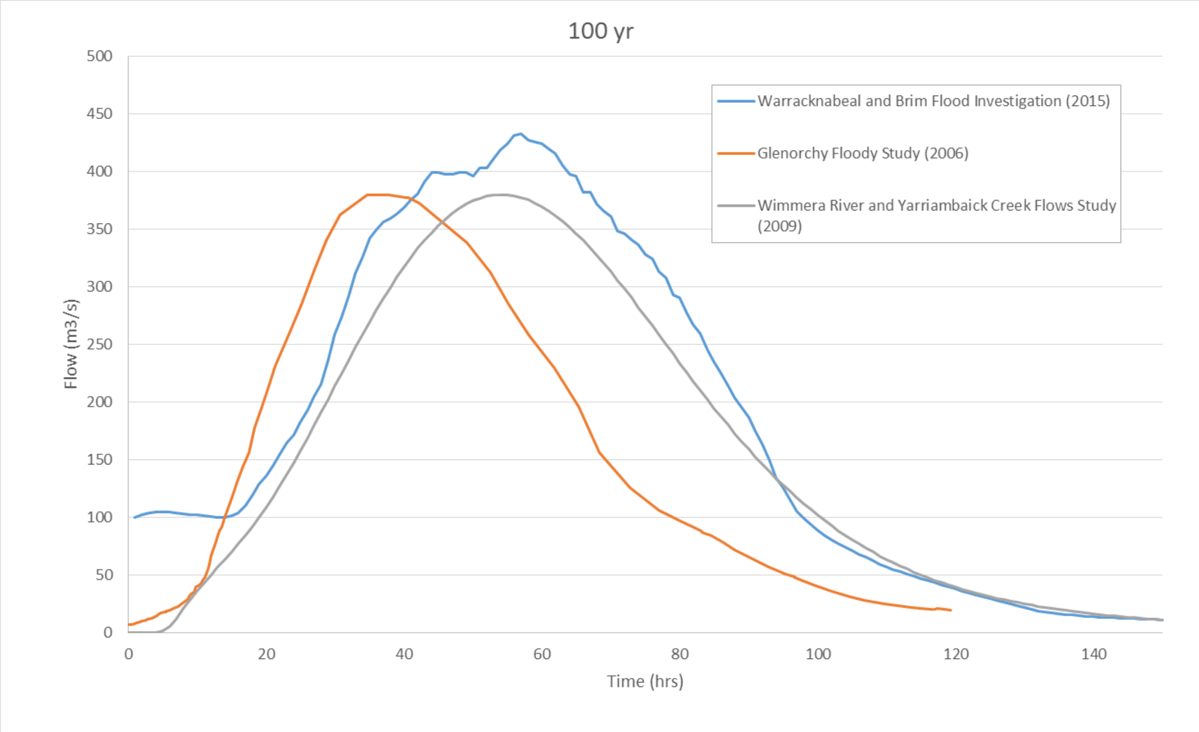
APPENDIX B GLENORCHY DESIGN FLOW HYDROGRAPH COMPARISONS

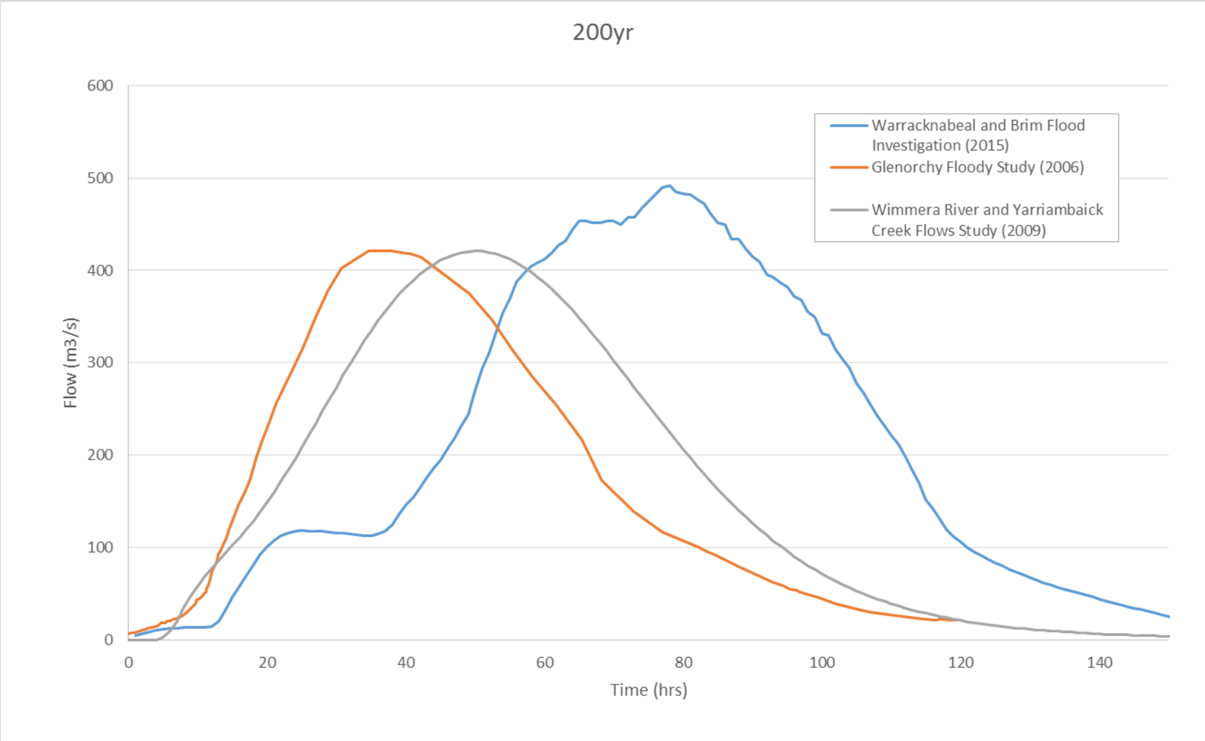

5yr
Flow (m3/s)
Time (hrs)
0
20
40
60
80
100
120
140
160
180
0
20
40
60
80
100
120
140
Warracknabeal and Brim Flood Investigation (2015)
Glenorchy Floody Study (2006)
Wimmera River and Yarriambaick Creek Flows Study (2009)


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


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


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


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)

APPENDIX C SITE VISIT PHOTOS

Photo 01 – Yarriambiack Creek at the Wimmera River

Photo 02 – Yarriambiack Creek between the Wimmera River and Regulating infrastructure

Photo 03 – Yarriambiack Creek regulating infrastructure (Not taken during site visit, provided by Clare Wilson Wimmera CMA)

Photo 04 – Yarriambiack Creek gauging station at the Wimmera Highway

Photo 05 – Yarriambiack Creek at the Wimmera Highway

Photo 06 – Levee west of Warracknabeal Primary School

Photo 07 – Levee west of Warracknabeal Primary School

Photo 08 – One way culvert at Asquith Reserve/McIntyre St

Photo 09 – One way culvert at Lyle St

Photo 10 – Potential Levee location behind the lawn bowls club

Photo 11 – Craig Avenue bridge

Photo 12 – Warracknabeal Weir Pool western culverts

Photo 13 – Warracknabeal Weir Pool gates and pedestrian bridge

Photo 14 – Warracknabeal Weir Pool gates

Photo 15 – Warracknabeal Weir Pool eastern culverts

Photo 16 – Previous GWMWater Channel on Borung Highway (facing north)

Photo 17 – Previous GWMWater culvert on Borung Highway (facing south)

Photo 18 – Previous GWMWater channel on Borung Highway (facing east)

Photo 19 – Previous GWMWater channel on Borung Highway (facing south)

Photo 20 – Previous GWMWater channel on Borung Highway (facing north)

Photo 21 – Drainage through Wilken grain silos

Photo 22 – Levee at Kings Street Brim

Photo 23 –Brim Weir Upstream

Photo 24 –Brim Weir upstream gates

Photo 25 –Levee along private property boundary south east of the weir pool

Photo 26 –Levee along private property boundary south east of the weir pool

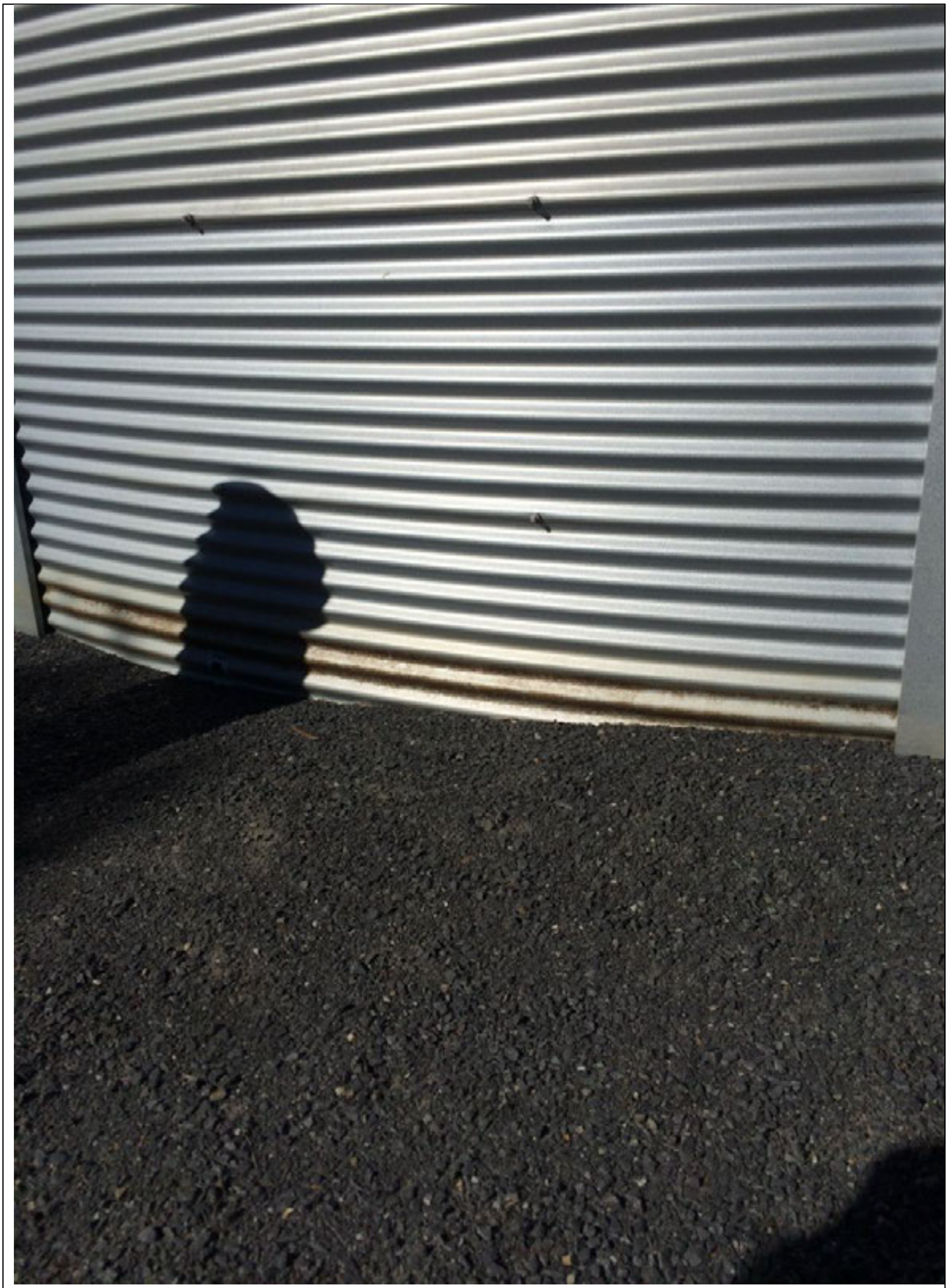


Photo 27 – Flood level on the Brim Recreation Reserve water tank

Photo 28 –Brim Recreation Reserve

Photo 29 –Henty Highway at Brim silos

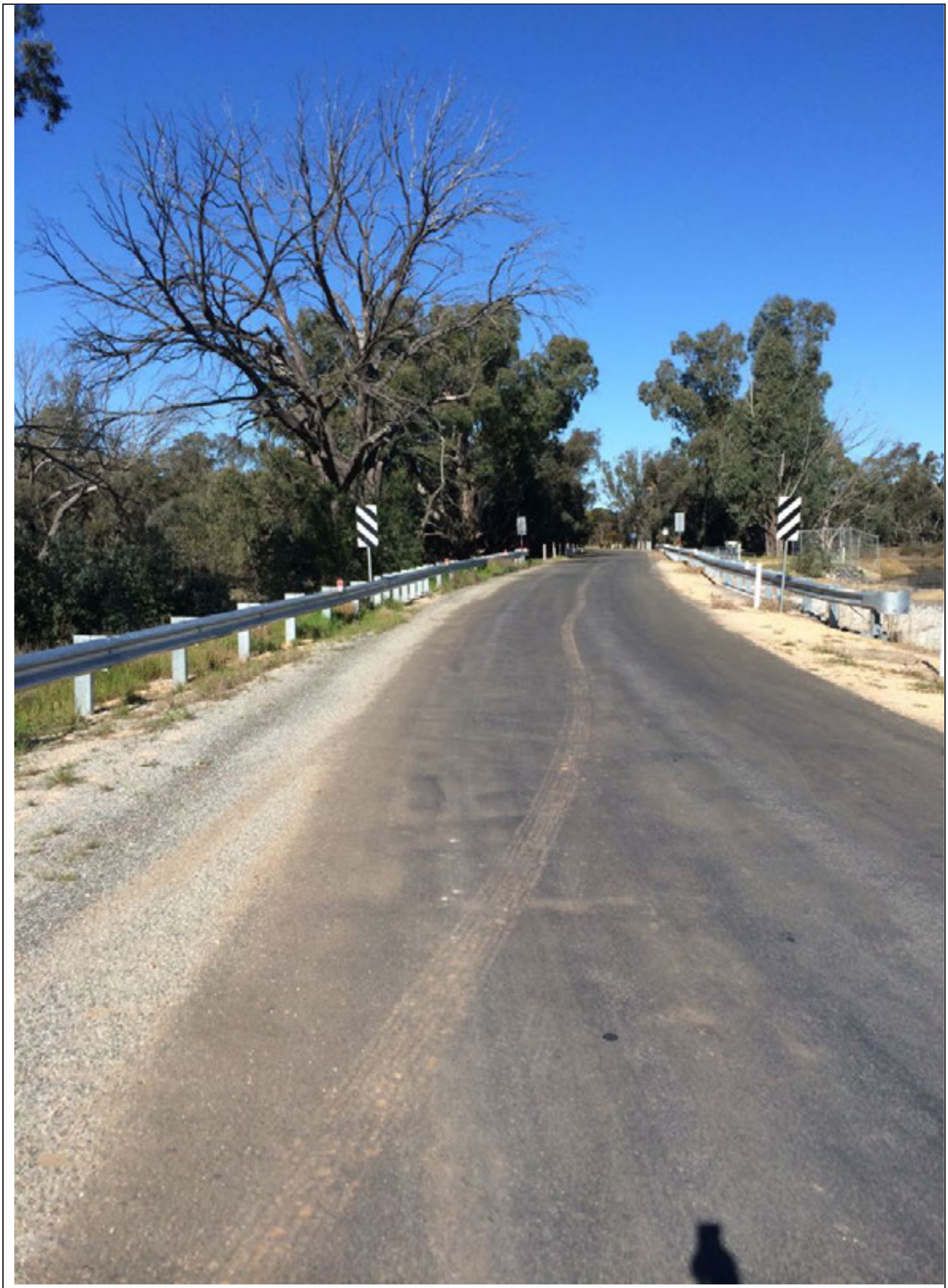


Photo 30 – Brim weir downstream

Photo 31 – Brim weir downstream

Photo 32 – Brim weir downstream culverts

APPENDIX D FLOOD INTELLIGENCE CARD AND PROPERTY INUNDATION LIST

Table 11-1 Yarriambiack Creek Flood Intelligence Card

<table>
<tr><th>Discharge at Yarriambiack Creek at Murtoa</th><th>AEP of flood</th><th>Consequence / Impact</th><th>Action
Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible</th></tr>
<tr><td colspan="4">▪ It is important that sand and sandbags are available for residents along Yarriambiack Creek at a range of locations specific for their use and made available to residents as soon as possible after it becomes apparent that flooding is likely. These sandbags should be made available from early morning to late evening to allow sandbagging to continue outside general office hours. Sandbags should be available from several locations as some areas will be isolated. Residents using sandbags need to be aware of the correct way to lay sandbags and also be aware that due to the length of inundation some water will pass through the bags. Pumps may be used to remove this water if an area of ground is able to be excavated to create a low point to pump water from.
▪ The location of road closures should be confirmed using the maps shown in Appendix E and an on ground assessment.</td></tr>
<tr><td colspan="4">USING THIS INTELLIGENCE CARD. Obtain the predicted level at the Yarriambiack Creek gauge at Murtoa (Wimmera Highway), this will relate directly to the Wimmera River gauge at Glenorchy. The general relationship between the Glenorchy and Murtoa gauges is shown below this table. Consider the appropriate flood inundation map. Review all consequences and actions in this table, from the first row down to the approximate expected severity of flooding. Initiate all actions in a logical sequence remembering that water will rise quickly and that some actions may need to be initiated in an order that is different from their relative placement in this table.</td></tr>
<tr><td colspan="4">Note that:
○ Mapping and flood modelling have been based flooding in Yarriambiack Creek only and the potential for a rainfall event occurring at the same time as flood inundation must be considered.
○ It is likely stormwater runoff may cause localised inundation prior to floodwater arriving, this will recede.</td></tr>
<tr><td>905 ML/d
(0.843 m)</td><td>20% AEP (5-year ARI)</td><td>Yarriambiack Creek remains relatively confined to the channel, some breakouts into vegetated areas including:
• Immediately north of Banyena Pimpinio Road (south of the Golf Course)
• Immediately south of Horsham-Minyip Road (agricultural paddock)
• Several flood runners between Horsham Minyip Road and Daveys Road
• Between Mayberrys Road and Moloneys Road (over topping of Moloneys Road in several locations east of the Yarriambiack Creek channel to depths of up to 30cm)
• Immediately south of Dumbuoy Road (overtopping in several locations</td><td>Warn residents along Yarriambiack Creek localised inundation is likely. No major assets are likely to require flood protection measures.
Consider closing minor Yarriambiack Creek crossings, worst impacted crossings are Moloneys Road and Dumbuoy Road with numerous locations overtopping.
Provide specific warnings the properties on Dumbuoy Road isolation is possible (in particular the Rusty Nail - surrounded by flood water).
Provide general warnings to rural residents living along Yarriambiack Creek access to their properties may be limited via minor Yarriambiack Creek crossings and an alternate route through agricultural paddocks should be considered.</td></tr>
</table>

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
		• Agricultural inundation between Tarrent Road and Morella Road (western side of Yarriambiack Creek) • Quarry west of Yarriambiack Creek at Lah There is one property isolated during a 20% AEP flood event due to inundation of Dumbouy Road, immediately south of Warracknabeal (The Rusty Nail). Numerous minor road crossings of Yarriambiack Creek are likely to be inundated, as well as private crossings.	Ensure inundation mapping is available online and at request. Monitor water levels at Yarriambiack Creek crossings and broader floodplain and timing flows in at the Yarriambiack Creek at Murtoa (Wimmera Highway) and Wimmera River at Glenorchy streamflow gauges.
1,166 ML/d (0.95 m)	10% AEP (10-year ARI)	The flood extent is similar to the 20% AEP (5-year ARI) event with only a small increase in Wimmera River flow. Flood pattern remains the same with a slight increase in depth and extent. The flood extent is increased most in the areas of: • Banyena Pimpinio Road • Depth of inundation at Moloneys Road increased by around 5cm. • Inundation of Ailsa Road at several locations at depths less than 10cm. • Roses Road (multiple points of inundation – inundation isolating a dwelling on Yarriambiack Creek north of Roses Road) • Flood runners between Tarrant Road and Morella Road • Immediately upstream of the Brim Weir pool No major additional roads have been inundated; however depth of inundation has increased by 50-150mm depending on location.	Consider closing rural crossings of Yarriambiack Creek dependent on individual flood risk and monitoring inundation. Provide specific warning to resident north of Roses Road isolation is possible with inundation on multiple points of their access. Continue to monitor and update residents of Dumbuoy Road they are likely to be isolated. Monitor water levels throughout the area and timing flows in at all streamflow gauges.

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
1,743 ML/d (1.205 m)	5% AEP (20-year ARI)	The flood extent shows several additional breakouts from the 10% AEP (10-year ARI) event, including: • Between Schaches Road and Banyena Road • Banyena Road is inundated at multiple locations • Drillers Road is inundated at multiple locations (provides access to one property) • Yarriambiack Drive is inundated at several locations • Inundation of Roses Road has increased (isolation of one property in very close proximity to flood water) • Moloneys Road inundation increased by 10cm. • Inundation of Ailsa Road increased on the eastern side • Increase in inundation extent downstream of Cemetery Road • Inundation upstream of the Warracknabeal Weir Pool increases to a low area to the west • Water breaks out of Yarriambiack Creek downstream of Warracknabeal Weir and enters the industrial area immediately north of the township. • Morella Road inundated at several locations • Overtopping of the Henty Highway south of Ryans Road • Inundation in very close proximity (<10m) to a property east of the Henty Highway immediately south of Ryans Road, potential to be flooded below floor. • Property west of the Henty Highway north of Ryans Road isolated. Inundation depths have generally increased by 10-20cm in 10% AEP (10-year ARI) levels.	Consider closing rural crossings of Yarriambiack Creek dependent on individual flood risk and monitoring inundation. Specific attention should be paid to: • Banyena Road • Drillers Road • Moloneys Road • Ailsa Road Provide specific warnings and construct Levee 09 protecting the industrial area north of Warracknabeal (Provide specific warnings and provide sandbags to the property immediately north of Roses Road, west of Yarriambiack Creek. Provide specific warnings to residents north of Brim in close proximity to Ryans Road they are likely to be isolated and with one dwelling potentially subject to below floor inundation. Provide sandbags to property potentially inundated below floor on immediately south of Ryans Road (accessed on the eastern side of the Henty Highway) Continue to monitor and update residents of north of Roses Road they are likely to be inundated Continue to monitor and update residents of Dumbuoy Road they are likely to be isolated. Monitor water levels throughout the area and timing flows in at all streamflow gauges.

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
3,368 ML/d (2.171 m)	2% AEP (50-year ARI)	The flood extent shows in increase in inundation from the 5% AEP event (20-year ARI). The major changes in impacts are: • Greenhills Road inundated at several locations with a property west of Greenhills Road potentially isolated surrounded by flood water • Horsham Minyip Road inundated in several locations at depths up to 25cm • One property to the east immediately north of Daveys Road surrounded by flood water and isolated • Minyip Dimboola Road inundated for a significant length (greater than 500 m) • Yarriambiack Drive inundated for a significant length (greater than 250 m) • Property immediately north of Roses Road inundated below floor (west of Yarriambiack Creek) • Inundation of the Henty highway at Kellalac • Several inundation points of Mayberrys Road • Significant inundation of Ailsa Road (greater than 500 m) • One property flooded below floor north of Dumbuoy Road (The Rusty Nail) • Significant increase in inundation west of Cemetery Road with two properties inundated below floor and one property isolated in Cemetery Road • Two properties inundated below floor in Asquith Avenue • Inundation up McIntyre Road • Significant increase in inundation along Warunda Avenue with eight properties inundated, five below floor, three above. Inundation of the access to this area • Significant inundation in Kokoda Avenue with 6 properties flooded below floor and one above	Close all rural crossings of Yarriambiack Creek Close Horsham Minyip Road at Yarriambiack Creek Broad scale flood mitigation levees are required in Warracknabeal including the following – • Levee 01 – Preventing below floor inundation in Cemetery Avenue • Levee 13 – Preventing below floor inundation in Asquith Reserve • Levee 05 – Preventing above and below floor inundation in Warunda Avenue • Levee 11 – Preventing inundation in Craig Avenue and Kokoda Avenue • Levee 06 – Preventing inundation in Asquith Avenue • Levee 10 - preventing inundation in Craig Avenue Continue to monitor and update residents on Yarriambiack Creek north of Warracknabeal.

<table>
<tr><th>Discharge at Yarriambiack Creek at Murtoa</th><th>AEP of flood</th><th>Consequence / Impact</th><th>Action
Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible</th></tr>
<tr><td></td><td></td><td>Significant inundation in Craig Avenue with twelve properties flooded below floor south of Menin Street and three north of Menin Street
One property in Asquith Avenue inundated below floor
Significant inundation through the industrial area north of Warracknabeal, one property flooded above floor
Significant inundation of Baums Road (greater than 300 m)
Isolation of two properties north of Ryans Road, both east and west of the Henty Highway</td><td></td></tr>
<tr><td>5,028 ML/d
(2.303 m)</td><td>1% AEP (100-year ARI)</td><td>Similar to January 2011 flood when extensive damage was caused to both residential and agricultural land – refer to Wimmera CMA estimated extent. In Warracknabeal a significant levee was constructed during January 2011 which largely mitigated the potential damages.

The extent is similar to that of the 2% AEP (50-year ARI) event with no change to the properties inundated south of Warracknabeal, aside from greater depths. There are several increases to the number of properties inundated in Warracknabeal including:
Water in very close proximity or flooding under floor of all Cemetery Road properties west of Dumbuoy Road
Water flooding sheds and in close proximity to a property at the western end of Wood Street
Two buildings in Asquith Reserve flooded above floor with a further four flooded below floor and several in very close proximity to inundation
Two buildings in McIntyre Street flooded below floor</td><td>Consider closing the Henty Highway

Additional to the levee sections listed in for the 2% AEP event, construct the following levees –
Levee 02 – Preventing above floor inundation of a shed (inundation of this area is slightly exacerbated (2 cm) due to the construction of levees further downstream)
Levee 04 – Preventing inundation of the school and Campbell Street
Continue to monitor and update residents on Yarriambiack Creek north of Warracknabeal.</td></tr>
</table>

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
		• Four buildings flooded below floor in Lyle Street on the northern side, two on the southern side including the Covent. • Water is flooding in and around St Mary's Catholic Primary School potentially flooding buildings below floor • One building flooded below floor in Fong Tong Avenue but all properties at risk of below floor inundation • Three dwellings in Warunda Avenue flooded above floor, all properties either flooded below floor or in very close proximity to inundation • One property in The Avenue flooded above floor, all properties either flooded below floor or in very close proximity to inundation (large increase inundation extent on the 2% AEP event) • A backwater is now occurring up Anderson Street with the potential to flood properties below floor • There is a large increase inundation on the 2% AEP event west of Yarriambiack Creek, in and around Symes Street, Menin Avenue, Kokoda Avenue, Tobruk Avenue, David Street and Alamein Avenue. There are four dwellings flooded below floor, one three in Craig Avenue and on in Kokoda Avenue. There are properties flooded below floor in all streets and avenues north of Elizabeth Street. Access to the western side of Warracknabeal is limited with inundation in all streets. • Northern end of Craig Avenue inundated • Inundation at the industrial area north of Warracknabeal is inundated with one building flooded above floor and likely to be numerous other properties flooded below floor	

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
		• Floodwater is now sitting against the Henty Highway south of Morella Road and inundating the highway at Darts Road • An overland flow path west of Yarriambiack Creek is enabled, floodwater flows from Batchica West Road, flows parallel to Yarriambiack Creek and stops flowing south of Hood Road. • Flood water is in very close proximity to a dwelling west of Yarriambiack Creek on Batchica West Road. • The overland flow path causes isolation of two properties on Witneys Road, one on Lah West Road and one on Exchange Road. Inundation is close to each dwelling and associated sheds. • The Henty Highway is inundated south of Lah Angle Road • Brim West Road west of the Brim weir pool is inundated • Inundation and isolation has worsened along the Henty Highway at Ryans Road. • Overland flow south of Ryans Road is occurring creating an additional flow path to the north east of Yarriambiack Creek.	
6,567 ML/d (5.05 m)	0.5% AEP (200-yr ARI)	South of the Henty Highway at Kellalac the inundation extent is similar to that of the 1% AEP event with all minor and major roads over topping. All property isolation is the same with greater depths preventing access. Changes to inundation from the 1% AEP event include: • An additional overland flow path south of Bell Road on the western side of Yarriambiack Creek • An additional breakout from Yarriambiack Creek north of Werrigar Street causes isolation of one property at the far western end of Lynch Street	Almost all crossings of Yarriambiack Creek will now be closed. Continue to monitor and update all residents on Yarriambiack Creek.

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
		• Floodwater is impaction all of McIntyre Street with Dimboola Road properties experiencing flooding at the rear • Three properties in Dimboola Road inundated below floor west of Yarriambiack Creek • Four properties in Asquith Reserve flooded above floor • One property in McIntyre Street flooded below floor • All properties between Warunda Drive and Yarriambiack Creek are flooded below floor, three flooded above floor in Lyle Street • Seven properties in Warunda Avenue flooded above floor, one below • All properties in The Avenue flooded above or below floor, three above • Inundation in Anderson Street has increased to flood all properties between the Avenue and Woolcock Street below floor, one below • All properties on the western side of Yarriambiack Creek north of Elizabeth Street are at high risk of below floor inundation, propertied are flooded above floor in all streets • A breakout from Yarriambiack Cree at Asquith Avenue has over topped Rainbow Road and inundated properties on Kelsall Street (seven below floor) Bowman Street (nine below floor, five above floor), Devereux Street (one below floor, two above floor), Clifford Street (13 below floor), Railway Road (three below floor), Schickerling Street (one above floor, one below floor) and east of the Henty Highway (one below floor). This inundation does not occur in the 1% AEP event and is a significant extension in	

Discharge at Yarriambiack Creek at Murtoa	AEP of flood	Consequence / Impact	Action Actions may include (but not limited to) evacuation, closure of roads, sandbagging, issue of warnings and who is responsible
		inundation. A significant depth of flood water accumulates on the western side of the Henty Highway with the road over topping. • The grain storage facility is impacted with one building flooded above floor • The Henty Highway is inundated to a much greater extent south of Goads Road • Properties on Witneys Road experience much greater inundation around buildings with some sheds potentially flooded North of Brim the flood extent and depth have increased with a similar pattern of inundation. All road major and minor in the vicinity of Yarriambiack Creek are likely to be inundated including the Henty Highway at several locations.	

Table 11-2 Detailed List of Properties Flooded

Legend **Building within 50m of flood extent**

Buildings flooded above floor or within 100mm of being flooded above floor are highlighted in bold RED

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
0	ALAMEIN AVE	STUMPS, CLADDING	-	-	-	-	-	-
3	ALAMEIN AVE	STUMPS, FIBRO	-	-	-	-	-	-0.253

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
4	ALAMEIN AVE	STUMPS, CLADDING	-	-	-	-	-	-0.326
6	ALAMEIN AVE	STUMPS, BRICK	-	-	-	-	-	-0.236
8	ALAMEIN AVE	STUMPS, HARDI PLANK	-	-	-	-	-	-0.209
10	ALAMEIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
12	ALAMEIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
2	ANDERSON	SLAB, BRICK	-	-	-	-	-	-
3	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.155
4	ANDERSON	SLAB, BRICK	-	-	-	-	-	-
5	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-0.214	-0.106
6	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
7	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.285
8	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
9	ANDERSON	STUMPS, CLADDING	-	-	-	-	-	-0.246
11	ANDERSON	DIRT, IRON (SHED)	-	-	-	-	-	**0.193**
12	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
14	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
15	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.165
18	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.405
19	ANDERSON	STUMPS, CLADDING	-	-	-	-	-	-0.295
20	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.28
21	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.276
22	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
26	ANDERSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
24	ANDERSON ST	House	-	-	-	-	-	-
0	ASQUITH AVE	DIRT, IRON (SHED)	-	-	-	-	**0.127**	**0.206**
0	ASQUITH AVE	STUMPS, FIBRO	-	-	-	-	-0.554	-0.464
1	ASQUITH AVE	STUMPS, CLADDING	-	-	-	-0.349	-0.192	**-0.073**
5	ASQUITH AVE	STUMPS, BRICK	-	-	-	-	-0.477	-0.361
7	ASQUITH AVE	STUMPS, BRICK	-	-	-	-	-	-0.441
9	ASQUITH AVE	STUMPS, BRICK	-	-	-	-	-	-0.342

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
11	ASQUITH AVE	STUMPS, BRICK	-	-	-	-	-	-0.224
13	ASQUITH AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
15	ASQUITH AVE	SLAB, BRICK	-	-	-	-	-	-
0	ASQUITH RES RD	STUMPS, WEATHERBOARD	-	-	-	-0.155	**0.041**	**0.15**
1	ASQUITH RES RD	SLAB, BRICK	-	-	-	-	-	-
4	ASQUITH RES RD	STUMPS, CLADDING	-	-	-	-0.175	**0.022**	**0.132**
6	ASQUITH RES RD	STUMPS, WEATHERBOARD	-	-	-	-	**-0.038**	**0.073**
10	ASQUITH RES RD	STUMPS, RENDERED	-	-	-	-	-0.146	**-0.036**
12	ASQUITH RES RD	SLAB, BRICK	-	-	-	-	-	-
14	ASQUITH RES RD	STUMPS, HARDI PLANK	-	-	-	-	-0.309	-0.189
18	ASQUITH RES RD	STUMPS, CLADDING	-	-	-	-	**-0.064**	**0.056**
20	ASQUITH RES RD	SLAB, BRICK	-	-	-	-	-	-
22	ASQUITH RES RD	SLAB, BRICK	-	-	-	-	-	-
28	ASQUITH RES RD	STUMPS, HARDI PLANK	-	-	-	-	-	-
0	BATCHICA WEST RD		-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
4166	BORUNG HWY	Shed	-	-	-	-	-	-
0	BOWMAN	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.328
0	BOWMAN	STUMPS, IRON (SHED)	-	-	-	-	-	-0.15
0	BOWMAN	SLAB, IRON (SHED)	-	-	-	-	-	-
0	BOWMAN	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.403
0	BOWMAN	SLAB, IRON (SHED)	-	-	-	-	-	-
0	BOWMAN	STUMPS, IRON (SHED)	-	-	-	-	-	-
0	BOWMAN	VACANT LOT	-	-	-	-	-	**0.444**
0	BOWMAN	SLAB, BRICK	-	-	-	-	-	-
1	BOWMAN	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.278
2	BOWMAN	STUMPS, RENDERED	-	-	-	-	-	-0.18
2	BOWMAN	SLAB, IRON (SHED)	-	-	-	-	-	**0.167**
2	BOWMAN	STUMPS, HARDI PLANK	-	-	-	-	-	**-0.114**
3	BOWMAN	STUMPS, CLADDING	-	-	-	-	-	-0.324
4	BOWMAN	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.152

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
5	BOWMAN	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.302
9	BOWMAN	STUMPS, BRICK	-	-	-	-	-	-0.233
11	BOWMAN	STUMPS, CLADDING	-	-	-	-	-	**0.024**
13	BOWMAN	STUMPS, CLADDING	-	-	-	-	-	0.174
15	BOWMAN	STUMPS, CLADDING	-	-	-	-	-	**0.064**
26	BOWMAN	SLAB, IRON (SHED)	-	-	-	-	-	-
36	BOWMAN	STUMPS, CLADDING	-	-	-	-	-	-
38	BOWMAN	SLAB, BRICK	-	-	-	-	-	-
3	BURMA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
1520	CANNUM FIVE CHAIN RD		-	-	-	-	-	-
0	CEMETARY RD	SLAB, IRON (SHED)	-	-	-	-	-	-
0	CEMETARY RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
0	CEMETARY RD	STUMPS, CLADDING	-	-	-	-	-	-
0	CEMETARY RD	STUMPS, BRICK	-	-	-	-0.633	-0.497	-0.386
0	CEMETARY RD	SLAB, IRON (SHED)	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
3	CEMETARY RD	STUMPS, FIBRO	-	-	-	-	-	-
1	CEMETERY RD	House	-	-	-	-	-	-
1	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	**0.176**
3	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	**-0.064**
5	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.113
6	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.152
7	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.173
8	CLIFFORD	STUMPS, CLADDING	-	-	-	-	-	-0.323
9	CLIFFORD	STUMPS, HARDI PLANK	-	-	-	-	-	-0.142
10	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.332
11	CLIFFORD	STUMPS, HARDI PLANK	-	-	-	-	-	-0.173
12	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.223
13	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.263
15	CLIFFORD	STUMPS, HARDI PLANK	-	-	-	-	-	-0.383
16	CLIFFORD	STUMPS, HARDI PLANK	-	-	-	-	-	**-0.083**

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
17	CLIFFORD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.284
19	CLIFFORD	STUMPS, HARDI PLANK	-	-	-	-	-	-
0	CORAL AVE	STUMPS, CLADDING	-	-	-	-	-	-0.25
1	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
2	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.241	**-0.077**
4	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.102	**0.055**
5	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.112
6	CORAL AVE	STUMPS, CLADDING	-	-	-	-	-0.112	**0.041**
7	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.229
8	CORAL AVE	SLAB, BRICK	-	-	-	-	-0.202	**-0.055**
11	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.318
13	CORAL AVE	STUMPS, RENDERED	-	-	-	-	-	-
15	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.229
17	CORAL AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.334	-0.21
0	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
0	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
0	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	**-0.018**
0	CRAIG AVE	SLAB, BRICK	-	-	-	-	-0.16	**-0.037**
0	CRAIG AVE	STUMPS, CLADDING	-	-	-	-0.233	**-0.04**	**0.076**
0	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
0	CRAIG AVE	STUMPS, BRICK	-	-	-	-0.163	**-0.018**	**0.091**
0	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
2	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
4	CRAIG AVE	STUMPS, RENDERED	-	-	-	-	-	-
6	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
8	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	**-0.087**
16	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
30	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
32	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
36	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
38	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
40	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
42	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
44	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
46	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	**0.022**
48	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-
52	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	**0.098**
54	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
56	CRAIG AVE	STUMPS, HARDI PLANK	-	-	-	-	-	-
59	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
60	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.331
61	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.232
62	CRAIG AVE	STUMPS, CLADDING	-	-	-	-	-	-0.53
63	CRAIG AVE	STUMPS, CLADDING	-	-	-	-	-0.322	-0.219
64	CRAIG AVE	STUMPS, RENDERED	-	-	-	-	-0.194	**-0.09**

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
65	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-0.171	**-0.064**
66	CRAIG AVE	STUMPS, CLADDING	-	-	-	-	-0.141	**-0.035**
67	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.305	-0.157	**-0.048**
70	CRAIG AVE	STUMPS, BRICK	-	-	-	-0.325	-0.182	**-0.074**
72	CRAIG AVE	STUMPS, BRICK	-	-	-	-0.527	-0.387	-0.28
74	CRAIG AVE	STUMPS, RENDERED	-	-	-	-0.324	-0.184	**-0.076**
76	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.169	**-0.025**	**0.084**
78	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.103	**0.04**	**0.15**
80	CRAIG AVE	STUMPS, CLADDING	-	-	-	-0.126	**0.017**	**0.127**
82	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	**-0.081**	**0.062**	**0.174**
84	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-0.195	**-0.082**
86	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.188	**-0.041**	**0.074**
88	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.177	**-0.031**	**0.082**
90	CRAIG AVE	STUMPS, CLADDING	-	-	-	-0.172	**-0.036**	**0.079**
91	CRAIG AVE	SLAB, BRICK	-	-	-	-	-0.167	**-0.047**

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
92	CRAIG AVE	STUMPS, BRICK	-	-	-	-0.489	-0.35	-0.237
94	CRAIG AVE	STUMPS, CLADDING	-	-	-	-	-0.275	-0.165
96	CRAIG AVE	STUMPS, HARDI PLANK	-	-	-	-	-	-0.188
98	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.315	-0.178
100	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-	-0.134
108	CRAIG AVE	STUMPS, BRICK	-	-	-	-	-0.157	**-0.032**
110	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
112	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.174	**-0.05**
114	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.186	**-0.064**
116	CRAIG AVE	STUMPS, CLADDING	-	-	-	-0.321	-0.115	**0.008**
118	CRAIG AVE	STUMPS, WEATHERBOARD	-	-	-	-0.38	-0.172	**-0.048**
122	CRAIG AVE	House	-	-	-	-	-	-
126	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
132	CRAIG AVE	SLAB, BRICK	-	-	-	-	-	-
962	DAVEYS RD		-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
1081	DAVEYS RD		-	-	-	-	-	-
0	DAVID	SLAB, IRON (SHED)	-	-	-	-	-	-
0	DEVEREUX	SLAB, IRON (SHED)	-	-	-	-	-	-
3	DEVEREUX	STUMPS, RENDERED	-	-	-	-	-	0.076
5	DEVEREUX	STUMPS, WEATHERBOARD	-	-	-	-	-	0.085
3	DIMBOOLA RD	House	-	-	-	-	-	-
5	DIMBOOLA RD	STUMPS, CLADDING	-	-	-	-	-	-
5	DIMBOOLA RD	House	-	-	-	-	-	-
9	DIMBOOLA RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
11	DIMBOOLA RD	STUMPS, BRICK	-	-	-	-	-	-
19	DIMBOOLA RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
19	DIMBOOLA RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
33	DIMBOOLA RD		-	-	-	-	-	-
39	DIMBOOLA RD		-	-	-	-	-	-
9	DIXON ST		-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
0	DUMBOUY RD	SLAB, BRICK	-	-	-	-	-	-
56	DUMBOUY RD	House	-	-	-	-	-	-
153	DUMBOUY RD		-	-	-	-	-	-
179	DUMBOUY RD		-	-	-	-	-	-
35	DUMBOUY RD	House	-	-	-	-	-	-0.004
189	DUMBOUY ROD	Restaurant	-	-	-	-	-	0.204
1	ELIZABETH AVE	SLAB, BRICK	-	-	-	-	-	-
2	ELIZABETH AVE	STUMPS, FIBRO	-	-	-	-	-	-
3	ELIZABETH AVE	SLAB, BRICK	-	-	-	-	-	-
5	ELIZABETH AVE	SLAB, BRICK	-	-	-	-	-	-
7	ELIZABETH AVE	SLAB, BRICK	-	-	-	-	-	-
11	ELIZABETH AVE	SLAB, BRICK	-	-	-	-	-	-
4	FONG TONG AV	Motel	-	-	-	-	-	0.072
2	FONG TONG AVE	SLAB, BRICK	-	-	-	-	-	-
3	FONG TONG AVE	SLAB, BRICK	-	-	-	-	-0.232	-0.098

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
4	FONG TONG AVE	SLAB, BRICK	-	-	-	-	-	-
1125	GREENHILLS RD		-	-	-	-	-	-
234	HENTY HWY	Shed	-	-	-	-	-	-0.187
2560	HENTY HWY		-	-	-	-	-	-
2690	HENTY HWY	House	-	-	-	-	-0.282	-0.218
2787	HENTY HWY	House	-	-	-	-	-	-
2787	HENTY HWY		-	-	-	-	-	-
0	HENY HWY	SLAB, IRON (SHED)	-	-	-	-	-	-
0	JAMOUNEAU	STUMPS, WEATHERBOARD	-	-	-	-	-	-
2	JAMOUNEAU	STUMPS, WEATHERBOARD	-	-	-	-	-	-
4	JAMOUNEAU	SLAB, BRICK	-	-	-	-	-	-
6	JAMOUNEAU	SLAB, IRON (SHED)	-	-	-	-	-	-
8	JAMOUNEAU	STUMPS, BRICK	-	-	-	-	-	-
10	JAMOUNEAU	STUMPS, WEATHERBOARD	-	-	-	-	-	-
12	JAMOUNEAU	VACANT LOT	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
14	JAMOUNEAU	STUMPS, BRICK	-	-	-	-	-	-
2	JAMOUNEAU ST	House	-	-	-	-	-	-
12	JAMOUNEAU ST		-	-	-	-	-	-
0	JEPARIT RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.266
0	JEPARIT RD	SLAB, IRON (SHED)	-	-	-	-	-	-
0	JEPARIT RD	SLAB, BRICK (SHED)	-	-	-	-	**0.088**	**0.166**
1	JEPARIT RD	STUMPS, HARDI PLANK	-	-	-	-	-	-0.253
3	JEPARIT RD	STUMPS, CLADDING	-	-	-	-	-	-0.246
5	JEPARIT RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
7	JEPARIT RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
8	JEPARIT RD	SLAB, BRICK	-	-	-	-	-	-
9	JEPARIT RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
0	KELSALL	STUMPS, CLADDING	-	-	-	-	-	**-0.104**
0	KELSALL	STUMPS, CLADDING	-	-	-	-	-	**-0.044**
0	KELSALL	SLAB, IRON (SHED)	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
2	KELSALL	STUMPS, BRICK	-	-	-	-	-	-0.445
4	KELSALL	STUMPS, BRICK	-	-	-	-	-	-
5	KELSALL	STUMPS, BRICK	-	-	-	-	-	-
6	KELSALL	STUMPS, FIBRO	-	-	-	-	-	**-0.063**
7	KELSALL	SLAB, BRICK	-	-	-	-	-	-
8	KELSALL	STUMPS, BRICK	-	-	-	-	-	**-0.035**
9	KELSALL	STUMPS, BRICK	-	-	-	-	-	-
11	KELSALL	STUMPS, BRICK	-	-	-	-	-	-
13	KELSALL	STUMPS, CLADDING	-	-	-	-	-	-
16	KELSALL	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.373
18	KELSALL	STUMPS, HARDI PLANK	-	-	-	-	-	-0.146
20	KELSALL	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.185
26	KELSALL	SLAB, IRON (SHED)	-	-	-	-	-	**0.174**
32	KELSALL	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.226
1	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.141

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
1	KOKODA AVE	SLAB, BRICK	-	-	-	**0.033**	**0.173**	**0.282**
2	KOKODA AVE	STUMPS, CLADDING	-	-	-	-	-	-0.179
2	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	**-0.124**
2	KOKODA AVE	STUMPS, CLADDING	-	-	-	-	-	-0.327
3	KOKODA AVE	STUMPS, RENDERED	-	-	-	-0.349	-0.203	**-0.094**
4	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.33	-0.226
5	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-0.412	-0.268	-0.159
6	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.312	-0.206
7	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-0.217	**-0.072**	**0.037**
8	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.212
9	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-0.342	-0.202	**-0.094**
10	KOKODA AVE	STUMPS, FIBRO	-	-	-	-	-	-
11	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-0.506	-0.372	-0.266
12	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.168
13	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.253	-0.148

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
15	KOKODA AVE	STUMPS, BRICK	-	-	-	-	-	-0.153
17	KOKODA AVE	STUMPS, FIBRO	-	-	-	-	-0.365	-0.256
19	KOKODA AVE	STUMPS, WEATHERBOARD	-	-	-	-	-0.312	-0.202
0	LYLE	STUMPS, BRICK	-	-	-	-	-0.201	-0.123
0	LYLE	STUMPS, BRICK	-	-	-	-	-	-0.225
4	LYLE	SLAB, BRICK	-	-	-	-	-	-
6	LYLE	House	-	-	-	-	-	-
8	LYLE	SLAB, BRICK	-	-	-	-	-	**-0.066**
10	LYLE	STUMPS, BRICK	-	-	-	-	-	-
12	LYLE	STUMPS, CLADDING	-	-	-	-	-	-
2	LYLE ST	SLAB, CLADDING	-	-	-	-	**-**	**0.089**
4	LYLE ST	HOUSE	-	-	-	-	**-0.07**	**0.085**
9	LYLE ST	School	-	-	-	-	-0.424	-0.336
13	LYLE ST		-	-	-	-	-	-
0	McINTYRE	STUMPS, HARDI PLANK	-	-	-	-	-0.325	-0.203

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
3	MCINTYRE ST	Note: Vacant Block	-	-	-	-	-0.122	**0.002**
1	MENIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	**-0.063**	**0.077**
3	MENIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	**-0.053**	**0.082**
4	MENIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.286
5	MENIN AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	**-0.011**
6	MENIN AVE	STUMPS, FIBRO	-	-	-	-	-	-0.304
7	MENIN AVE	SLAB, FIBRO	-	-	-	-	-	0.217
0	PHILLIPS	SLAB, BRICK	-	-	-	-	-	-
0	PHILLIPS	SLAB, BRICK	-	-	-	-	-	-
1	PHILLIPS	SLAB, BRICK	-	-	-	-	-	-
0	RAILWAY	SLAB, IRON (SHED)	-	-	-	-	-	-
0	RAILWAY	STUMPS, IRON (SHED)	-	-	-	-	-	-0.12
111	ROSES RD	House	-	-	-	-	-0.619	-0.56
0	SCHICKERLING ST	SLAB, IRON (SHED)	-	-	-	-	-	**0.078**
0	SCOTT	STUMPS, BRICK	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
10	SIMSON	BRIM REC, RESERVE,	-	-	-	-	-	-
0	SYMES AVE	STUMPS, CLADDING	-	-	-	-	-0.176	**-0.037**
2	SYMES AVE	STUMPS, HARDI PLANK	-	-	-	-	-	-
0	TEICHELMAN CT	House	-	-	-	-	-	-
0	THE AVENUE	SLAB, RENDERED	-	-	-	-	-	-
0	THE AVENUE	Bowls Club	-	-	-	-	-	-
1	THE AVENUE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.349
3	THE AVENUE	STUMPS, CLADDING	-	-	-	-	-	-0.23
5	THE AVENUE	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.24
7	THE AVENUE	STUMPS, CLADDING	-	-	-	-	-0.121	**0.003**
9	THE AVENUE	STUMPS, WEATHERBOARD	-	-	-	-	**-0.06**	**0.061**
11	THE AVENUE	STUMPS, WEATHERBOARD	-	-	-	-	-0.257	-0.138
13	THE AVENUE	SLAB, BRICK	-	-	-	**-0.026**	**0.135**	**0.246**
19	THE AVENUE	SLAB, BRICK	-	-	-	-	-	-
0	TOBRUK AVE	SLAB, BRICK	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
1	TOBRUK AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
2	TOBRUK AVE	STUMPS, BRICK	-	-	-	-	-	-0.187
3	TOBRUK AVE	STUMPS, WEATHERBOARD	-	-	-	-	-	-
4	TOBRUK AVE	STUMPS, CLADDING	-	-	-	-	-0.165	**0.007**
8	TOBRUK AVE	STUMPS, HARDI PLANK	-	-	-	-	**-0.026**	**0.144**
12	TOBRUK AVE	SLAB, BRICK	-	-	-	-	-	-
0	WARRACKNABEAL JEPARIT RD	SLAB, IRON (SHED)	-	-	-	-	-	-
31	WARRACKNABEAL JEPARIT RD	SLAB, FIBRO	-	-	-	-	-	-
33	WARRACKNABEAL JEPARIT RD	SLAB, IRON (SHED)	-	-	-	-	-	-
33	WARRACKNABEAL JEPARIT RD	SLAB, IRON (SILO)	-	-	-	-	-	0.225
35	WARRACKNABEAL JEPARIT RD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
39	WARRACKNABEAL JEPARIT RD	DIRT, IRON (SHED)	-	-	-	**0.063**	**0.13**	**0.176**
1	WARUNDA AVE	SLAB, BRICK	-	-	-	-	-	-
1	WARUNDA AVE	SLAB, BRICK	-	-	-	**0.063**	**0.217**	**0.338**
3	WARUNDA AVE	SLAB, BRICK	-	-	-	**0.063**	**0.217**	**0.34**

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
5	WARUNDA AVE	SLAB, BRICK	-	-	-	0.073	0.228	0.351
5	WARUNDA AVE	STUMPS, BRICK	-	-	-	-	-	-
7	WARUNDA AVE	SLAB, BRICK	-	-	-	-0.247	-0.092	0.031
9	WARUNDA AVE	SLAB, BRICK	-	-	-	-0.209	-0.051	0.075
11	WARUNDA AVE	SLAB, BRICK	-	-	-	-0.408	-0.249	-0.122
13	WARUNDA AVE	SLAB, BRICK	-	-	-	-0.277	-0.118	0.01
9	WATSON	STUMPS, FIBRO	-	-	-	-	-	-
10	WATSON	STUMPS, FIBRO	-	-	-	-	-	-
11	WATSON	STUMPS, FIBRO	-	-	-	-	-	-
12	WATSON	STUMPS, FIBRO	-	-	-	-	-	-
14	WATSON	STUMPS, FIBRO	-	-	-	-	-	-
18	WATSON	STUMPS, WEATHERBOARD	-	-	-	-	-	-
20	WATSON	STUMPS, CLADDING	-	-	-	-	-	-
2	WERRIGAR ST	HOUSE	-	-	-	-	-	-
11	WERRIGAR ST	CHILDCARE CENTRE,	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
43	WHITNEYS RD		-	-	-	-	-	-
106	WHITNEYS RD		-	-	-	-	-	-
0	WOOD	STUMPS, WEATHERBOARD	-	-	-	-	-	-
0	WOODBINE	SLAB, BRICK	-	-	-	-	-	-
0	WOOLCOCK	STUMPS, BRICK	-	-	-	-	-	-
1	WOOLCOCK	STUMPS, BRICK	-	-	-	-0.158	**-0.006**	**0.113**
2	WOOLCOCK	STUMPS, RENDERED	-	-	-	-	-0.27	-0.173
3	WOOLCOCK	STUMPS, CLADDING	-	-	-	-	-	-0.158
4	WOOLCOCK	STUMPS, WEATHERBOARD	-	-	-	-0.293	-0.16	**-0.056**
5	WOOLCOCK	STUMPS, WEATHERBOARD	-	-	-	-	-	-0.311
6	WOOLCOCK	STUMPS, HARDI PLANK	-	-	-	-	-0.392	-0.289
7	WOOLCOCK	STUMPS, BRICK	-	-	-	-	-	-0.369
8	WOOLCOCK	STUMPS, BRICK	-	-	-	-	-	-0.302
9	WOOLCOCK	STUMPS, CLADDING	-	-	-	-	-	-0.278
10	WOOLCOCK	STUMPS, WEATHERBOARD	-	-	-	-	-	-

Location			Depth above OR below floor for each AEP					
House No.	Street Name	Notes	5yr	10yr	20yr	50yr	100yr	200yr
10	WOOLCOCK	HOUSE	-	-	-	-	-	-
14	WOOLCOCK	STUMPS, WEATHERBOARD	-	-	-	-	-	-

APPENDIX E DESIGN MAPPING

Provided as attachment

APPENDIX F WARRACKNABEAL LEVEE DESIGN

Provided as attachment